TECHCOMMENTARY

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WATERJET CUTTING

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Clean Cuts on Difficult Materials

Manufacturers cutting plastics, glass, metals, and even food seeking to improve productivity and quality are often thwarted by the slow and inexact cutting of knives, shears, saws, and other cutting technologies. Manufacturers find that some materials, including fiberglass, graphite/epoxy composites, and other new materials, cannot be cut to required tolerances even by faster methods such as plasma arc or laser cutting. But waterjets can cut to near-net shape on complex configurations and produce high-quality, dust-free cuts in virtually any material.

Waterjet cutting uses a highly pressurized stream of water, sometimes with an added abrasive, to erode the workpiece. The waterjet stream, moving at nearly three times the speed of sound, can penetrate almost any material and thickness. Waterjets are often used on composites and plastics that cannot tolerate heat, mechanical damage, or delamination. And because the jet of water is constricted to a small diameter at such high pressures, the workpiece does not get wet.

Waterjets are widely used in aerospace, automotive, electronics, and other industries to cut products as wide ranging as

- Titanium aircraft components
- Printed circuit boards
- Automobile dashboards
- Diapers
- Cake and candy.

Waterjets were first used in production in the early 1970s to cut cardboard forms. Since then, its capabilities have grown, partially due to the use of abrasive waterjet systems. A variation of pure waterjet, abrasive waterjet routinely cuts metals and harder, denser composites at greater thicknesses.

Automated waterjet cutting systems offer power, accuracy, and repeatability, making them an attractive cutting alternative. Currently there are 1500 waterjet systems in use worldwide, with an expected growth of 20% per year as more manufacturers seek the benefits of waterjet cutting for their applications.

Advantages

Waterjet cutting provides many advantages when traditional cutting methods prove inadequate.

Improved product quality—Waterjet cutting does not generate heat in the material being cut, so the product has no heat affected zone (HAZ), dross, or heat warpage, eliminating thermal and mechanical distortion. It cuts with a very narrow cutting width, or kerf, leaving a clean, finished edge.

Flexibility—Waterjet can cut a wide range of materials including

- Metals—titanium, lead, aluminum, steel
- Plastics
- Composites—fiberglass, graphite/epoxy
- Engineering materials—Kevlar®, Kapton®, Duroid®, Teflon®
- Paper
- Glass.

Waterjets can cut materials of varying thicknesses and densities without complicated adjustments.

Adaptable to automation—Nearly all waterjet systems utilize some type of automated carrier device. From *x-y* motion tables to CAD/CAM and 5-axis robotic systems, automated waterjets increase accuracy and cut complex shapes, contours, and configurations. Unlike conventional processes, waterjet cutting is omnidirectional, enabling accurate cuts to be made at any angle, even a tight inside radius. Waterjet can easily cut starter holes in the center of a workpiece, a task extremely difficult with

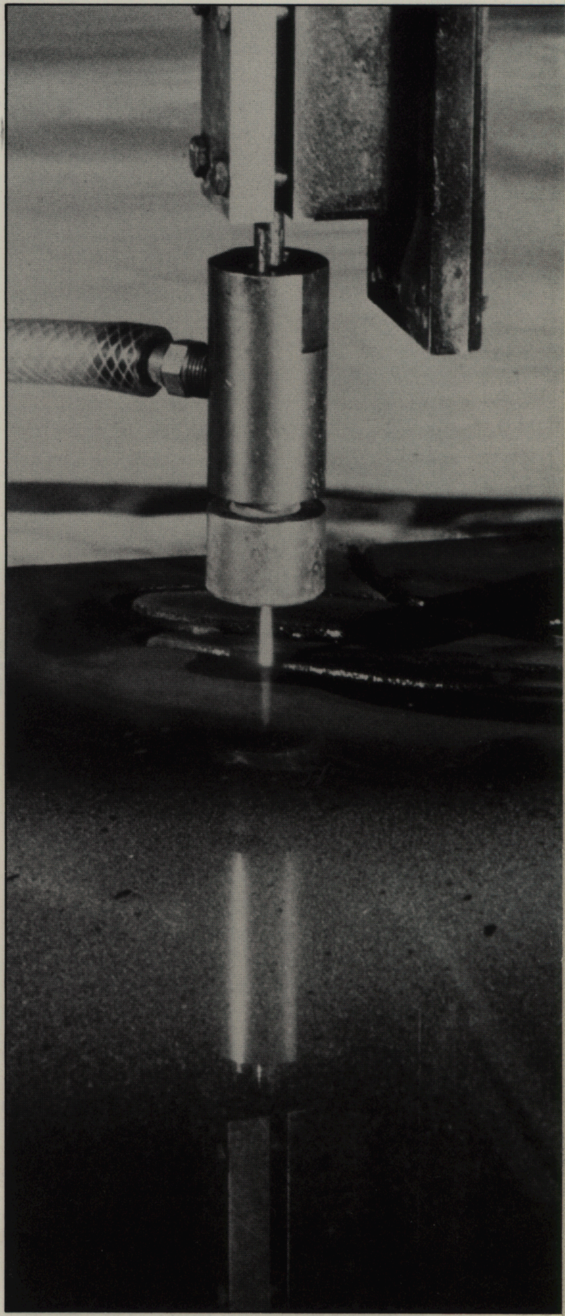


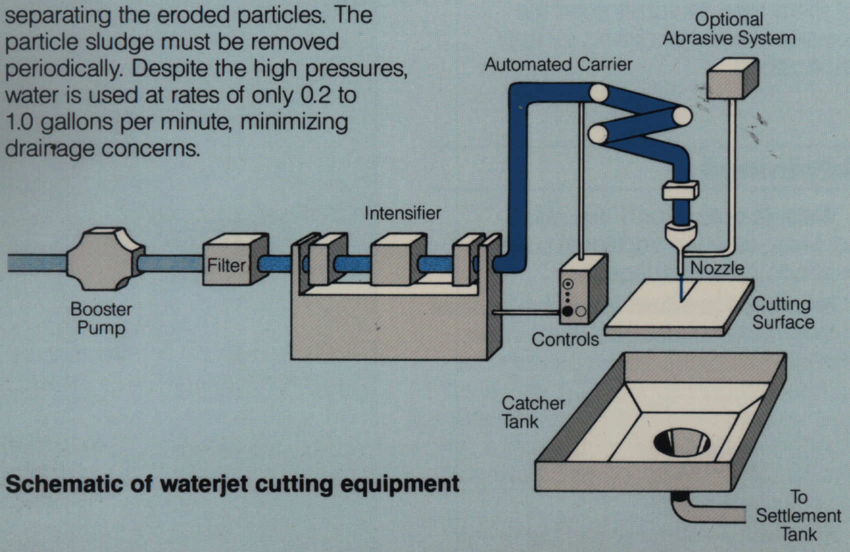
***Figure 1.* Waterjet cuts difficult shapes and contours on glass quickly and accurately—a slow, difficult task using saws.**

Cutting with Water

Waterjet cutting uses a highly pressurized stream of water to erode the workpiece. Abrasive waterjet is a variation that introduces an abrasive such as garnet, silica, or zirconium into the stream to erode the workpiece. A waterjet system can quickly be converted to an abrasive system to cut thicker, harder materials.

Water is initially filtered to remove impurities, then pumped through an intensifier, a high-pressure pump that generates pressures as high as 60,000 pounds per square inch (psi). The water is forced through a constricting orifice, usually a synthetic sapphire ranging from 0.003 to 0.020 in. in diameter. The pressurized water exits the orifice (at velocities up to 3400 feet per second) in a coherent jet, yielding clean cuts with a kerf often no wider than the stream itself. Abrasive systems require a carbide insert inside the nozzle. This creates a vacuum and draws the abrasive into the stream and directs it to the orifice.

As the jet passes through the workpiece, a catcher traps the still-powerful stream and eroded particles. Large catching tanks under the cutting table are used with vertical waterjet systems. For omnidirectional systems, compact tube-like catchers move with the nozzle. The water then flows to a settlement tank, separating the eroded particles. The particle sludge must be removed periodically. Despite the high pressures, water is used at rates of only 0.2 to 1.0 gallons per minute, minimizing drainage concerns.



Schematic of waterjet cutting equipment

most methods. And waterjet integrates well into existing manufacturing systems.

Fewer production steps—Waterjets produce a clean edge cut, even on dense or hard materials, often eliminating finishing steps. The waterjet does not burn the cut edge so cleaning is not required.

Reduced dust and pollutants—The waterjet carries away the eroded material, practically eliminating dust, pollutants, and toxic fumes associated with other cutting methods.

Waterjet does have cutting limitations that should be considered. Due to the power of the jet, waterjet cuts all the way through a workpiece, making closed angles and enclosed sections difficult to cut. For example, you could not cut 2 in. deep into a 4-in.-thick workpiece. Current research in waterjet cutting systems addresses these limitations.

Alternate Technologies

Many manufacturers are still using traditional cutting methods, like band saws, knives, diamond-tipped tools, shears, and punch presses. When looking to convert to a more efficient system—one that can cut complex shapes with greater accuracy—the choices narrow to three methods: plasma, laser, and waterjet cutting.

Waterjets are likely to be chosen when a cut causing no heat distortion is required. Waterjet is often used when accurate cuts with minimal kerfs, no HAZ, and a finished quality edge are needed. Waterjet can be used on most materials and thicknesses but is slow on some materials.

Plasma cutting provides high speeds at great thicknesses but is primarily used on metals. Plasma can cause a wide kerf and heat distortion and generally cannot achieve the tolerances capable with waterjet systems. Plasma cutting systems are discussed in *TechCommentary* Vol. 4, No. 5.

Laser cutting achieves high speeds with minimal kerfs on thin materials. Primarily used for metals and composites under ½ in. thick, lasers can cause heat distortion, delamination of composites, and even toxic fumes on epoxy-based materials. Lasers are described in *TechCommentary* Vol. 3, No. 9.

Applications

The versatility of waterjet cutting makes it attractive to manufacturers in almost any industry. Automated waterjet systems can increase cutting speed and accuracy to improve production in many applications.

Automotive—The automotive industry is rapidly switching to composites, plastics, and new materials for automotive components. The industry now relies on waterjet to cut to near-net shapes for many components, including

- Plastic and fiberglass dashboards
- Wood fiber composite door panels
- Carpet and headliner fabrics
- Plastic gas tank shields
- Interior plastic trim for vans.

In automotive foundries, waterjet cuts gates and risers from iron and aluminum castings.

In another application, cutting asbestos brake linings for passenger cars, an automotive manufacturer switched from conventional sawing to waterjet. The switch increased cutting speeds and accuracy. The waterjet system uses a bank of six nozzles and cuts 30 to 50% faster than conventional sawing. The kerf was 0.155 in. with sawing and is only 0.010 in. with waterjet, reducing material usage. Dust was eliminated with waterjet—an important factor when cutting asbestos. The increased cutting speeds and other advantages result in savings of about $25,000 per year.

Electronics—Waterjets are often used in the electronics industry to cut loaded and unloaded circuit boards. The hairlike size of the kerf and the omnidirectional, sharp corner cutting capabilities of the waterjet permit precise cuts on composites without separating the composite layers. While lasers are also used for this application, some composites contain fibers that conduct heat and cause delamination.

Aerospace—The aerospace and aircraft industries must utilize hard, dense metals and composites that can

Figure 2. Waterjet cutting composite aircraft parts for the interior cabin eliminates costly trimming and finishing steps.

withstand impact and drastic temperature changes. However, these characteristics also make them difficult to cut. Waterjet cuts exact shapes to meet strict tolerance specifications on

- Graphite/epoxy composites in structural wing components of military transport planes
- Fiber-reinforced composites for skin sections of helicopters and walls inside airplanes
- Contour trimming of advanced composite structures made from graphite, Kevlar®, and titanium
- Titanium for aircraft skins and ducts, landing gear, and turbine blades.

Other applications—Because waterjet is capable of cutting nearly any material at almost any thickness, its applications are widely varied and include cutting

- Vegetables and frozen foods
- Corrugated boxes
- Rock and concrete for excavation
- Astroturf®
- Stained glass.

Technical Considerations

When a manufacturer decides to convert from conventional tools to increase production, the primary choices are plasma, laser, and waterjet cutting systems. Although waterjet systems can cut most any material, their feasibility should be evaluated for each application. Many factors must be considered to determine if waterjet is right for your operation.

Material type—Waterjet is primarily used to cut materials for which plasma and lasers cause too great a kerf or HAZ. Composites, titanium, and food products are most often cut with waterjet because other methods are ineffective on these materials. Table 1 lists some of the materials and their thicknesses commonly cut with waterjet as well as cutting speeds.

Material thicknesses and cutting speeds—Waterjet is capable of cutting steel up to 3 in. thick and concrete slabs up to 12 in. thick. However, for practical applications, cutting speeds are the limiting factor. Thinner, softer materials, such as cardboard and rubber can be cut at speeds up to 3600 inches per minute (ipm). Achievable cutting speeds depend on the complexity of the cutting pattern, the nature and thickness of the material, and the capabilities of the carrier device.

Kerf—The amount of kerf depends on the material being cut, its thickness, and the diameter of the nozzle orifice. Typical kerfs range between 0.005 and 0.03 in.

Tolerances—The tolerance, or cutting accuracy, achievable with waterjet depends on the same factors as does the kerf. Generally, the tolerance achieved corresponds to the diameter of the nozzle orifice. Tolerances to 0.015 in. can often be obtained without further machining.

Abrasives—Abrasives are usually needed to cut metals and hard or dense composites. A grit, often garnet, silica, or zirconium, is pulled into the waterjet for greater erosive action. Abrasives can slightly increase kerf width.

Operating parameters—Operating parameters include water pressure, orifice diameter, and standoff distance. These parameters are set to optimum levels for each material, thickness, and desired cutting speed. The equipment supplier will help you determine the proper parameters for your application.

Power requirements—Most waterjet systems operate on 25 to 100 horsepower intensifiers, but some as large as 500 horsepower are used when many nozzles are required. One to twelve nozzles or cutting stations can be run from each intensifier pump. Power requirements range from 19 to 75 kW depending on the size of intensifier required.

Safety—Although there are inherent dangers when working with high-pressure equipment, safety concerns are minimal with waterjet cutting systems. Multiaxis systems are totally enclosed to reduce the pressure hazard and noise. Fire hazards associated with flame processes are eliminated. Dust, pollution associated with mechanical

Table 1. **Waterjet Cutting Speeds on Representative Materials and Thicknesses**

	Material	Thickness, in.	Speed, ipm
Waterjet	ABS plastic	0.087	40–80
	Cardboard	0.055	240
	Graphite composite	0.06	36
	PC boards	0.06	118
	Plexiglas®	0.118	35
	Rubber	0.050	3600
Abrasive Waterjet	Aluminum	3.0	1.5
	Carbon steel	0.750	8
	Glass	0.50	15
	Kevlar®	0.56	12
	Stainless steel	1.0	2
	Titanium	0.12	18

Table 2. **Comparison of Waterjet Cutting with Competing Processes**

	Waterjet[a]	Laser[b]	Plasma Arc[b]
Material type	Any materials	Most metals and many nonmetals	Metals only
Material thickness, in.	Up to 12	Under 0.5	Up to 6
Equipment costs, $	65,000–100,000	100,000–500,000	1,200–40,000
Kerf width, in.	0.003–0.125	0.010	0.027
HAZ	none	0.01	0.03
Tolerance	0.015	0.001	0.03

a) Ranges for a variety of materials.
b) Values for 1/4-in. steel.

methods, and dangerous fumes produced by lasers on some materials are also nearly nonexistent.

Economic Considerations

When evaluating a cutting method, consider both capital and operating costs.

Capital costs—A typical waterjet cutting system can be purchased for $65,000 to $100,000 and includes pumps, nozzles, and intensifier. The cost varies depending on the number of nozzles required, as additional intensifiers may be needed. Adding a relatively simple 3- and 5-axis system adds about $100,000. Some highly accurate robotics can cost as much as $500,000 but increase the complexity of shapes and configurations that can be cut. Special nozzles and the abrasive flow system add about $8,000 for abrasive cutting systems.

Operating costs—Operating costs include nozzles (possibly abrasives and carbides), electricity, water, and labor. Operating costs are estimated at $3 per hour for waterjet and $11 per hour for abrasive systems.

Abrasives, required for abrasive waterjet systems, are consumed at rates of 0.5 to 3 pounds per minute. Garnet, a commonly used abrasive, costs 25 to 30 cents per pound. Parts life varies greatly depending on pressure, water quality, and whether an abrasive is used. For waterjet systems, the constricting sapphire orifice lasts at least 50 hours and sometimes up to 300 hours, depending on water purity. For abrasive systems, the carbide is replaced every 4 to 6 hours, the orifice itself every 50 hours. An orifice costs $16 and a carbide costs $11. Both can be replaced in less than a minute. Labor costs are often reduced because only one operator may be required. The training time is approximately 3 days to operate the automated equipment but can take much longer if parts design is involved.

Outlook

Future developments in waterjet cutting systems focus on increasing attainable pressures and creating more accurate nozzles. These developments are expected to result in more efficient use of abrasives, further improvement in automated systems, and the use of portable waterjet systems for the construction industry.

The use of engineering plastics and composites demands the accurate cutting obtainable with automated waterjet cutting systems. As the use of these types of materials increases and as more manufacturers discover the many ways waterjet can benefit their cutting operations, the popularity of waterjet cutting continues to grow.

The information in this issue of *TechCommentary* gives an overview of the capabilities of waterjet cutting systems. If you think your company could use such a system, talk with your electric utility marketing representative and equipment vendors.

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CENTER FOR MATERIALS FABRICATION
An EPRI R&D Applications Center
505 King Avenue • Columbus, Ohio 43201-2693
(614) 424-7742