2005 WJTA American Waterjet Conference
August 21-23, 2005 • Houston, Texas

Paper

STRATEGIES FOR INTRODUCING NEW ABRASIVE WATERJET TECHNOLOGIES

D. S. Miller
Miller Innovations
Harrold, Bedford. UK

ABSTRACT

New abrasive waterjet machining systems are being developed that extend the operating range of abrasive waterjets. However, entry into the market of these new machining systems is dependent on factors that are not immediately obvious. The paper looks at the infrastructure needed to commercialise fine and micro abrasive waterjets. In particular the paper discusses how the quality control, packaging and distribution of abrasive becomes increasingly important as abrasive waterjet diameters are reduced. Reasons are given as to why abrasive waterjet equipment manufacturers need to develop proprietary abrasive delivery systems.

Organized and Sponsored by the WaterJet Technology Association

1. INTRODUCTION

Technologies have been developed to extend the operating envelope of abrasive waterjets so that they cut with smaller diameter jets (Miller 2005). Figure 1 shows the operating envelope for fine (FAWs) and micromachining (MAWs) abrasive waterjets. Also shown on Figure 1 is the operating envelope for conventional abrasive waterjets (AWJs) and lasers. It can be seen from Figure 1 that the cutting beam diameter range of AWJs is quite restricted so abrasive waterjets are currently excluded from competing and complementing lasers in important machining markets.

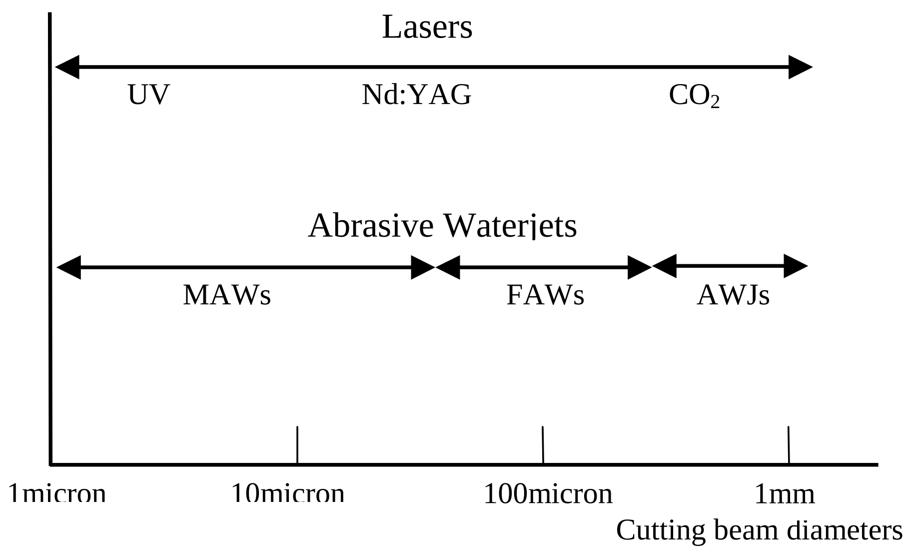

Figure 1. Operating envelope covered by abrasive waterjets and lasers

Before FAWs and MAWs can be exploited the infrastructure has to be developed to provide the abrasive needed by these systems. Per minute a MAW will use one to two percent and a FAW two to ten percent of the amount of abrasive used by a typical AWJ. However, on a weight basis, this abrasive in packaged form will probably be priced at two to over ten times that of abrasive for AWJs, even though the base cost of the abrasive may be similar to that for AWJs.

In the case of MAWs, the supply of abrasive is likely to provide high added value for the abrasive waterjet equipment manufacturer if abrasive is supplied in proprietary cartridges. A company that brings MAW machining systems to the market needs to ensure an adequate return from the systems associated with abrasive preparation, quality assurance, packaging and use.

2. ABRASIVE FOR FAWs AND MAWs

AWJs use free flowing garnet and olivine abrasive with mean particle diameters typically above 80microns. Inter-particle forces for such abrasive are low and gaps between particles are sufficiently large that air readily moves through a bed of abrasive. The free flowing nature of the abrasive and the precision with which it can be metered is typified by the flow of sand in hourglasses and egg timers. As particle sizes are reduced to those needed by FAWs and MAWs inter-particle forces increase, air movement through a bed of abrasive virtually ceases and the abrasive readily absorbs moisture that increase cohesive forces. Under these conditions abrasive can no longer be induced to flow unless it is suspended in a liquid.

Abrasive is normally air classified, with the best suppliers providing a product for AWJs that has little fines and contaminating material. Air classification produces a product that has a high level of contaminants at the particle sizes required for FAWs and MAWs. Low-density materials, such as plastics and fibres, and particles that have high drag coefficients, such as flakes of rust, clay and mica platelets, are present in abrasive at levels that cause FAW and MAW nozzles to block within a fraction of a second.

Before garnet and other abrasives are used in FAWs and MAWs they have to go through a classification process, which will usually be fine sieving for cutting jet diameters of 50μm and larger. Once classified, abrasive needs to be a handled all the way to a cutting nozzle in a manner that guarantees that oversize abrasive or contaminant particles do not reach a nozzle. Clean preparation and handling practices used by other industries for powders and wet mixtures need to be adopted for the abrasive supply chain.

Abrasive mixtures for MAWs and FAWs will usually be formulated with an additive. In the past the use of abrasive mixtures with additives has proved to be a problem because long chain organic polymers have been used that are difficult to hydrate and to handle. Such additives also cause cutting performance to deteriorate and this deterioration increases as jet diameters are reduced. Abrasive mixture formulations have been developed that minimise problems caused by the use of additives.

3. OPERATING EXPERIENCE WITH FAWs AND MAWs

3.1 MAWs

The author set out eight years ago to develop MAW technology for licensing. The abrasive waterjet generation mode chosen involves passing a suspension of abrasive in pressurised water through a nozzle (Miller 2004). As MAWs use a fraction of a kilogram of abrasive per hour they can be operated in batch mode with an abrasive storage vessel being refilled when required. By operating in batch mode the flow circuits of MAWs only need a few components and these components can be engineered for high reliability. The abrasive storage vessel for a MAW may have a quick opening feature to allow the exchange of cartridges of abrasive mixture, or alternatively, a vessel can be filled through a valve from a sealed container of abrasive mixture.

Suspension jets have 4 to 5 times the cutting energy density of AWJ jets at the same water pressure. MAWs can, therefore, operate at much lower water pressures than AWJs and still cut at economically viable rates. 700bar (10,000psi) is probably the optimum operating pressure for MAWs. The barrel of a quick opening abrasive vessel for 700bar service does not need to be massive, so it can be easily removed and replaced by hand, enabling an abrasive cartridge to be changed in under a minute. Fittings and tubing are readily available for 700bar duty and low cost pneumatic intensifier pumps are suitable to generate 700bar water pressures at the flow rates needed. Such pumps can be assembled within a standard pneumatic cylinder and the operation of two pumps synchronised under the control of a PLC to give virtually pressure ripple free water flow.

After four years of development work (Miller 2003) the mechanical aspects of 50micron diameter MAWs were working well but nozzle blockages were an ongoing problem. Development work, including abrasive preparation, was being carried out in an environment that was far from ideal as regards avoiding abrasive contamination. In order to prove that nozzle blockages were not an inherent characteristic of MAWs the author, over several weeks, eliminated most contamination sources until cutting could be carried out for periods extending to a day without nozzle blockages.

Having established that quality assured abrasive and clean systems could overcome nozzle blockages the author was faced with whether or not to develop an abrasive preparation and packaging systems that could virtually guarantee contamination free abrasive. Abrasive preparation and packaging will be a key part of the exploitation strategy of a MAW manufacturing company and, therefore, needs to be developed to the company's requirements. Without the input from an exploiting company the author made the decision to put on hold further development and testing of MAWs except for improving abrasive cartridge design.

A consideration in putting on hold MAW developments was the fact that MAWs have too little in common with AWJs, both technically and market wise, for companies in the abrasive waterjet industry to be comfortable with the technology. Although MAWs are mechanically simple in design they are viewed as involving several new technologies and they address needs in industries that AWJ manufacturers are not familiar with. A bridging development was, therefore, desirable between AWJs and MAWs to reduce the number of perceived new technologies, as well as allowing AWJ manufacturers to extend their operations into markets that need MAW capabilities. FAWs were conceived as being this bridging development.

3.2 FAWs

The author could see no reason why abrasive/water mixture technologies developed for MAWs could not be used for miniature entrainment cutting heads. As MAWs are particularly effective for jet diameters below 50microns the decision was made to develop FAW entrainment cutting heads that could fill the jet diameter gap between MAWs at 50microns and the minimum jet diameter of 300microns or so possible with AWJ cutting heads.

To be able to trial FAW cutting heads a low flow, ultra high-pressure pump was needed. No suitable pump could be found so the author decided to build a direct driven cam pump that could also be developed for MAWs (Miller 2005). The largest FAW jet diameter the author could reasonably run from the available 2-phase electrical supply was 90microns, so this diameter was adopted for trials. It should be noted that an AWJ manufacturer could provide FAWs as an add-on to AWJ systems powered by their standard intensifier pumps, as these pumps can run at low water flows.

From a fluid dynamic assessment of previous designs of entrainment cutting heads for abrasive/water mixtures the author concluded that none were suitable for FAWs. Prior art cutting heads had flow passage geometries similar to ones the author has used in compact energy dissipaters. A fluid dynamic approach to the design of cutting heads has resulted in a patent applied for cutting head that can operate with liquid, air or vapour as the abrasive carried fluid (Miller 2005).

Garnet abrasive with a mean diameter of 8microns was used as standard for trials with both MAWs and FAWs. The particle size is small for effective operation of 90micron diameter jets but the author needed the flexibility to use the same batches of abrasive for FAWs and MAWs down to 40micron jet diameters. Blocking of focus tubes on FAW cutting heads has not been a problem.

Initial results from cutting trials with FAWs are given in a companion paper (Miller 2005). What particularly stood out from the trials was the dynamic response of FAW systems. Because abrasive is statically suspended as a mixture, cutting action can be started and stopped at the frequency a valve can be opened and closed or, as in the trials, how often a pump can be started, reach cutting pressure and then be stopped. Four surface features per second were achieved with the experimental pump used for the MAW trials but substantially higher rates are possible.

As with MAWs, the author has concluded that abrasive packaging and feed systems for FAWs need to be developed within an exploiting company's business and marketing strategy. Rather than develop one specific abrasive packaging and feed systems the author has carried out restricted trials on a number of systems to demonstrate the practicality of developing abrasive feed systems for FAWs. Methods of feeding abrasive mixtures investigated include:

- Filling proprietary plastic cartridges with abrasive mixture. Cartridges were fitted with a piston driven by pressurised air or by mechanical means. Some trials were made with hypodermic syringes to test flowability of abrasive mixtures in small passageways
- Abrasive mixture in a vessel pressurised with air
- Abrasive mixture in a plastic transportation pouch that was put into a vessel and the vessel pressurised with air
- Gravity feed from plastic transportation pouches and from stainless steel storage vessels
- Direct pumping of abrasive mixture using a peristaltic pump.

The method of abrasive feed adopted will depend on factors such as whether the system is in permanent or occasional use. In the case of occasional use a well-stabilised abrasive mixture is desirable with a positive means of feeding abrasive mixture to a cutting head. A high utilisation application may operate with gravity feed, using a mixture with a low additive concentration and a powered mixing device to maintain abrasive suspension.

3.3 Abrasive

Abrasive is prepared by sieving and mixing with water to form a high abrasive concentration mixture. The mixture is stabilised, to a greater or lesser, extent depending on when it is to be used and on the abrasive feed system. The author favours a well characterised, inorganic, non-stringy additive that hydrates readily and does not to contribute to blockage problems through contamination or agglomeration of particles. A patent has been applied for the use of the additive for abrasive mixtures.

During the development of MAWs and FAWs garnet abrasive has mainly been used. At one stage, to try and overcome MAW nozzle blockages, the author switched from garnet to 3micron aluminium oxide that met the requirements of an aerospace quality specification. Nozzle blockages continued as the abrasive contained substantial amounts of contaminants. Subsequent investigation found that the abrasive had only been screened at the 63micron level in order not to reduce output from the production plant. The production process produced the desired abrasive particle sizes but the abrasive became badly contaminated during the process. In polishing operations, it would seem, low hardness contaminants are accepted as they are rapidly broken up by the polishing process and do not damage critical surfaces. In abrasive waterjet operations contaminants can bring the cutting process to a stop.

Abrasive quality requirements for MAWs are outside of the experience of abrasive suppliers who think in terms of the mean particle size of their abrasive, whereas maximum particle size of any particle in a batch of abrasive is what matters as regards FAWs and MAWs. When discussing abrasive requirements with abrasive producers it is vital that they understand that every abrasive particle, agglomerated or not, and every contaminant particle has to pass through a single closely dimensioned hole. The abrasive supplier will invariably pass the responsibility of upgrading the quality of abrasive to the purchaser.

Contaminants are usually soft or friable so that methods could be developed to pulverise such particles during the abrasive preparation process. To some extent, this may occur as abrasive enters a focus tube of FAWs, accounting for the low incidence of focus tube blockage the author has experienced.

The author has carried out cutting trials with 300 and 50nanometer diameter aluminium oxide abrasive in 40micron MAW jets to demonstrate that abrasive waterjets should be able to operate down to micron and sub micron cutting jet diameters (Miller 2003). Blockage problems were experienced with what was provided as de-agglomerated abrasive but in reality contained a percentage of agglomerated particles. The extensive research world wide to produce tight tolerance nano particles is likely to provide abrasives for micron diameter MAWs that is free from agglomerated particles.

It is worth pointing out that MAWs and smaller diameter FAWs can use diamond nozzles so that operating with aluminium oxide abrasive is practical. As yet the benefits for machining ceramics, glass and other hard, brittle materials with aluminium oxide have not been investigated.

4. DISCUSSION

The most important criterion as to whether a particular mode of abrasive waterjet operation is worth developing is the predicted dependability of systems that uses that mode. Dependability is taken to encompass ease of manufacture, performance, operability, reliability and serviceability. It its wider sense dependability extends to the profitable manufacture and use of abrasive waterjet systems.

At the feasibility stage, judgements about the potential dependability of systems that use a particular mode of abrasive waterjet generation are subjective but essential in identifying the aspects that will determine dependability. A MAW is assembled from relatively few mechanical components and its operation controlled by computer. Individually and collectively the components can be engineered and manufactured to meet reasonable dependability criteria. Early on in the development of MAWs it became evident that the abrasives supply chain is the critical dependability factor for MAWs. Parts of the supply chain need a significant one off investment that is dependent on the form of the supply chain.

Setting up the abrasive supply chain requires investment that needs to be directed to achieving commercial objectives. An analogy is inkjet printers where the printer manufacturer achieves a significant return from sales of proprietary cartridges. It is inappropriate for the author to pre-empt in what form abrasive for MAWs will be supplied by a MAW manufacturer so work on MAWs is being confined to investigating what form proprietary abrasive cartridges could take.

The abrasive requirements for FAWs are less stringent than for MAWs. FAWs can initially be an add-on to AWJ systems so the risks involved to bring them to the market is low. The establishment of a FAW abrasive supply chain will help in the development of an abrasive supply chain for MAWs

5. CONCLUSIONS

1. Exploitation of FAWs and MAWs requires a quality assured abrasive supply chain.
2. Risks to bring new abrasive waterjet systems to the market can be minimised by developing the abrasive supply chain for FAWs and extending it on to MAWs.
3. FAW and MAW system manufacturers should develop proprietary abrasive packaging and delivery systems.

6. REFERENCES

Miller, D. S. (2003) “Developments in Abrasive Waterjets for Micromachining,” Proceedings of the 2003 WJTA American Waterjet Conference, Houston.

Miller, D. S. (2004) “Micromachining with Abrasive Waterjets,” Journal of Materials Technology 149, Elsevier.

Miller, D. S. (2005) “New Abrasive Waterjets to Compete with Lasers,” Proceedings of the 2003 WJTA American Waterjet Conference, Houston.