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# Water Jet Technology Association

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JET NEWS

DECEMBER 1989

## From the President's Desk

This issue of *Jet News* contains a review by Tom Labus on the Industrial Applications of Fluid Jets. Look at the myriad of materials that are cut routinely by jets: paper products, textiles, building materials, rubber, fiberglass, plastics, composites, food, metals, ceramics, and glass. This list expands daily as people apply the unique features of fluid jets to industrial problems.

The application of jet cutting to new materials sometimes is a difficult process requiring ingenuity of the operator and many trials and errors. New applications under development now include cutting steel tubing and cutting thick synthetic fibers. It is difficult to get a consistent cut through a tube from the outside because the jet expands in the airspace at the tube bore. This can be avoided if the tube is big enough to cut from the inside out or can accommodate a catcher in the bore. The problem being worked on now is how to make high quality, high tolerance cuts in small tubes which can neither accept a catcher in the bore nor can be cut from the inside out.

Cutting thick synthetic fibers causes a problem because the woven threads tend to dissipate the jet's energy causing incomplete or inconsistent cutting at depth. This problem might be a good candidate for cutting with jets containing chemical collimating agents. It is a problem, however, that has so far resisted solution.

I am confident that many new applications for fluid-jet cutting will be discovered. The world of water-jet cutting is very new and, thus, has all the rigor, enthusiasm, and potential of youth.

– George A. Savanick, Ph.D.

## Industrial Applications of Fluid Jets

by Thomas J. Labus, University of Wisconsin-Parkside

### INTRODUCTION

High-speed water jets have been accepted as standard cutting tools in a wide variety of industries ranging from food and paper to ceramics, metals, and advanced composites. The acceptance of this technology by industry has accelerated significantly within the past years, and advances in the technology promise to widen the applications even further. The high technology cutting machines market is projected to be between $340 and $440 million by 1991 and water jets will have a significant impact in this area. Besides cutting uses, cleaning, deburring, turning, milling, polishing, etc., applications will also increase because of advances in the technology. Because of the evolution in the technology, a more proper term instead of water jets, is "fluid jets" since it incorporates water, abrasive, pulsed, cavitating and other jet forms.

In addition, fluid jets integrate easily with robots because the jet cutters are light-weight, produce low tool reaction forces, have omni-directional cutting capabilities, and realize their full potential in terms of part quality and productivity when integrated with automated equipment. In a recent survey of robot manufacturers[1], "waterjet cutting" was segregated on an application basis and specific robots identified for use in this category. Equipment manufacturers are not only aware of the technology, but also of its specific needs in terms of integration with their units.

### BASIC TECHNOLOGY

There are three different types of water jets (i.e., continuous, pulsed, and cavitating) with the continuous jet being responsible for almost all of the active industrial applications. The continuous jet is utilized in two forms: "water-only" and abrasive.

The first type[2] was employed for industrial applications in 1971 and represents the bulk of current installations. The abrasive jet is a modification of the water-only jet, whereby fine abrasive particles are injected into the jet stream, substantially enhancing the cutting action. Water-only jets are limited to materials characterized as being fibrous, porous, granular or soft, with porosity and hardness being the more important parameters. Hard, dense materials, such as glass, metals, and fired ceramics, require abrasive jets to be cut effectively.

The distinction about when to use water-only versus abrasive jets requires some comment. Current equipment capabilities have a maximum operating pressure level of 411 MPa (60,000 psi). The addition of abrasives at this pressure and lower levels, to the jet, allows the range of materials capable of being cut to be substantially expanded. This expansion comes at the cost of contaminating a basically clean-cutting process, and increased operating costs. An increase in the max-pressure capability of the equipment can extend the cutting range while keeping the process clean, but it requires an advanced high-pressure pumping system. It is important to remember that the 411 MPa (60,000 psi) limit is imposed by available equipment and not a process barrier.

Tables 1 and 2 (see pages 6-7 ) provide representative values of cutting speed, nozzle size and operating pressures for various materials and thickness for water only and abrasive jets. The data in Tables 1 and 2 are presented as indicative of performance potential, but testing is required in each application because of the substantial influence of material properties on the cutting process. Some theoretical work has been accomplished to model the cutting action, but the overall process is extremely complex with material properties playing an important role. Testing for commercial use still is the first step in a successful application of fluid jet technology.

Extensive cutting performance data is available for certain materials which can eliminate or minimize the amount of testing required. The purpose of the test cutting is to relate performance (i.e., cutting rate and quality of cut for a given material) to unit size (i.e., nozzle diameter and jet pressure). With these parameters established, capital and operating costs for the jet system can be established, and trade offs defined which influence economic justification.

(continued on page 3)

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*The question "Who ought to be the boss?" is like asking, "Who ought to be the tenor in the quartet?" Obviously, the man who can sing tenor.*

Henry Ford

## Accident Case Study – Shipyard

**by Paddy Swan, S.P.D. Swan Consultants, Derbyshire, U.K.**

A contractor working on a shipyard issued the following equipment to his staff: helmets, goggles, ear defenders, steel-toe-capped boots, waterproof clothing.

A diesel-driven pump unit with air start and chalwyn valves was used. The pump had an unloader and was supplied complete with 500 meters of 4-ply wire spiral-reinforced hose and a dry shut-off gun.

The job was to clean the double-bottomed tanks of ULCC in drydock for repair and survey. This necessitated using the full run of hose from the pump unit placed on the dock side. Carrying out the job required a four-man team – an operator had to enter a confined space and jet in a prone position with a further operator by the entrance to the tank, one on deck and one taking care of the unit on the dockside.

All the operators were experienced, and with the exception of one operator who had 5 years of experience, none of the rest had less than 10 years of experience in practical jetting.

The pressure and flow were kept fairly low to ensure that the operator jetting was as comfortable as possible, working at about 4000 psi (280 bar) and 7 gpm (32 l/m). A pit jet was being used during the job.

At lunchtime, 12:15 p.m., the job was shut down and the entire team went to the pub as it was one of the team member's birthday. They returned at 1:45 p.m. and they took up their original positions to start the afternoon shift.

The pump was not yet started when the operator on the gun, moving into a new position in the next bay, was heard to cry out that he was hit. The operator was pulled out of the tank and was found to be bleeding profusely with bright red blood coming in spurts from the area of the groin. The operator was dead on arrival at the hospital.

**WHAT ARE THE PRINCIPAL CAUSES OF THIS ACCIDENT AND COULD THE OPERATOR HAVE BEEN SAVED?**

**(see answer on page 10)**

## Safety Labels at Ingersoll-Rand

Damon Schroter, Senior Product Manager of Ingersoll-Rand (IR) Waterjet Cutting Systems, sent the following labels that IR uses on water-jet cutting machinery. It is a good practice to use such labels to warn operators and observers of possible hazards.




## Industrial Applications Of Fluid Jets, *from page 1*

As with any technology, fluid jets have advantages and disadvantages.

**Advantages:**

1. Increased cutting efficiency over conventional methods.
2. Multiple-layer cutting capability.
3. Increased cutting speeds.
4. Wide range of materials cut with minimum system changes.
5. Selective cutting capability.
6. Easily integrated with automated equipment.
7. Low reaction/target forces.
8. Non-contacting cutter.
9. No parent material properties modification.
10. Cutting medium can be any fluid.

**Disadvantages:**

1. High initial capital cost.
2. Pre/post water treatment.
3. Environmental effects.
4. Abrasive jet effects on ancillary equipment.
5. User education in terms of safety, water quality maintenance, and contamination issues.

Each of these areas deserve some discussion to clearly define the specifics associated with each advantage/disadvantage.

Increased cutting efficiency when compared to conventional methods is interpreted in broad terms to include the total impact of fluid jets on the overall process. To illustrate, consider the cutting of food products such as nut bars and other pressed, brittle food composites. Conventional mechanical cutting methods tend to break or crack these items. The extent of this breakage is in the range of 40 to 60 percent, and although 90 percent of this breakage can be recycled, it represents additional cost in recycling energy and time. Fluid-jet cutting of these materials at identical production rates reduces the initial 40 to 60 percent breakage to less than 1 percent, thereby eliminating the need for any recycling. In justifying the use of fluid jets, cutting efficiency is defined in terms of the total competitive process, and not just cutting rates.

The multiple-layer cutting capability of fluid jets can be extended to materials in which mechanical methods have not been traditionally successful, such as glass. Glass can be cut using an abrasive water jet. Tolerances are within ± .25 mm on any linear in-plane dimension, and are in ± .12 mm in-depth direction. In addition, because of the small-cut width and the low-target forces, more parts could be obtained from the same stock size due to closer part nesting.

*Figure 1* shows an installation for slitting corrugated boxboard. This application illustrates the increased cutting speed capability of fluid jets. In this case, the web cutting speed can be increased significantly [as high as 355 cm/sec (140 in/sec)] without risking delamination. In addition, no dust is generated which increased the life of down-stream printing plates.

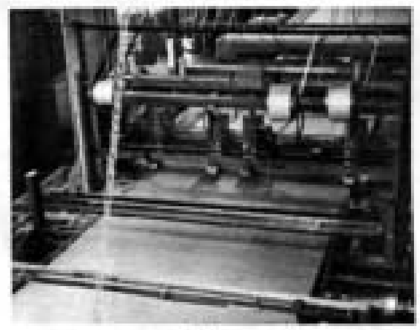

**Figure 1**

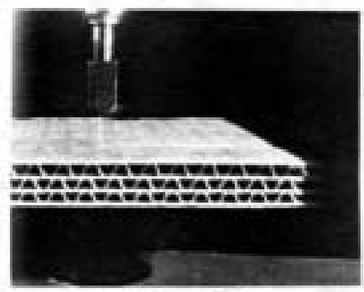

**Figure 1A**

**Figures 1 and 1A** - *Waterjet slitting of corrugated boxboard. (Photographs courtesy of Ingersoll-Rand Waterjet Cutting Systems.)*

A wide range of materials can be cut with minimum system changes. The significant parameters which control the cutting process include the jet pressure, nozzle size, abrasive type and feed rate (if employed), standoff distance, and cutting speed for a given target material. All of the above parameters, except for nozzle size, can be controlled via software commands. Nozzle size is not necessarily changed even when different materials are being cut. Tables 1 and 2 (see pages 6-7)provide typical performance data for both "water-only" and abrasive jets for a wide variety of materials. The data in these tables do not necessarily represent maximum or optimum performance, and test cutting of the specific material of interest is recommended for system design/sizing purposes.

Fluid jets also have a selective cutting capability when compared to mechanical methods. In laminated materials having a wide range of mechanical properties, the jet can remove an overlayer without damage to the substrate and without sophisticated tool controls to monitor the location of the interface surface. This selective material removal capability becomes more difficult to maintain as the mechanical properties of the constituent members of the laminate approach each other.

Integration of fluid jets with automated equipment does not pose significant barriers. Fluid jets are true point cutters, hence tool width considerations can normally be neglected and their multi-directional cutting capability make shape cutting as easy as drawing with a pencil. Numerically-controlled and robot-controlled systems are very common in many industrial applications.

Low-reaction forces, in the range of 3 to 67 N (0.75 to 15 lb), coupled with small payloads make fluid jets and robots a natural combination. The structural support requirements for robots are, therefore, dictated by the mass of the actuating components and their dynamics, and not tool cutting forces. These low-reaction forces also result in simpler part fixtures and reduced fixture costs. When fluid jets are used in cleaning, deburring, or descaling operations, the reaction forces are generally much larger than the foregoing values since lower pressure and larger nozzle sizes are used. Multiple nozzles are often employed which further increases the magnitude of the reaction forces. Care should be exercised when employing fluid jets when large nozzle sizes are used.

Since the jet is a non-contacting cutter, abrasive materials such as abrasive papers, grinding wheels, and composites can be cut without wear of the cutting tool. The water jet nozzle wears due to high-speed erosion, but not to the same degree as a mechanical tool would when cutting these materials.

Fluid jets provide some unique environmental advantages in terms of reduced respirable dust levels and the ability to operate in a hazardous environment safely. Munitions reclamation or naturalization is routinely accomplished using fluid jets. Fiberglass can be cut without the dust generated by conventional methods. Abrasive jets are not "clean" cutters like the "water-only" jets and care must be taken to protect support equipment against stray abrasive accumulation. This subject will be discussed in later sections.

**(continued on page 6)**

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# Industrial Applications Of Fluid Jets, *from page 3*

## TABLE 1. - Water-Only Jet Cutting Data

| Target material | Thickness, inch | Cutting rate, in/sec | Nozzle diameter, inch | Jet pressure, psi |
|---|---|---|---|---|
| **Building materials:** | | | | |
| Asbestos board | 0.71 | 60.0 | .008 | 28,600 |
| Ceiling tile: | | | | |
| Fireguard - 5/8 | 0.68 | 70.0 | .005 | 40,000 |
| Textured - 3/4 | 0.83 | 70.0 | .005 | 40,000 |
| Cement asbestos | 0.24 | 0.6 | .008 | 43,000 |
| Composite insulation | 2.36 | 4.0 | .006 | 55,000 |
| Gypsum board | 0.39 | 3.9 | .008 | 28,600 |
| Insulation board | 2.0 | 65.6 | .008 | 28,600 |
| **Composites:** | | | | |
| Ceramic tape | 0.061 | 6.0 | .005 | 55,000 |
| Fiber F.P. preforms | 0.375 | 4.0 | .006 | 55,000 |
| Foil/felt/foil | 0.75 | 0.75 | .008 | 55,000 |
| Glass epoxy lam. | 0.12 | 1.64 | .008 | 57,000 |
| Graphite | 0.061 | 0.6 | .006 | 55,000 |
| Epoxy lam. | 0.07 | 1.32 | .008 | 57,000 |
| Kevlar | 0.22 | 0.6 | .012 | 55,000 |
| Epoxy board | 0.06 | 1.0 | .006 | 50,000 |
| PC board | 0.027 | 2.0 | .005 | 55,000 |
| Nomex - 9# | 0.75 | 1.5 | .008 | 55,000 |
| PC boards: | | | | |
| G10 | 0.062 | 0.08 | .006 | 55,000 |
| Kapton | 0.062 | 0.07 | .006 | 55,000 |
| FR-4 | 0.062 | 2.0 | .006 | 55,000 |
| SMP | 0.12 | 40.0 | .006 | 50,000 |
| **Fiberglass:** | | | | |
| Corrugated | 0.09 | 4.0 | .005 | 55,000 |
| Fiberglass | 0.15 | 0.2 | .007 | 55,000 |
| Glass base mat | 1.0 | 14.0 | .007 | 50,000 |
| Glass insulation | 12.0 | 16.6 | .006 | 50,000 |
| Red board | 0.25 | 10.0 | .005 | 55,000 |
| Wallboard | 0.38 | 10.0 | .006 | 55,000 |
| **Foods:** | | | | |
| Almond brittle | 0.45 | 4.0 | .004 | 30,000 |
| Cheddar cheese | 3.5 | 3.0 | .006 | 55,000 |
| Chocolate | 0.38 | 4.0 | .004 | 40,000 |
| Crispbread (5 layers) | 1.19 | 4.0 | .004 | 55,000 |
| English muffins | 0.75 | 2.0 | .004 | 55,000 |
| Fish-cod | 0.5 | 5.0 | .004 | 40,000 |
| Fruit leather | 0.13 | 2.0 | .004 | 40,000 |
| Granola | 0.5 | 4.0 | .004 | 40,000 |
| Mozzarella | 1.5 | 16.0 | .006 | 30,000 |
| Peanut bar | 0.42 | 4.0 | .005 | 40,000 |
| Pecan pie | 1.25 | 3.0 | .006 | 55,000 |
| **Medical products:** | | | | |
| Dust mask | 0.1 | 2.0 | .005 | 55,000 |
| Kidney filter | 4.0 | 4.0 | .012 | 55,000 |
| **Miscellaneous:** | | | | |
| Brake lining (uncured) | 0.27 | 2.4 | .007 | 55,000 |
| Buffing pad | 0.42-1.1 | 12.0 | .006 | 55,000 |
| Foam board | 2.0 | 4.0 | .005 | 55,000 |
| Formica | 0.05 | 24.0 | .005 | 50,000 |
| Green ceramic | 0.5 | 7.0 | .005 | 50,000 |
| Juice container | 0.014 | 100.0 | .004 | 40,000 |
| Lead battery plate | 0.25 | 2.0 | .006 | 50,000 |
| RTV removal | 0.015 | 4.0 | .007 | 10,000 |
| Sound pad | 0.09 | 20.0 | .006 | 50,000 |
| Unfired alumina cer. | 0.17 | 0.8 | .004 | 55,000 |
| **Paper products:** | | | | |
| Cardboard | 0.056 | 4.0 | .004 | 55,000 |
| Chipboard (paper) | 0.10 | 12.0 | .005 | 55,000 |
| Corrugated board | 0.31 | 131.0 | .010 | 57,000 |
| | 0.55 | 82.4 | .014 | 57,000 |
| Davy board | 0.17 | 5.0 | .006 | 55,000 |
| Filter paper | 0.010 | 4.0 | .004 | 30,000 |
| Kleenex | 1.0 | 4.0 | .005 | 55,000 |
| Milk carton paper | 0.014 | 230.0 | .004 | 40,000 |
| Newsprint | 16 sheets | 240.0 | .004 | 40,000 |
| Press board | 0.12 | 3.3 | .008 | 43,000 |
| Sand paper (120 grit) | 1 layer | 80.0 | .005 | 40,000 |
| **Plastics:** | | | | |
| ABS | 0.22 | 1.0 | .006 | 55,000 |
| Acrylic | 0.52 | 0.8 | .008 | 55,000 |
| Lexan | 0.01 | 4.0 | .008 | 55,000 |
| Mylar sheet | 0.007 | 200.0 | .004 | 55,000 |
| Plexiglass | 0.12 | 1.0 | .007 | 55,000 |
| Polycarbonate | 0.085 | 0.8 | .006 | 55,000 |
| Polyester | 0.5 | 24.0 | .006 | 55,000 |
| Polyethylene | 0.38 | 20.0 | .004 | 40,000 |
| Polypropylene | 0.08 | 3.4 | .004 | 55,000 |
| PVC | 0.141 wall | 0.2 | .009 | 55,000 |
| PVC | 0.03 | 12.0 | .004 | 55,000 |
| Teflon | 1.85 | 0.4 | .007 | 55,000 |
| **Rubber:** | | | | |
| Gasket material | 0.25 | 6.0 | .005 | 55,000 |
| | 0.06 | 32.8 | .008 | 28,600 |
| Inner silicone sleeves | 1.0 | 0.6 | .004 | 55,000 |
| Molding | 1.25 | 0.6 | .007 | 55,000 |
| Rubber tile | 0.12 | 6.0 | .006 | 55,000 |
| Rubber window gasket | 0.03 | 2.0 | .004 | 30,000 |
| Tire | 1.97 | 0.3 | .008 | 57,000 |
| Urethane | 0.08 | 4.0 | .004 | 55,000 |
| **Textile:** | | | | |
| Carpet | 0.46 | 12.0 | .006 | 55,000 |
| Finished leather | 0.06 | 50.0 | .005 | 40,000 |
| Glass fiber cloth | 0.06 | 1.3 | .008 | 57,000 |
| Leather | 0.09 | 13.1 | .008 | 43,000 |
| Naugahyde | 0.5 | 20.0 | .004 | 55,000 |
| Rubber-backed carpet | 0.72 | 5.0 | .006 | 55,000 |
| Silk | 11 layers | 12.0 | .005 | 55,000 |
| Vinyl | 5 layers | 8.0 | .005 | 55,000 |
| Wool felt | 1.0 | 2.0 | .008 | 55,000 |

## Industrial Applications Of Fluid Jets, *from page 6*

The material being cut does not suffer any modification of physical properties when machined using fluid jets. The abrasive jet does not alter the surface hardness of the cut as opposed to the heat-affected zone created by a flame or plasma torch. Thus, special tools are not required to machine the cut surfaces and their attendant costs are reduced.

The cutting fluid is not restricted to water. Saline solutions are used routinely in medical applications and oils in food processing. Certain additives (i.e., long-chain polymers) are used to promote jet stability for large standoff-distance applications, but their benefits must be weighed against the attendant costs. Most of the fluid jet installations in industry do not employ the long-chain polymers because they are not warranted.

With the benefits of fluid jets enumerated, the disadvantages need to be discussed giving due consideration to their impact on industrial applications.

One of the traditional barriers to implementing fluid jet systems has been their high initial capital cost. This occurred because of the state-of-the-art technology and the small installed industrial base. Over the past 10 years, the industrial base has grown steadily and the availability of equipment has increased while entry-level costs have decreased. Details of system costs based on size will be provided later. One additional point regarding fluid jet system costs should be noted. Fluid jet systems are inherently flexible manufacturing systems since they can be altered to meet changing market conditions. Although their initial cost may be higher than conventional technology, their flexibility allows a longer useful life. Many of the systems built in the mid-1970's are still in operation today.

Water treatment is a critical issue in controlling the operating/replacement costs in a fluid jet system. A pretreatment of the water is necessary to insure long nozzle life and a post-treatment may be required based on the nature of the application. The pretreatment is primarily a "softening" process to control the precipitation of dissolved solids in the water and mechanical filtration to handle the larger size particles.

The water quality in every application should be checked to insure that the proper treatment is being used. Simple water softening can be employed, but the water source coupled with the application, may require deionized water, or other treatment methods such as reverse osmosis. Post-treatment of the water may be required based on the nature of the application and the local regulations governing the disposal of wastes. For most cutting applications, the total water consumption is less than 19 l/min (5 gpm). For cleaning applications, flow rates are in the range of 38 to 114 l/min (10 to 30 gpm). The pretreatment requirement applies mainly to high-pressure fluid-jet cutting where small nozzles, i.e., less than 0.5 mm (0.20 in) are employed, since this is the range of nozzle sizes where precipitates in the water can cause substantial nozzle wear. This water treatment requirement has a parallel in the "cutting fluids" used by conventional machine tools and the use of "chip wringers" to separate chips from the oil prior to recirculation.

Just as there are positive environmental aspects of fluid jets, there are also some down-side effects. Increased humidity in the immediate cutting area can occur and control may be necessary based on the application. Noise levels are below OSHA level requirements, but care should be taken in catcher design to insure complete capture of the jet. A jet issuing into free air can produce noise levels up to 100 dB.

The use of abrasive jets requires the protection of equipment on which the jet is mounted, and containment of jet or protection of machinery near the fluid jet cell against stray abrasive buildup and contamination. The use of abrasive jets also contaminates the workpiece, hence a secondary cleaning operation may be required to produce the desired surface condition. Abrasive jets also complicate catcher designs because of the greater cutting ability of the abrasive jet versus the "water-only" jet. The operating/maintenance costs of abrasive jets are substantially higher than "water-only" jets by nearly a factor of 10. This issue will be discussed later, but again it should be viewed in total context of the application.

User education is a basic issue in any process, but new technology faces additional problems, especially when it represents a radical departure from current practices. This is often the case with fluid jet applications. Safety is of paramount concern because of the high pressures involved. For manually-operated equipment, a standard is available from the Water Jet Technology Association[8]. For automated equipment, many system suppliers provide operator training as part of the basis package and it is essential that the operator is fluent in all aspects of the system.

System maintenance is crucial to insuring proper operation and a long system life. The level of contamination in the system should be kept to a minimum and maintenance of the equipment should be accomplished in a clean area away from the normal operating environment.

**TABLE 2 – Abrasive Jet Cutting Performance Data**

| Target material | Thickness, inch | Cutting rate, in/min | Nozzle diameter, inch Sapphire | Nozzle diameter, inch Mixing | Pressure, psi |
|---|---|---|---|---|---|
| **Ceramics and glass:** | | | | | |
| Aluminum oxide - | | | | | |
| 85 pct | .25 | 2.5 | .018 | .062 | 30,000 |
| 94.5 pct | .25 | 1.0 | .018 | .062 | 30,000 |
| 99.9 pct | .25 | 0.5 | .018 | .062 | 30,000 |
| Ceramic sheet | .028 | 2.0 | .018 | .062 | 30,000 |
| Glass capacitor | .25 | 12.0 | .018 | .062 | 30,000 |
| Glass | .25 | 350.0 | .018 | .062 | 30,000 |
| Mirror glass | .19 | 30.00 | .018 | .062 | 30,000 |
| Mud stone | 1.25 | 60.0 | .018 | .062 | 30,000 |
| Quartz glass | .125 | 6.0 | .018 | .062 | 30,000 |
| **Composites:** | | | | | |
| Acrylic | .50 | 15.0 | .018 | .062 | 30,000 |
| 2014 Alum/15 pct SiC | .5 | 7.1 | .013 | .047 | 35,000 |
| Brake liners | 1.25 | 12.0 | .018 | .062 | 30,000 |
| Carbon | 2.75 | 24.0 | .018 | .062 | 30,000 |
| Fiberglass laminate | .67 | 24.0 | .018 | .062 | 30,000 |
| Kevlar/graphite | .88 | 16.0 | .018 | .062 | 30,000 |
| Magnesium/26.5 pct SiC | .5 | 4.7 | .013 | .047 | 35,000 |
| Phenolic | .37 | 8.0 | .018 | .062 | 30,000 |
| Tire treads | .5 to 1.2 | 12.0 | .018 | .062 | 30,000 |
| Wood laminate | 1.8 | 12.0 | .018 | .062 | 30,000 |
| **Metals:** | | | | | |
| Aluminum | 1.0 | 2.0 | .018 | .062 | 30,000 |
| Amaire | 1.1 | 1.0 | .018 | .062 | 30,000 |
| Cast iron | 0.32 | 6.0 | .018 | .062 | 30,000 |
| Cold-rolled steel | 0.79 | 2.0 | .018 | .062 | 30,000 |
| HY80 steel | 1.0 | 0.5 | .018 | .062 | 30,000 |
| Inconel | .045 | 24.0 | .018 | .062 | 30,000 |
| 718 | .062 | 9.0 | .013 | .047 | 35,000 |
| | .062 | 15.0 | .009 | .030 | 45,000 |
| | .062 | 12.0 | .018 | .062 | 45,000 |
| Magnesium | .075 | 48.0 | .018 | .062 | 30,000 |
| Molybdenum | 0.25 | 1.0 | .018 | .062 | 30,000 |
| Ree bar | 0.75 | 1.5 | .018 | .062 | 30,000 |
| S.S. 301 | .063 | 6.0 | .018 | .062 | 30,000 |
| S.S. 321 | .063 | 6.0 | .018 | .062 | 30,000 |
| Titanium | 0.13 | 18.0 | .018 | .062 | 30,000 |

(continued on page 8)

## Industrial Applications Of Fluid Jets, *from page 7*

### NEW DEVELOPMENTS

Abrasive jets are produced by injecting fine abrasive particles downstream of a high-speed water jet. The point where the abrasive and water jet interact is called the mixing chamber. After the random mixing occurs, the jet is refocused through a secondary nozzle and directed toward the workpiece. The only difference between an abrasive jet system and a "water-only" jet system is a change in the nozzle and the addition of an abrasive feed mechanism.

The development of abrasive jets was aimed at increasing the range of materials that could not be cut by "water-only" jets. It has accomplished this, but it also has added the following considerations versus "water-only" jets:

1. Hazards due to rebounding abrasives.
2. Pollution of area and product with abrasives.
3. Additional cost of abrasives.
4. Significantly shortened abrasive nozzle lives.

Abrasive jets were developed to skirt the pressure limitations of current equipment when attempting to cut hard, dense materials. Although "water-only" jets operating at pressures near 685 MPa (100,000 psi) can cut some of the materials which abrasive jets cut, they are not as efficient. The abrasive jet provides a viable alternative to producing industrial grade hardware capable of operating reliably at pressures up to 685 MPa.

### APPLICATIONS

Fluid jet applications vary from slitting corrugated boxboard and cutting automotive door panels to machining hard, dense ceramics and metal matrix composites, to name a few. The data in Tables 1 and 2 (see pages 6-7) show the broad range of materials that can be processed with fluid jets. The examples which follow are used to illustrate basic application principles and support the reliability of fluid jets for industrial use. Because fluid jet technology has evolved over the years on an application-by-applications basis, the systems tended to be dedicated units designed for specific tasks. The realization that fluid jets are flexible manufacturing tools opens up new possibilities in terms of treating fluid jets as just another tool available to the robot. This type of philosophical approach allows the robot to choose the appropriate tool for the function it has to perform, thus increasing the flexibility of the cell to adapt to changing production requirements.

| Material type | Percent savings |
|---|---|
| Closed-cell neoprene | 40 |
| Fiberglass | 49 |
| Gaskets | 200 |

Figure 2

Integration of a CAD system with robots or NC controlled equipment provide an efficient method for cutting 2-D parts from flat-sheet stock. This type of system with "nesting" software is being used to shape cut closed-cell neoprene, fiberglass insulation, and gaskets for industrial refrigeration systems[10]. This system produces direct labor and benefit savings over conventional methods as shown in *Figure 2*.

This type of system also fits well into the "just-in-time" production approach and generates an internal rate of return for the project of 51 percent based on material, labor, and inventory savings.



Integration of fluid jets with automated equipment results in achieving its full potential. Manually-operated equipment enjoys some of the environmental benefits of fluid-jet cutting, but it does not realize the productivity, consistent quality of cut, and material utilization benefits that fully automated fluid-jet cutting provides. A key element in successful automated water jet applications is appropriate software to interface with off-line computers for parts programming and production control. If the part is registered relative to the robot, then standard NC programming can be used to generate the cutting path. For a part that is not registered relative to the robot, a combination of TEACH capabilities, or a vision system to locate the part in the cutting envelope and axis transformation software are used to generate the nozzle cutting path using the stored final part geometry.

Computer interfacing, coupled with multiple water jets and electro-optics, are used in the fish processing industry to cut fillets to a target weight, accurate to ± 0.5 ounce, with a 95 percent confidence limit. This ten-nozzle system operates at 377 MPa (55,000 psi) and has increased productivity by 300 percent over convention mechanical cutters.

**(continued on page 9)**

## Industrial Applications Of Fluid Jets, *from page 8*

*from page 8*

There are 44 water-jet corrugated boxboard slitting units in operation worldwide. Multiple nozzles are mounted on movable carriages. The movable carriage allows adjustment of slitting widths quickly and easily. The major advantages of fluid jets in this application include the following:

1. Increased cutting rate beyond mechanical methods while maintaining cut quality.
2. No edge damage to the product (*Figure 3*).
3. Edge trim savings due to the ability to cut closer to the edge of the board while maintaining cut quality.
4. No dust on board: printing rolls on equipment farther down the line required less frequent cleaning.

Change over requires simply valving from one bank of nozzles to the other.

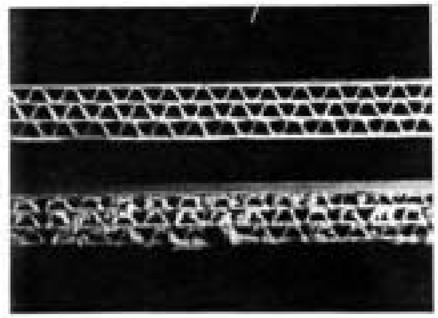

**Figure 3** - *Difference between a waterjet cut edge (top) and an edge produced by conventional knife slitting (bottom). (Photograph courtesy of Ingersoll-Rand Waterjet Cutting Systems.)*

There are 62 fiberglass insulation slitting systems in operation worldwide, cutting not only fiberglass insulation, but wool, particle board, gypsum board, and plastic baseboards and moldings. Fluid jet advantages over conventional methods include:

1. Increased cutting rate.
2. Dustless cutting providing improved worker safety.
3. Undamaged edge cut which produces a uniform product quality throughout.

Fluid jets are also used to deflash lead frames used on integrated circuit board assemblies. This type of deflashing produces a reduction in board rejection rate from 15 percent to less than 1 percent and an increase in productivity of 150 percent over conventional trim dies.

The type of automation employed is dictated by the application and does not necessarily have to be sophisticated to be effective. An X-Y fluid jet tracing system can be used for flat goods cutting such as shoe uppers/lowers, puzzles, and synthetic fibers. These units are controlled via an optical tracer and have a moving slot catcher to follow the multiple nozzle heads. Fluid jet advantages in this application include:

1. Multi-layer cutting without edge deformation.
2. Maximum material utilization due to closer pattern nesting from reduced kerf width.

The use of fluid jets by the automotive industry to cut and trim pressed fiber door panels (*Figure 4*), to cut carpeting, clean castings, deburr transmission valve housings and to machine composites indicates the versatility of the technology. All of the foregoing applications are indicative of the broad range of materials that can be processed using fluid jets and the variety of techniques available to integrate fluid jets into industrial processes.

This brief summary of industrial fluid jet technology was presented to provide an introduction to the basics of the technology, list advantages and disadvantages as related to conventional methods, identify the significant jet parameters that relate performance and costs (both operating and capital) and to review some basic applications where fluid jets have been successfully employed. Fluid jets are not a "cure-all" solution, but they are a solution that, if properly applied, will provide significant economic, productivity, quality, and environmental gains for many industrial applications.

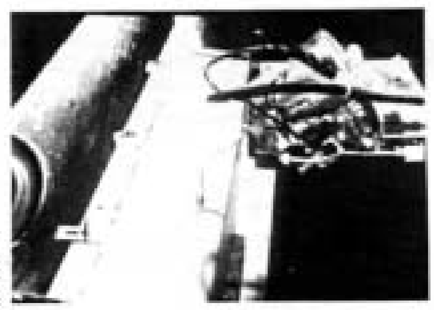

**Figure 4** - *Pure waterjet trimming of a formed door panel with a Robotic's, Inc. Five-axis manipulator and a 40-hr. intensifier. (Photograph courtesy of Ingersoll-Rand Waterjet Cutting Systems.)*

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## 2nd Pacific Rim International Conference On Water Jet Cutting

The 2nd Pacific Rim International Conference on Water Jet Cutting will be held at the Hotel Meridian (Orchard Road) in Singapore, January 17-19, 1990. The conference is organized and sponsored by the Nanyang Technical Institute Singapore and the Water Jet Society of Japan. Authors are invited to submit titles and abstracts of papers regarding the fluid mechanics of jets, jet cutting, and material removal processes, jet cutting and cleaning systems, industrial applications, medical applications, manipulator design, and safety and environmental considerations. Completed manuscripts are due on December 31, 1989. Accepted papers must be submitted and presented in English.

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## Accident Case Study – Shipyard, *from page 2*

**Answer to**

**WHAT ARE THE PRINCIPAL CAUSES OF THIS ACCIDENT AND COULD THE OPERATOR HAVE BEEN SAVED?**

Pressure not discharged from the line after shut down and faulty safety catch on gun. Gun trigger caught on projection. If the rest of the team had known that the injured man was bleeding, he could have been saved.

**Moral:** Teach discharge of pressure in line and remember, if a "wet suit" keeps water out, it will also keep blood in.

## Conference Proceedings Available

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