WJTA WaterJet Technology Association

Jet News

FEBRUARY 2004

Published by the WaterJet Technology Association for the benefit of its members

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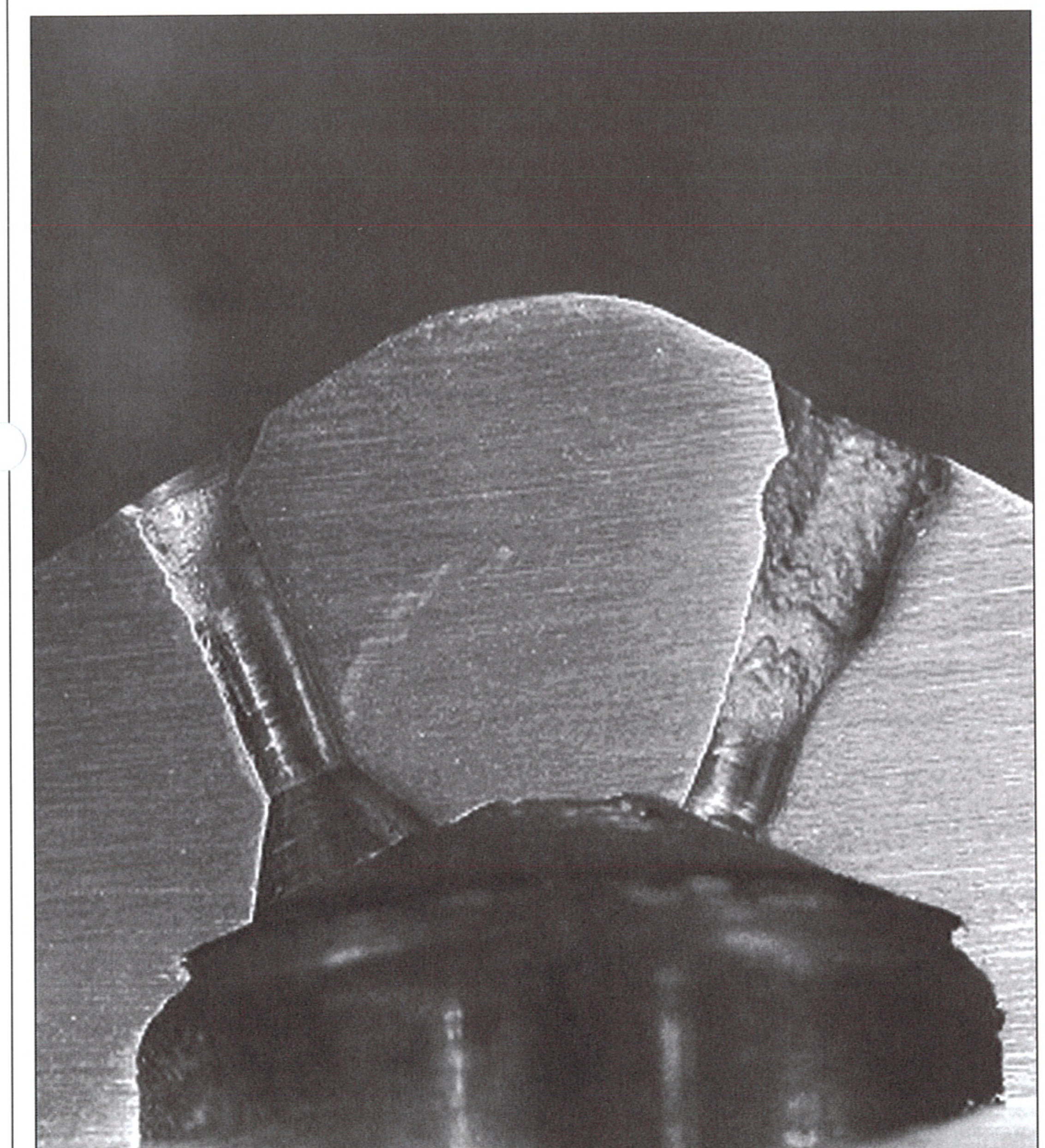
Cavitation Erosion Damage In A Steel Nozzle



This cross section of a steel nozzle shows that the shape of the inlet to the orifice can affect the rate of cavitation damage. Note that the flow passage with the chamfered inlet has less cavitation damage than the unchamfered cylindrical flow passage. See article, "Waterjet Nozzle Material Types," on page 2.

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Waterjet Nozzle Material Types

By: D. Wright, J. Wolgamott, G. Zink
StoneAge, Inc., Durango, Colorado, U.S.A.

ABSTRACT

There are three common nozzle material types used in waterjet cleaning: steel, carbide, and sapphire. Each has advantages in certain applications, while having real limitations in others. Jet quality produced and life expectancy are both critical issues for industrial waterblast nozzles. This paper presents the results of lab testing and field analysis to determine the wear rate and failure modes of each material type. Commercially available examples were tested under typical waterblast operating conditions and wear was determined by measurement of orifice size and visual deterioration of the jet quality. Recommendations are given for nozzle material depending on operating conditions.

1. INTRODUCTION

Nozzles are often the least expensive component and the high pressure pump is the most expensive component of a waterblast system, but the nozzle determines the effect with which the waterjet energy generated by the pump is delivered to the target. Initial jet quality of a new nozzle is dependent on the design of the nozzle, and can vary by as much as 60 percent between one type and another.

Through use, all nozzle materials wear and result in deteriorating jet quality and decreasing production rates. Another result of nozzle wear may be decreasing pump pressure; as some nozzle materials wear the orifice size increases, requiring an increase in flow rate to maintain the same pressure. Since waterblast pumps have a fixed output in flow, once their maximum output is reached, the pump pressure decreases as the orifice size increases.

The various nozzle materials wear differently depending on the water quality and chemistry, the operating pressure, and the nozzle design.

2. TESTING

Commercially available nozzles were tested five at a time in a manifold, at pressures between 112 and 126 MPa (16,000 and 18,000 psi). Nozzle orifice size and visual jet quality were compared over operating times up to 40 hours. Tests were conducted with water filtered to 25 micron. Additional information is based on reports from field use.

3. RESULTS

3.1 Carbide Nozzles

Tungsten carbide nozzles are usually considered to be the most durable of all material types. In cases of dirty unfiltered water, they are the most durable. In applications where flow rates exceed 190 lpm (50 gpm) or more, water may not be filtered and these users typically get the longest life from carbide nozzles.

There are conditions where carbide nozzles are not the best type of material to use; at pressures above 10,000 psi and with water filtered to 25 micron or better, the life of a carbide nozzle may be as short as 10 to 20 hours. These nozzles wear by erosion of the material; this wear can be quite uniform, where the orifice size increases uniformly and the nozzle still produces a coherent jet. In these cases, a worn nozzle is defined by being so large that the desired operating pressure cannot be maintained. This problem is most evident with small orifice sizes. For example, if a .7 mm (.028 in.) diameter nozzle is being used, a 0.1 mm (.004 in.) increase in orifice size is a 15 percent change, resulting in a 30 percent change in flow rate.

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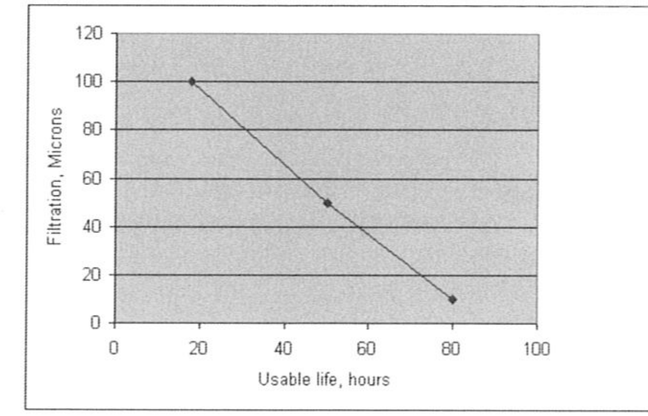
Steel nozzles will outlast carbide when water filtered to 25 micron or better is used; this difference in life becomes greater with operating pressures above 70 MPa (10,000 psi). Steel nozzles can wear rapidly with dirty water conditions. The life of a steel nozzle is also dependent on the design of the nozzle; a good design can allow a life of up to 200 hours, while a poorly designed nozzle may have a life of only 40 hours.

Sapphire nozzles require filtration to 10 micron or better to have a reasonable life. They are very fragile, and dirty water can cause instant failure. With properly filtered water, sapphire nozzles can last 200 hours or more.

Paper reprinted from the ***Proceedings of the 2003 WJTA American Waterjet Conference****, August 17-19, 2003, Adam's Mark Hotel, Houston, Texas, by permission of the authors.*

Figure 10. Nozzle life at 70 MPa (10,000 psi), drilled steel nozzle head



Recommended Material	Operating Conditions
Carbide	Dirty, unfiltered water; pressures below 140 MPa (20,000 psi)
Steel	Water filtered to 25 micron or better, pressures below 140 MPa
Sapphire	Water filtered to 10 micron or better, pressures above 140 MPa

Table 1. Recommended nozzle materials depending on operating conditions

Hydrodemolition On A Nuclear Dome, from page 14

20,000 psi (138N/mm²) was used, delivered at a rate of 80 gpm (290 liters/minute).

The nozzle was mounted on an arrangement of a lance and gimbals. These were manipulated hydraulically by robotic control, so that the jet could oscillate forwards and backwards to cut the concrete.

The system rode on a beam-mounted roller assembly, and traversed from left to right for a predetermined number of passes before advancing forward. All the while, the 'angle of attack' was varied in both the horizontal and vertical planes. "Put simply," said Sirois, "the motion is rather like using a garden hose to clean a path – you move it constantly, while gradually taking a step forward."

All the parameters had been pre-programmed, based on the extensive testing carried out beforehand. The project itself was preceded by delivery of full sized test sections of the track that were elevated onto a frame. Mock-ups of dome segments were cast and then water jetted to refine the settings.

Fitzgerald closely monitored progress of the live operation. Few parameters needed to be changed. There were times when pockets of softer or harder concrete were encountered. "Here you can do one of two things – slow down, or do a second pass. I prefer to slow down – I like to get it done first time round."

The lance was intentionally not lowered down as the cut deepened. This meant that it became gradually further away from the cut face, and hence less intense. In particular, this gave added control in the final stages, as by then the nozzle was about 24 inches (600mm) from the face.

Particular care was needed in the final inch or so to avoid damage to the protective shielding that was keeping water out of the reactor building.

This shielding was an essential part of the operation. A particular concern had been that any water entering the nuclear reactor building would have been treated as contaminated. Ingress was avoided by constructing elaborate water containment facilities beneath the plugs.

Steel, plywood and rubber structures protected the interior of the building from the water. Run-off water from the dome went through a system of settlement containers and sand filtering to about 5 microns. Its pH was checked and balanced. Samples were rigorously monitored for compliance with Environmental Protection Agency specifications, and only then could be discharged.

Safety was paramount throughout the project. One aspect of this was to prevent any risk of the plug falling into the reactor building during the hydrodemolition. It was secured to a steel frame even before cutting started. Both plug and frame were later lifted out as one.

The crane needed for the 200,000-pound (90 ton) lifts was in itself an impressive sight. It arrived on site on almost 160 trucks and took some five weeks to assemble.

Security was also essential, because of the sensitivity of the nuclear installation. Staff had to be vetted, as well as undergoing physical tests. They even had to undergo a week of schooling before being allowed onto the project.

"The huge amount of time and engineering devoted to this aspect of the project was the key to making it work," said Sirois. "Other companies had been offered the chance to bid on it, but we were the only one that would," he said.

The company is convinced of the potential for similar applications around the world, and is already looking for opportunities to put the experience to further use.

SPIR STAR Authorized Distributor In Canada

SPIR STAR, manufacturer of high pressure hose to 50,000 psi, is pleased to announce that Red-L Distributors LTD in Edmonton, Canada, is now an authorized distributor and assembly center for the provinces of British Columbia, Alberta, and Saskatchewan. Red-L will now be able to better service local customers by having a complete stock of hose and fittings in addition to being able to repair high pressure hose assemblies.

For further information, contact Jamie Ludwig or Rick Lafrance at 780-437-2630 or toll free in Canada at 1-800-252-9390.

Waterjet Nozzle Material Types, from page 2

However, if a nozzle size of 2.0 mm (.079 in.) is being used, the 0.1mm increase in orifice size is a difference of only 5 percent in size, causing a 10 percent change in flow rate.

Another failure of carbide nozzles occurs when the erosion does not occur uniformly. There may be a slight change in orifice size, but the big change occurs in the quality of the jet produced. In these cases the evidence of the nozzle being worn is indicated by reduced production rates, with the jet having deteriorated in cutting ability by half or more.

Tungsten carbide is composed of carbide particles cemented together by a binder. Ratios of binder to carbide vary, as well as binder types. Both of these variables affect the toughness as well as the erosion resistance of the nozzle. In our tests, cobalt binder to carbide ratios of 5 percent and 15 percent were tested, and there was a difference in both wear rate and type of wear. The wear mechanism of carbide materials when used as a nozzle material is not well understood; it is likely erosion of the binder, possibly combined with corrosion-erosion.

Figure 1 shows the change in orifice size for the two different carbide types, and Figures 2 and 3 show the jet patterns produced by each type after the tests. The 5 percent binder had a relatively consistent wear around and through the orifice, and is shown in Figure 4. The 15 percent binder did not change in size much but had uneven wear in the form of deep pockets which affected jet quality. Figure 5 shows the effect on pressure with wear of the 5 percent binder carbide nozzle, if the output of the pump's flow rate is constant.

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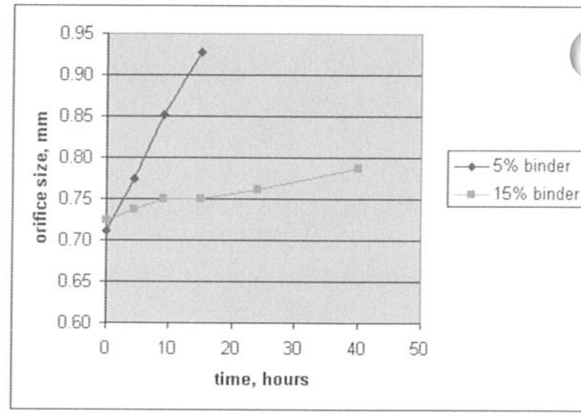
Figure 1. Wear rates in orifice size for two different types of carbide nozzle material



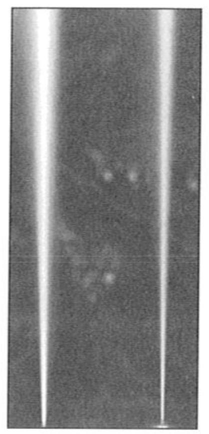


Figure 2. Jet pattern produced by the 5% binder nozzle after 15 hours on the left, compared to new of the same material and design on the right

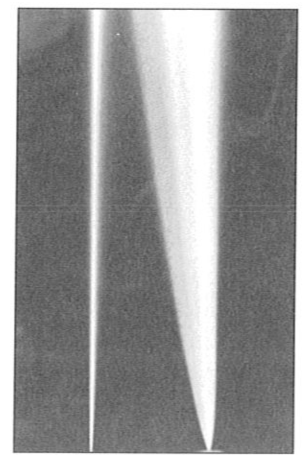


Figure 3. Jet pattern produced by the 15% binder nozzle after 40 hours on the right, compared to new of same design and material on the left

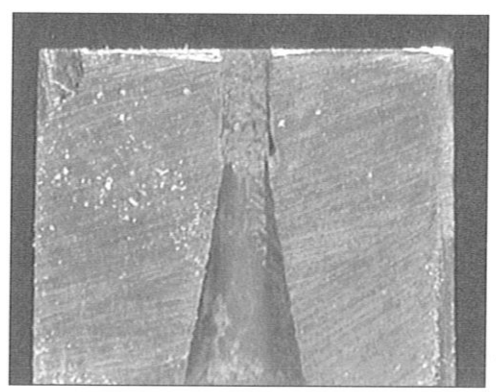
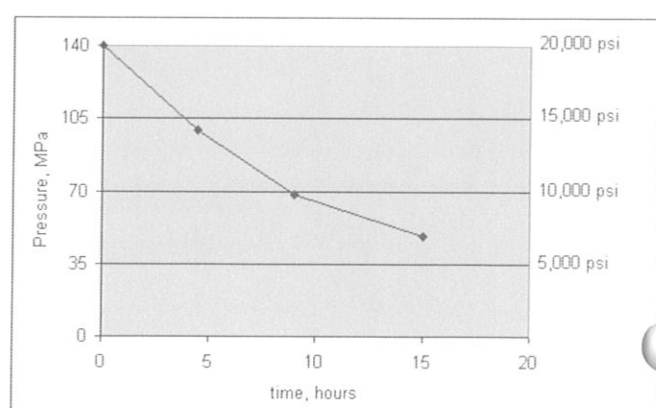


Figure 4. Section of 5% binder carbide nozzle after 15 hours

Figure 5. Effect of orifice wear on pump pressure, 5% binder carbide nozzle

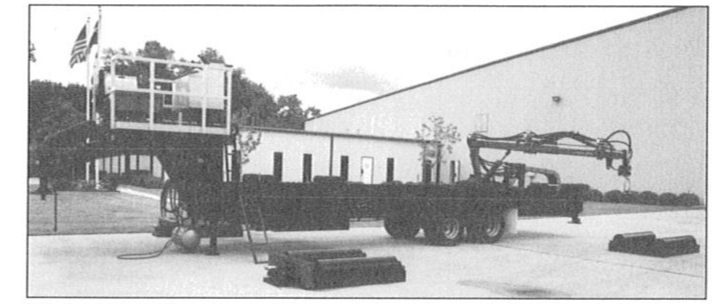


Waterjet Equipment For Rent

The Gardner Denver Water Jetting Systems rental unit program is steadily growing in size and scope. Sometimes a customer has a requirement date on a purchased unit that is sooner than our production schedule may allow for, so we have been able to fill that gap with one of our rental units to cover their obligations.

The rental program has also proven to be an ideal way for customers to "try it before buying it". Customers are impressed with our Liqua-Blaster multi-speed units, which offer a wide range of flows and pressures with the simple shift of a transmission.

The Gardner Denver multi-speed units are especially attractive when compared to changing out the fluid ends in order to change pressures.



And even more attractive when one considers the staggering cost of the time and effort it takes to change out fluid ends over the lifetime of a unit.

Rental equipment available from Gardner Denver Water Jetting includes:

1. Shell-Side Cleaning Machine, Trailer-Mounted
2. Liqua-Blaster Model 920GVSDS, 5 Speed, Skid-Mounted, 8.5-20 KPSI, 43-94 GPM, 500 HP
3. Liqua-Blaster Model 1010VSDS, 9 Speed, Skid-Mounted, 7-10 KPSI, 119-77 GPM, 500 HP
4. Liqua-Blaster Model 1020VSDS, 9 Speed, Skid-Mounted, 12.5-20 KPSI, 61-37 GPM, 500 HP
5. Liqua-Blaster Model 636VSDT, 5 Speed, Trailer-Mounted, 36 KPSI, 6.9 GPM, 170 HP

For more rental unit information, call John Jacobson toll free at 1-800-231-3628.

hydrodemolition, said North American Services Group senior project manager Jack Sirois.

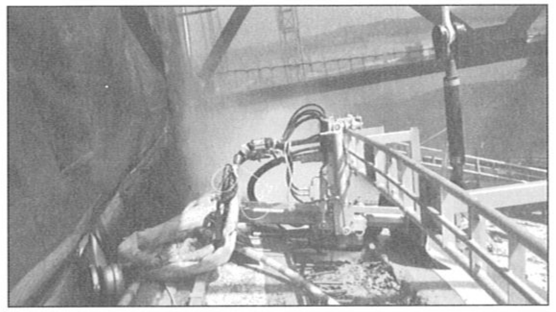
The high-pressure waterjet cut out two oval sections from high in the dome. These "plugs" were of 24-inch (600mm) thick reinforced concrete, about 40 feet (12.2m) across, with perimeters of 120 feet (36m). Each was removed as a single piece.

Hydrodemolition is fast and effective for accurate removal of material. The constantly moving waterjet is forced into voids in the concrete left by entrained air bubbles. Pressure builds until the water overcomes the strength of the concrete. It is a very aggressive process, explained North American Services Group Hydrodemolition Division Manager, Rick Fitzgerald.

It was seen as the only viable means of cutting the openings, as it was essential to avoid damage to the rest of the building. "Hydrodemolition has very definite advantages," he said. Hammering out the concrete could have caused hairline cracking in the remaining structure, as well as damage to the rebar. It would also have needed a lot more people. "One robot does the work of 15 to 20 jackhammers," added Fitzgerald.

Aquajet Systems and North American worked together on the design, development and testing of the robot-controlled hydrodemolition system and the track it was mounted on. It was also essential to devise a reliable shielding method to keep the used water out of the reactor building.

Ideas for design and engineering of the track and robotic head went back and forth between the two companies. North American would supply the specifications it needed for parameters such as the water pressure, the angles of the cut and the configuration of the



dome, and would check the subsequent designs on its own CAD system. "We had an excellent working relationship, although we had never worked together before," said Sirois.

"Aquajet Systems has been in the business a long time and is very innovative," added Fitzgerald.

Use of Internet communications meant that the two companies could work closely together even though they were thousands of miles apart, said Sirois.

"We knew the basic concept we wanted," he said. The approach was to cut through the 24 inch (600mm) concrete in several distinct phases, starting by jetting a cut roughly 12 inch (300mm) deep all the way round. This was done in a single pass.

Hydrodemolition leaves reinforcement undamaged. This is normally the desired outcome, as most projects then involve placing new concrete around the existing reinforcement.

However the dome's reinforcement had to be removed too, in order to leave the clear openings needed. The top mat of reinforcement was cut out before the lower half of the concrete was jetted. The rebar would otherwise have deflected the jet, effectively reducing the pressure and costing valuable time.

Aquajet Systems manufactured all the tracks and frame and the cutting assembly to be mounted on, as well as supplying the robotic equipment. As the structure is a dome, there wasn't a single straight line on the track, said Fitzgerald. It curves in two dimensions and was mounted about 36 inches (1m) above the dome.

The robotic equipment was in two parts. The main "brains" unit was the HD-6000 Aquajet Aqua Cutter. This worked from a central platform and remotely activated the complex hydraulics that controlled the direction of the jet. The second part – the roller assembly that manipulated the lance – walked its way around the rail system using rack and pinion.

The jet emerged from a special ceramic hydrodemolition nozzle, specified at 3.6mm diameter in order to deliver the required pressure. The water pressure needs to be higher than the strength of the concrete. In this case, the concrete strength was of the order of 7,000-9,000 psi (48N/mm^2 to 62N//mm^2) and a water pressure of

(continued on page 16)

BHR Group Schedules Waterjet Conference

The 17th International Conference on Water Jetting – Advances and Future Needs, will be held in September 2004 in Mainz, Germany. Details regarding the program, registration and hotel accommodations will be available soon. For more information, contact Catriona Rolfe, Conference Organizer, BHR Group Limited, The Fluid Engineering Centre, Cranfield, Bedford MK43 0AJ, JK, Tel: 44 (0) 1234 750422, Fax: 44 (0) 1234 750074, Email: crolfe@bhrgroup.com.

Overall, the 15 percent binder material showed the longest life.

De-ionized water will also cause very rapid failure of carbide nozzles. With this type of water condition, the erosion of the orifice size can result in a useful life of less than 10 hours.

3.2 Steel Nozzles

Nozzles made from steel vary widely in design and in quality. They are built as replaceable threaded inserts, or can be made by drilling into a disposable head or bit, as would be used in tube cleaning. Those made as replaceable inserts typically have a better jet quality because the inlet to the nozzle can be formed as desired; holes drilled into a head do not have this option and have the worst quality. The better quality replaceable nozzles usually have longer life as well. With water filtered to 25 micron or better and pressures up to 140 MPa (20,000 psi), properly built steel nozzles can have useable lifetimes of 150 to 200 hours and will outlast carbide nozzles. Figure 6 shows the jet patterns produced after 40 hours by a steel nozzle and two different carbide nozzles. Wear in steel nozzles is defined by degradation of the jet pattern produced; orifice size change does not usually occur.

Steel nozzles wear by two mechanisms: cavitation erosion and abrasive erosion. The rate of cavitation erosion is mostly dependent on the design of the nozzle, while abrasive erosion will occur in all steel nozzles with the presence of abrasive particles in the water. Figure 7 shows a steel nozzle orifice with 50 hours use with recycled, unfiltered water; the wear due to abrasive erosion is very smooth and even. Figure 8 shows a drilled orifice in a head as an example of cavitation erosion in steel. It is rough and uneven, with pockets running across the flow path.

The shape of the inlet to the orifice can affect the rate of cavitation erosion. Figure 9 shows two drilled orifices in a steel head, with the one on the left having a chamfered inlet. Unfortunately, this is often not possible to do, as access to the back side of the orifice is needed to

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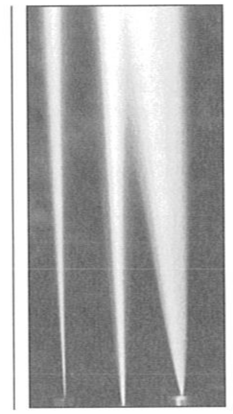

Figure 6. Jet pattern produced by steel nozzle after 40 hours on the left, compared to 5% binder carbide after 10 hours in center, and 15% binder carbide after 40 hours on right

Universal Minerals Patent RIP 3000 Rotary Injection Nozzle

By: Pete Mitchell
Universal Minerals

There have been growing concerns about the use of hardened blasting media in today's surface preparation market. The cost of containment and the use of more expensive blasting media that contractors are being forced to use are driving the costs of coating applications up everyday. The containment of dust from dry blasting has also become a prime concern in many shipyards and the use of open air dry blasting has been prohibited.

The use of high and ultra-high waterjetting has fulfilled some of the requirements needed to replace dry blasting. Previous dry blasted surfaces can now be stripped and cleaned leaving the original profile intact. With the use of ultra high waterjetting, containment is not an issue any longer because waterjetting does not produce dust.

The patented RIP 3000 rotary nozzle developed by Universal Minerals is beginning to show up in a few of the shipyards and petro-chemical plants in the U.S. This nozzle is a 360-degree rotating water nozzle that injects abrasives into the water stream. The nozzle can be used in conjunction with a rotating gyro gun from almost any manufacturer. Pressures ranging from 20,000 – 40,000 psi have been primarily used with this nozzle. The nozzle requires only $^1/_2$ to 1 pound per minute abrasive and only 2 to 5 GPM water consumption. This is only 30 to 60 pounds per hour where dry blasting consumption can be from 600 to 960 pounds per hour.

This marriage of ultra high water and abrasives has achieved two main functions. The operator can greatly

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Hydrodemolition In Dubai, from page 12

which is attached to a rotating joint on the end of the Robot's first standard rotating telescoping arm section. The standard Conjet feed beam, with its oscillating and traversing nozzle assembly, can also rotate a full 360° and swivel 180° on the tower actuator. This articulation gives unprecedented controlled movement and positioning of the jetting nozzle to reach into previously inaccessible areas with the standard arm.

"Due to the difficult access we were unable to use the conventional arm with the 362 Robot," says Kier Dubai project engineer Paul Dann. "But the tower system and the multi-positioning feed beam allowed us to work inside the same 2m width of available access without extending the standard 362's arm. The tower system is exceptionally versatile. For example if we have an open top square shaft or chamber and needed to remove concrete from the inside surface of all the four walls, this can be done by lowering the tower with the feed beam and rotating to any wall surface and then step up on tower mode after making each pass of the nozzle. We have found the additional degree of movement achieved with the tower system extremely useful for the majority of work we now carry out. In the last five years we have removed about 15,000 m^3 of concrete in the Middle East Region using hydrodemolition."

The high-pressure water for the modified Robot 362 was provided by one of Kier's complementary diesel driven Conjet 345 Power packs housed in a silenced 20 ft (6.1 m) long ISO container. Water at a pressure of 900 bar and flow of 187 litres/min was fed through a flexible hose to the Conjet Robot's nozzle from a high pressure pump driven by a 480 hp (360 kW) Caterpillar diesel engine.

Kier Dubai operates an extensive fleet of hydrodemolition equipment, including two Robot 362s with tower extensions, a Robot 322, two Jetframe 102 systems and three Conjet 345 Power packs.

Safety Committee Solicits Comments On Improvements To Recommended Practices

The WJTA Safety Committee hereby solicits comments regarding improvements to the publication, *Recommended Practices for the Use of Manually Operated High Pressure Waterjetting Equipment*. While Recommended Practices is reviewed periodically at the biennial conferences of the WaterJet Technology Association, your comments and suggestions for improving the publication are invited and welcome anytime.

Please address your comments and suggestions to: Safety Committee, c/o WJTA, 917 Locust Street, Suite 1100, St. Louis, MO 63101-1419, fax: (314)241-1449, e-mail: wjta@wjta.org, web site: www.wjta.org.

Hydrodemolition In Dubai

Contractor Kier Group's Kier Dubai division, in the United Arab Emirates, has further enhanced the versatility of its Conjet Robot 362 hydrodemolition machine. Kier Dubai asked Conjet to design a special attachment for the Robot to overcome extremely difficult access problems so the company could use the Conjet high-pressure water jetting equipment to selectively remove concrete, which had been cast in the wrong place during the construction of the deck of a new bridge.

Kier Dubai's standard Conjet Robot 362, with its conventional arm, was unable to reach and remove the concrete, which another contractor had misplaced during the construction of the bridge deck's tendon housings. The shutters on the ends of four 1.8 m tall tendon-housing walls had moved during casting. Kier Dubai, with its vast experience of hydrodemolition in the Middle East region, was called in to selectively remove a 900 mm length of each of the 800 mm wide walls.

To overcome the difficult access, Conjet designed for Kier Dubai a fully adjustable sliding lattice tower extension, with an articulating, multi-positioning Conjet feed beam assembly holding the jetting nozzle, to reach and cut out all unwanted heavily reinforced 60 Mpa concrete. The tower is controlled to move in and out of a matching frame,

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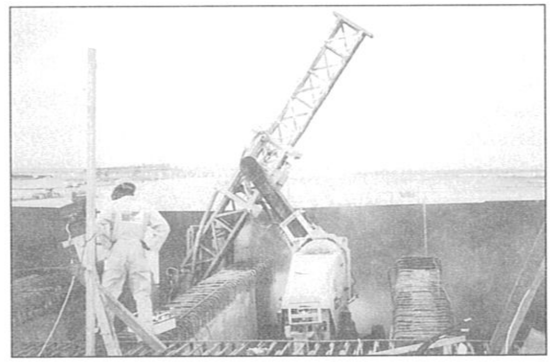
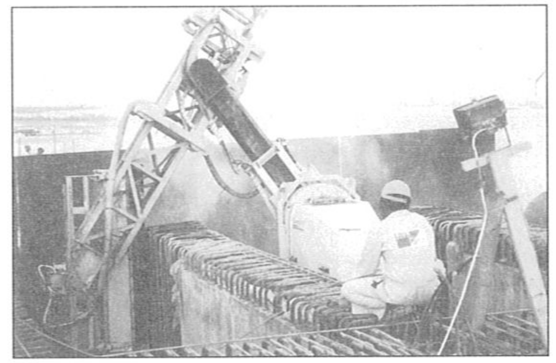
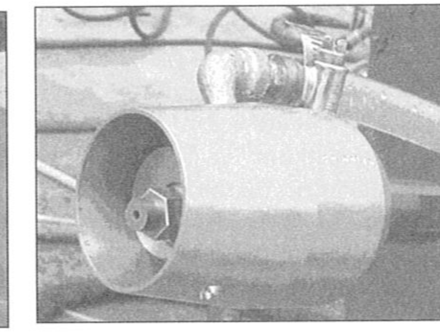




Universal Minerals Patent IP 3000 Rotary Injection Nozzle, from page 6

reduce dust problems or required containment and can still achieve a .5 – 5.5 mill profile depending on stand off distance and grit sizing that is used. The most common abrasive being used with it today is garnet. Garnet being harder and usually cleaner has produced some of the highest production rates, but any abrasive can be used with this nozzle. The new water-soluble abrasives have been used very successfully with the RIP 3000 also. The nozzle has been very effective in the removal of cold tar type coatings and others. In most all applications production can be 2-3 times faster than standard dry blasting without the dust problems, tons of abrasive usage, cleanup and disposal cost of spent abrasives.

It is also becoming growing knowledge that the use of high and ultra-high pressure water blasting techniques removes many of the potential soluble contaminates and debris that are being left on surfaces only dry blasted in the past. This leaves a much cleaner surface for the new coating. Production rates of this new equipment range from 5-7 sq. ft. per minute on most epoxy coatings of 10-14 mills. Higher rates have been achieved on enamels and others. Any contractor using ultra-high equipment can easily adapt this equipment to their existing line. Mill scale removal rates range from 6-10 sq ft. per minute.



It was once asked why use 36-40 k equipment when 10k waterjetting and abrasives will do ok? Production and water consumption. The increase in production between 10k and 40k is dramatic. Also, in most cases, higher water consumption rates (8-12 GPM) go up in order to achieve optimum performance at the lower pressures.

For more information regarding the RIP 3000 rotating abrasive nozzle, contact Universal Minerals, Inc., 4620 South Coach Drive, Tucson, Arizona 85714, toll free phone: 800-528-7086, phone: 520-748-0405, fax: 520-748-8503 or visit www.universalminerals.com or www.waterjetsupply.com.

Gardner Denver Unveils New Unit

Gardner Denver Water Jetting Systems, Inc. is unveiling a new line of 300 horsepower waterblasting units that are specially designed for waterjet cleaning contractors.

The new unit features new, rugged, easy-maintenance fluid ends, an upgraded power end, a lighter trailer, and a new belt-drive system. The end-user can quickly switch the pump fluid ends to accommodate the 10K, 20K or 40K PSI pressure ranges used in specific types of cleaning operations.

Special efforts were made to keep the unit extremely user-friendly, while maintaining operator safety and eliminating any excessive components. The result is a powerful machine that stands up under heavy contractor use.

Gardner Denver Water Jetting Systems will launch their new unit at the Pumper & Cleaner Environmental Expo at the Opryland Hotel in Nashville, Tennessee, February 19-21, 2004. Come see us at booth #S-51.

Gardner Denver manufactures a complete line of waterjetting equipment to perfectly match each industrial cleaning application, including high pressure units to 50,000 PSI, high flow units to 274 GPM, and high-horsepower units to 750 HP. Gardner Denver also offers a complete line of accessories ranging from shellside cleaners, rotary line cleaners, preheater cleaners, tube bundle cleaners, lancing machines, control guns, hoses, fittings and everything else down to precision high-pressure nozzles. Call 1-800-231-3628 or visit www.waterjetting.com for more information.

perform this operation. Operating pressure also influences the rate of cavitation erosion; a steel nozzle that might last 150 hours at 140 MPa (20,000 psi) will only last 20 to 30 hours at 250 MPa (36,000 psi).

In the case of the tube cleaning heads, where the nozzles are drilled directly into the head and erosion due to cavitation is the primary mode of failure, life is also dependent on water filtration. Figure 10 (on page 15) shows the average life based on water filtration for heads made of 17-4 stainless steel, at an operating pressure of 70 MPa (10,000 psi).

3.3 Sapphire Nozzles

Sapphire nozzles are most commonly used for operating pressures above 140 MPa (20,000 psi). They produce high quality jets in orifice sizes less than 1 mm (.040 in.) but have poorer quality jets in larger sizes, compared to carbide and good quality steel nozzles. Sapphire nozzles require very clean water, filtered to 10 micron or better. With good conditions, their life can approach 200 hours or more, as the material does not suffer from the erosion problems of carbide or steel nozzles. However, the sapphire material is very brittle, and any tiny chip on the edges of the orifice will destroy the jet quality. Any particles in the water passing through the nozzle will cause these chips, and if a large particle strikes the sapphire it can be instantly cracked. They are also quite easily damaged by rebound of the material being jetted. For these reasons, sapphire is not commonly used in waterblasting operations at pressures below 140 MPa (20,000 psi).

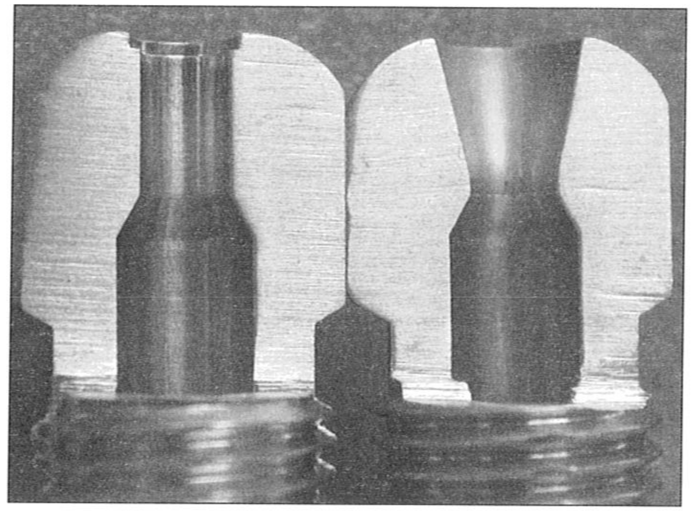


Figure 7. Steel nozzle on the right showing abrasive erosion from very dirty water

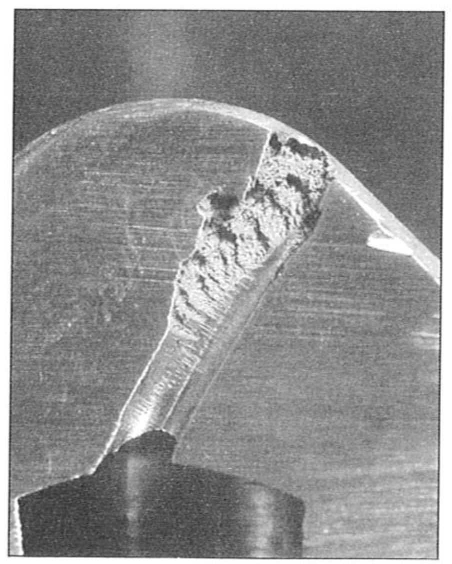


Figure 8. Steel nozzle with cavitation

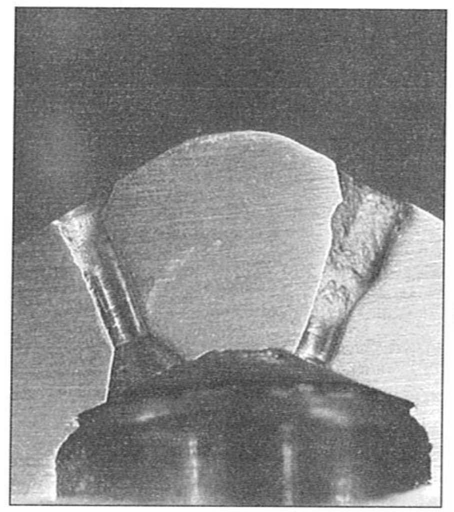


Figure 9. Steel nozzles, effect of inlet shape to orifice on cavitation erosion
(Also, pictured on the cover.)

4.0 CONCLUSIONS

There is no single nozzle material that is suitable for all operating conditions. Selection should depend on how well the water will be filtered and on the operating pressure. The nozzle design also has some effect on operating life; the initial jet quality produced is an indication of the quality of the nozzle design. Table 1 (on page 15) lists the nozzle material types discussed in this paper and the recommended conditions for each.

Carbide nozzles outlast all other materials when unfiltered water is used. There are different types of carbide available with variations in type of binder and binder percentage; these factors affect the type of wear and wear rate of carbide nozzles.

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The *Jet News* is published by the WaterJet Technology Association (WJTA) and is a benefit of membership in the Association.

Hydrodemolition On A Nuclear Dome

*Editor's Note: The June 2003 issue of **Jet News** contained a short description of the world's first use of hydrodemolition to create an opening in a nuclear reactor dome at the Sequoyah Nuclear Plant, Soddy-Daisy, Tennessee, USA. The article below presents a more detailed description of this application with emphasis on the design of the hydrodemolition equipment.*

A remarkable hydrodemolition project using an Aquajet HD6000 Aqua Cutter, played a key role in the replacement of equipment at a nuclear power station in Soddy-Daisy, Tennessee, USA. Meticulous preparation paid dividends during an intensive operation at the 23-year-old Sequoyah Nuclear Plant in Tennessee.

Four of the steam generators needed replacing in a $160 million project. Just 90 days were allowed, from shutting down the power station to resuming production. Every aspect of the work had to be carefully planned and monitored to meet the timescale.

Central to the project was the removal of two 90-ton pieces of the domed reactor roof, so that the old generators could be lifted out and replaced with the new ones. Cutting out the two "plugs" took just two weeks of round-the-clock hydrodemolition – but those two weeks were preceded by a year spent developing and testing the equipment.

Main contractor, Bechtel Power Corporation, appointed North American Services Group to cut the two large openings high on the dome. North American worked closely with Swedish hydrodemolition equipment specialist, Aquajet Systems, to develop a bespoke robot controlled system, using an Aquajet HD-6000 Aqua Cutter equipped with the robot arm accessory as the main "brain."

An innovative rail system allowed the waterjetting equipment to "walk" along the line that needed cutting. Both the track system and the nature of the project – working on a nuclear reactor dome – were firsts for

(continued on page 14)