International Marmara Sciences Congress (Imascon 2022 Spring)

13 – 14 May 2022 KOCAELI

PROCEEDINGS E-BOOK

Organizer

Sponsors

This congress proceedings book is published as an electronic format as e-book.

ISBN: 978-605-70762-4-3

Address	Kocaeli Üniversitesi Rektörlüğü, Umuttepe Yerleşkesi Kocaeli, TÜRKİYE
Phone	+90 262 303 1000
E-mail	info@imascon.com
Web	www.imascon.com

CLEANER PRODUCTION SOLUTIONS FOR ABRASIVE WATERJET CUTTING SYSTEM

Zeynep Cansu Ayturan
Konya Technical University, Engineering and Natural Science Faculty, Department of Environmental Engineering
zcayturan@ktun.edu.tr, ORCID: 0000-0001-9513-4949

Şükrü Dursun
Konya Technical University, Engineering and Natural Science Faculty, Department of Environmental Engineering
sdursun@ktun.edu.tr, ORCID: 0000-0001-9502-1178

Abstract
Waterjet technology is one of the fastest-growing machining processes used for cutting metal to depths over 100 mm. It is used in a wide range of industries from automotive and aerospace to medical and food industries. The impact of the water alone is enough to machine material, however, with the addition of abrasive, the material removal rate in the process is several orders of magnitude higher. Therefore abrasıve waterjet cuttıng system (AWJC) was developed for better performance. In the AWJC, an abrasive material is used in the cutting process to increase cutting efficiency for harder materials. The abrasive material is mixed with water. Mixing means gradual entrainment of abrasive particles within the water jet and finally, the abrasive water jet comes out of the focusing tube or the nozzle. During the mixing process, the abrasive particles are gradually accelerated due to the transfer of momentum from the water phase to the abrasive phase and when the jet finally leaves the focusing tube, both phases, water and abrasive, are assumed to be at the same velocity. Consumables in this process include water, abrasive, orifice, and mixing tubes. The cutting head is the main part of the machine where cutting occurs. In this study, a company using the AWJC system was visited and environmental problems with wastewater handling, abrasive material sludge, and waste cut materials were detected. To solve these problems, three applicable cleaner production solutions have been offered such as recycling of abrasive material, recycling of water, and good housekeeping applications.

Keywords: Cleaner production, abrasive waterjet cutting, waterjet technology, recycling

1. INTRODUCTION

The waterjet cutting technology erodes the material being cut, using a thin stream of water travelling at extremely fast speeds and under very high pressure. It follows the water erosion principle in nature, except that the process is accelerated and concentrated greatly. The water jet can cut soft materials such as corrugated cardboard, disposable diapers, tissue papers and automotive interiors. Also, the stream is thin as well as high pressure, 0.0404-0.010" of diameter. The material loss due to cutting is minimized and extremely detailed geometric cutting can be performed (Flow Shape Technologies Group, 2022).

Pure water jet cutting can cut thick, soft, light materials like fiberglass insulation up to 24" thick or thin, fragile materials. The cutting forces are very low and the fixturing is simple. Water jet erodes work at kerf line into small particles. The water inlet pressure is between 20k-60k psi and the water is forced through hole in jewel 0.007-0.020" diameter. Sapphires, Rubies with 50-100 hour of life can be used as the jewel. Also diamonds may be used with 800-2,000 hour life, but they are more expensive. The pure water jet cutting technology has been improved for different usages in various ways. The abrasive material usage allows the water jet cutting machine to cut much harder materials (Akkurt, 2013). The machine is then named as the Abrasive Water Jet Machine (AWJM). In the AWJM, an abrasive material is used in the cutting process to increase cutting efficiency for harder materials. In the facility Garnet is used as an abrasive material. Garnet is mixed with water for cutting just before the cutting device. Mixing means gradual entrainment of abrasive particles within the water jet and finally the abrasive water jet comes out of the focusing tube or the nozzle. During mixing process, the abrasive particles are gradually accelerated due to transfer of momentum from the water phase to abrasive phase and when the jet finally leaves the focusing tube, both phases, water and abrasive, are assumed to be at same velocity. Abrasive material is mixed with water at the application point and the mixing is done at the mixing point to prevent harm to the equipment due to abrasive material usage. Garnet (sandpaper) with 50-120-mesh is used, but typically 80-mesh is used. Standoff distance between mixing tube and work part is typically 0.010-0.200. It is important to keep it at a minimum to keep a good surface finish. Consumables include water, abrasive, orifice and mixing tube. Cutting head is the main part of the machine where cutting occurs. It is an important part of the machine in this study, because the head could be modified for cleaner production purposes (Natarajan et al., 2020).

1.1.Waterjet Processes

The water jet is used for many purposes which are cutting, drilling, milling, surface preparation, cleaning, coating removal, peening, and forming. The chosen facility used water jet technology for cutting and drilling, so these topics are covered in detail in this study.

1.1.1. Cutting

By far the most common application of the abrasive waterjet is cutting. A whole range of materials and thicknesses can be cut with good cut quality and little taper. Cutting speeds typically well in excess of 2 mm/s (120 mm/min or 7.2 m/hr) are commonly used in industry, however, for thicker and harder material this will drop to 0.1 mm/s (6 mm/min or 0.36 m/hr) or less. The process at this speed has to be carefully assessed as to whether it is economically viable. The cutting speed also depends on the surface finish required (rough cut or good quality cut), the pump pressure and nozzle set up (size of nozzle and size of orifice used) as well as the abrasive flow rate. Other factors such as the angle of jet attack, the standoff distance between the material surface and the nozzle and the actual material properties will also influence the cut and cut quality achieved (Folkes, 2009).

There are optimum cutting speeds for each material. As a rough guide, glass cuts twice as fast as aluminum and titanium cuts at half the speed as it would take to cut aluminum. Nickel and stainless steel tend to cut a bit slower than titanium, about 60% slower than aluminum. For example, if the glass was cut at 2 mm/s, aluminum would be in the order of 1 mm/s, titanium 0.5 mm/s and nickel and stainless steel 0.4 mm/s (Henning and Westkamper, 2007).

The effect of thickness on cutting speed is that increasing the thickness decreases the cutting speed. This is not quite a linear decrease. A material with a thickness of 12.7 mm would cut at a cutting speed half that required to cut a thickness 6.35 mm (half the thickness). However, the cutting speed of a material with a thickness of approximately 25.4 mm would be expected to be cut at a speed of 1/5 of the cutting speed that would be required to cut it if the material has a thickness of 6.35 mm (1/4 of the thickness). When cutting thicker materials striations on the surface become particularly noticeable. The average roughness (Ra) of the areas without striations is around 3.2 µm which is typical for a high-quality metal surface cut using the waterjet. Significant research has been conducted into the exact mechanisms behind this and the process has been modelled and studied using high speed cameras to understand it more fully (Wang, 2003).

There is almost no material that cannot be cut using the waterjet, though care has to be taken with some materials to avoid shattering or delamination. Recently, the waterjet has found significant demand in the composite industry where it is used to cut components for the aircraft fuselage. In some cases, where the fuselage itself is made from composite material, the waterjet can be used to cut out the windows. Machines used for such an operation are commonly fitted with a drill which predrills a hole before cutting commences. This is to prevent the risk of any delamination when the cut is initiated when a piercing (rather than "run in") operation is required. The waterjet will take the path of least resistance as it penetrates through a material when the cut is initiated. Any line of weakness along a fiber layer boundary can be exploited and the waterjet rather than continuing its path downwards can be deflected sideways. If the stream is coherent and powerful enough then the tendency for this to occur is decreased. However, due to the nature of composites and with possible minor flaws or imperfections between the layers the risk of delaminating the whole part is too high hence a hole is commonly predrilled with a drill rather than using a vacuum assist on the abrasive feed and careful selection of process parameters. Once a hole is initiated the waterjet cutting process has no problem since the angle of attack of the incident jet is altered and the water has somewhere to go. The predrilled hole allows the water to exit immediately so a cutting, rather than a piercing process, then takes place. In glass cutting a similar problem arises and can also be optimized by care with initiating the abrasive feed and ramping up the pump pressure (Wang, 2003).

Another example of the use of waterjet technology is in the cutting of car carpets. Most of the carpets seen in modern day cars are waterjet cut. These systems have a vacuum which immediately sucks the water away directly after the cutting process, so the component stays dry with minimal water ingression. Water jets have also been used to cut tissues and fish so their versatility in modern day industry is expanding. Industry has found benefits from this technology to include increased productivity, faster cutting and high-quality parts, flexibility to adapt designs and material changes, minimal kerf, raw material savings and reduced scrap, low operating costs, minimal force on the component, no thermal damage, net or near-net cutting with little or no hand finishing, reduced tooling costs, lighter, flexible tooling (Orbanic and Junkar, 2008).

Comparisons of this technology with others such as Electro Discharge Machining (EDM) and Laser cutting have been made however, these technologies tend to be complimentary rather than competitive. When a thin section is needed to be cut at speed then laser cutting should be considered. If the material is thick section or requires no heat affected zone or is made from copper or a similar material that is highly reflective to some laser wavelengths, then waterjet cutting may be more suitable. EDM is suited to highly accurate machining where time is not as important as accuracy. Overall, in the cutting industry, waterjet and abrasive waterjet technology has found its niche and it is expanding rapidly into new applications especially into areas where materials are becoming harder to machine (Wang, 2003).

1.1.2. Drilling

The application of abrasive water jets in drilling is increasing and water jets are commonly used to drill a wide range of components with varying sizes of holes. Holes in difficult to machine materials such as ceramics and metal matrix composite materials are of particular interest since these are difficult to machine with other methods. The requirement is like cutting in that the initial piercing operation has to be done with care on some materials. Trepanning of holes is common, and the process is faster if the waterjet is moving rather than stationary when initiating the hole. As with waterjet and abrasive waterjet cutting the depth and quality of hole required depends on the application and is process dependent. Holes can be drilled through multi-layered or coated materials without any problems. The hole can be tapered or not as required as well as angled (Louis and Von Rad, 2000; Folkes, 2009).

The waterjet process can machine almost any material so material type is generally not an issue, though, as mentioned before with cutting, extra care may be needed when drilling brittle materials such as glass or layered materials with flaws such as composites. The nozzle size used in normal waterjet applications is typically 1 mm, so, hole sizes greater than this can be achieved without too much problem. Smaller hole sizes require a smaller nozzle diameter (and orifice). Nozzles of 0.5 mm diameter are commonly available but smaller than that they must be specially ordered. Also, finer abrasive sizes (120 mesh) are commonly used to avoid any blockage of the nozzle. The versatility of the waterjet in that it can machine most materials and the demand for ever decreasing size holes in today’s shrinking world will lead to the development of high-pressure systems designed to machine micro size holes using waterjet (or abrasive waterjet) technology. Some systems are currently available, but they are still in their infancy, and this is an area of significant future development (Folkes, 2009).

Although water jet cutting is seen as an environmentally friendly technology, there are pollutants resulting from the process which should be carefully managed. Also, increasing efficiency results in lower energy consumption (Folkes, 2009). This study analyzes cleaner production methods for an abrasive water jet cutting machine. A typical flow diagram for AWJM is given in Figure 1.

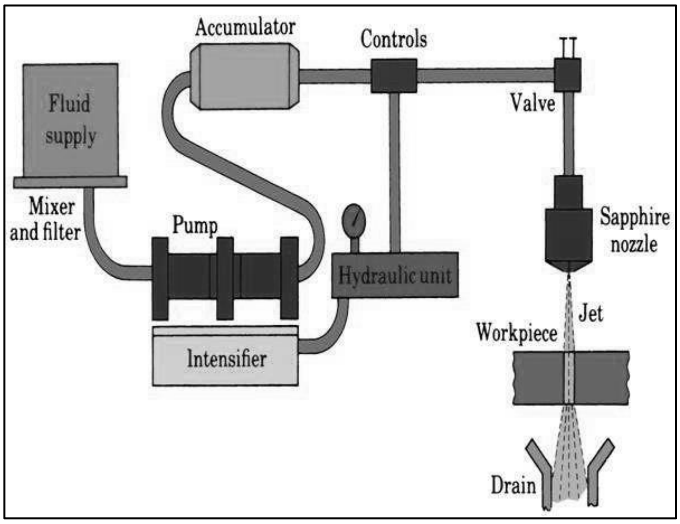

Figure 1. Typical AWJM flow diagram (Khan and Ali, 2011)

2. MATERIALS AND METHODS

Waste minimization audit is used for the cleaner production study. The steps followed and the information gathered is as presented below. Two field trips were conducted to the facility. There were some issues related with cleaner production where alternatives could be created. The problems determined can be stated as the following:

- The wastewater resulting from the cutting operation is given to the sewer without any treatment.
- The Garnet is not separated from the water used, so the contaminated sludge with the material dust in it is disposed of to the clear land.
- Recycling is not applied for water and Garnet.
- The waste material pieces resulting from the cutting of raw materials are not collected separately for recycling.
- The housekeeping is not applied sufficiently. The materials are not stored orderly or disposed of properly.

To solve these problems and increase the efficiency of the products cut in the facility by preserving natural resources, the following steps were followed to give cleaner production options.

2.1. Step 1: Pre-assessment

2.1.1. Prepare and organize audit team and resources

The audit team was constituted with the environmental engineers and consultants from academy.

2.1.2. Divide process into unit operations

The process is taken as one unit operation since it is one machine doing the work for all the facility.

2.1.3. Construct process flow diagrams linking unit operations

Constructed process flow diagram is given in Figure 2. The inputs of the system were determined as water garnet and raw material. The outputs of the system were determined as wastewater, waste material pieces, garnet sludge and cut product.

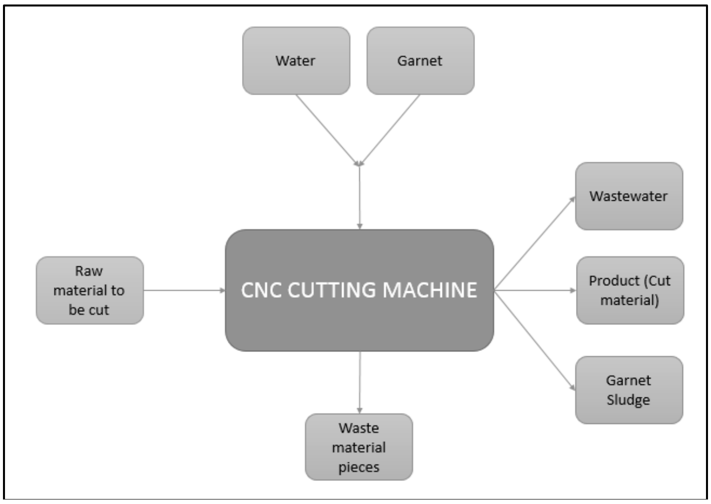

Figure 2. Flow diagram for the process

2.2. Step 2: Material Balance

2.2.1. Define process inputs and outputs and derive a material balance

The process inputs and outputs are defined and are summarized in Table 1. The derived material balance is as presented in Figure 3.

Table 1. Material Balance

Inputs	**Outputs**
Water (43200 L/month)	Wastewater (43200 L/month)
Garnet (2 ton/month)	Sludge (2 ton/month)
Electric ((200 tl/month) /(0.2392 tl/kW) = 836.12 kW/month)	Waste material pieces
Raw material to be cut/drilled	Cut/drilled material

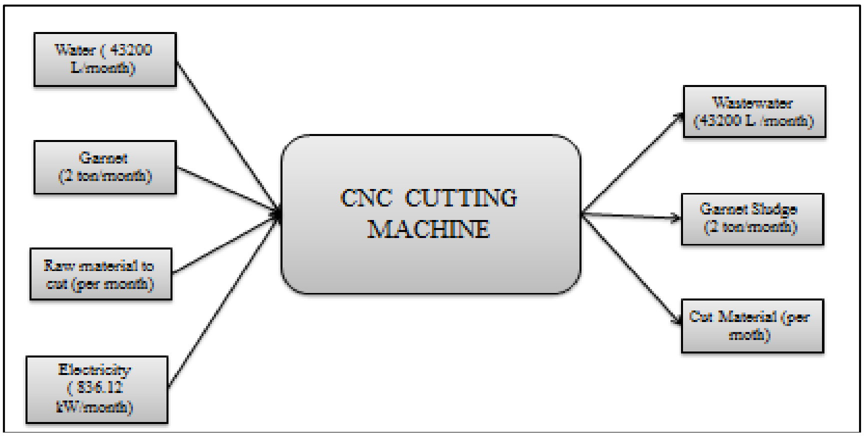

Figure 3. Material balance for the facility

2.3. Step 3: Synthesis

2.3.1. Identify waste reduction options

The identified waste reduction options are given in the below:

1. Recycling of Garnet

The goal of recycling is to clean the blasted abrasive so it can be used again productively. Ensuring that the recycled abrasive (known as the "working mix") is clean and contains abrasive particles with the appropriate size range involves two basic operations: the removal of oversized and undersized contaminants and the addition of virgin (make-up) abrasive. In order to accomplish this efficiently, both the blasted and virgin makeup garnet must be kept dry. Decontamination of the blasted (used) abrasive is accomplished by mechanical separation and air-wash separation. A rotary drum removes the large contaminants such as large paint chips, rust, welding rods and cigarette butts. An air-wash separator unit, working in conjunction with a dust collector, removes unwanted fine abrasive particles (“fines”). The most critical element of the recycling process is the creation of an effective “working mix” which is comprised of a range of small, medium and large abrasive particles. Given that a portion of the garnet breaks down each time it is blasted, a productive working mix should be created by adding virgin abrasive to the cleaned abrasive at a rate equal to the rate of attrition (i.e. breakdown rate). These additions should be made at regular intervals and be based on the number of fines extracted by the separation unit, daily visual inspections of the recycled abrasive and periodic sieve analyses (MBA, 2017).

2. Recycling of Water

Closed Loop Filtration Systems are specifically designed for waterjet cutting or water jet cleaning systems overflow water to the drain. Dissolved solids are the metals that are dissolved in water from the water jet cutting process. Filtration of the tank overflow will remove some of the suspended solids and spent abrasive. However, these overflow to drain systems do not remove dissolved solids (Jet Edge, 2022).

3. Substituting the Abrasive Material

Environmental issues and concerns have led the researchers to use such mediums and abrasives that do not require disposal, recycling or lead to pollution. Work is going on in the area of high-pressure cryogenic jet machining where liquid nitrogen replaces the water phase and dry ice crystals (solid CO_2 crystals) replace the abrasive phase leading to no need of disposal or waste generation. The removed work material in the form of microchips can be collected much easily reducing the chances of environmental degradation (Jerman et al., 2018).

4. Garnet Extraction for Disposal

The extraction process includes the extraction of Garnet from the wastewater for its disposal. Garnet is separated by a device where dewatering of garnet sludge occurs as well. This sludge then can be disposed of easily.

5. Good Housekeeping Applications

Safe storage should be applied at the facility. The materials to be cut are set in front of the facility without any order or protection from outside conditions. They may be contaminated or deformed. Also, if the storage were to be made in an order, efficiency would increase in the facility.

3. RESULTS AND DISCUSSION

3.1. Evaluate waste reduction options

Waste reduction options were all evaluated and discussed with the executive of company and three options were chosen, and the reasons are presented in below:

1. Recycling of Garnet

The management of sludge consists of garnet, dust of cutting materials and some portion of wastewater. This sludge is currently being disposed of to clear land. After evaluation of recycling garnet and substituting abrasive material, recycling garnet option is chosen due to feasibility studies. The price of liquid nitrogen is as high as 500-2000 dollars (LABRepCo, 2022). Also, some major modifications to the system are required to the water jet machine. Another option was Garnet extraction for disposal. Also, since recycling will be applied there will be no need for this process which includes purchasing of high-priced machinery. Some mini garnet recycling machines are available for installation in the facility which are about 20.000-25.000 dollars. If the price is to be too high for the company, the device may be bought together with other similar firms which are neighboring the facility.

The garnet may be disposed of properly to İzmit Waste and Waste Treatment, Incineration and Evaluation Inc. (IZAYDAŞ) since it is a hazardous sludge. The disposal prices are very high when the transportation and incineration prices are considered. Therefore, it can be stated that the machinery purchasing is a better option for long term, than paying fees to the government or applying proper disposal.

2. Recycling of Water

Water is another issue which is not disposed of properly. The wastewater resulting from the operation contains hazardous substances. Thus, it is a better option to recycle it then to treat it since the treatment systems are more expensive. A closed loop system is sold for 14.500 dollars which is again a price which can be paid once, instead of paying fees. It also, decreases water consumption and the purchasing price can be regained in a short time due to getting rid of high prices for water supply.

3. Good Housekeeping Applications

This option is the last option left to be applied in the facility without any payment. It just requires the training of the employees. The site can be planned so that materials, manpower, electricity, water etc. do not go to waste. Also, this topic covers the management of the CNC water jet cutting device. Although many parameters cannot be altered in the device, the pressure applied can be changed according to the material to be cut. The employees said that they are unaware of this fact, and they use the same pressure for every material. Altering the pressure will make the process more efficient, decreasing water and electricity consumption. Also, the safe and categorized storage of materials are required. The waste materials can be given to recycling facilities in the Organized Industrial Area in which the AWJ Facility is located as well.

4. CONCLUSION

The cleaner production study for the abrasive CNC water jet cutting is conducted using the waste minimization method. The study is important in terms of eliminating hazardous materials discharged into nature without treatment and coming up with solutions that are applicable. The chosen cleaner production alternatives are determined as recycling of garnet, recycling of water, and good housekeeping applications. Through these cleaner production measures, more environmental-friendly and sustainable production is possible. The determined waste reduction options were discussed with the company and they agreed to work on a waste reduction action plan.

ACKNOWLEDGEMENTS

This study was conducted by the help of an AWJ facility. We would like to thank to Begüm Yaşarkurt, Iulian Ronin and Uğur Avdan for their support on this study.

REFERENCES

Akkurt, A. 2013. The Cutting Front Side Geometry in The Applications of D3 Cold Work Tool Steel Material Via Abrasive Water, Gazi University Journal of Science 26(2), 225-239.

Flow Shape Technologies Group, 2022. How Waterjets Work. Available at: http://www.flowwaterjet.com/en/waterjet-technology/how-waterjets-work.aspx [Access Date: 04.05.22]

Folkes, J. 2009. Waterjet—An innovative tool for manufacturing, Journal of Materials Processing Technology, 209 (20), 6181-6189.

Henning, A., Westkamper, E., 2007. Dynamic analysis of the spatial-temporal behaviour of the cutting front in abrasive waterjet cutting. American WJTA Conference and Expo., Houston, Texas, Paper 5-B.

Jerman, M., Lebar, A., Sabotin, I., Dresar, P., Valentincic, J. 2018. Ice Jet Technology, MM Science Journal, 2379-2384.

Jet Edge, 2022. Closed Loop Filtration System the Resourceful Economizer. Available at: https://jetedgewaterjets.com/products/water-jet-accessories/closed-loop-filtration-system/#:~:text=Jet%20Edge's%20eco%2Dfriendly%20Closed,before%20entering%20the%20filtration%20system. [Access Date: 05.05.22]

Khan, A.A., Ali, M.Y. 2011. Application of Silicon Carbide in Abrasive Water Jet Machining, Silicon Carbide – Materials, Processing and Applications in Electronic Devices, Edited by Moumita Mukherjee, 431-452.

LABRepCo, 2022. Liquid Nitrogen Dewars. Available at: https://www.labrepco.com/product-category/cold-storage-products/ln2-cryogenic-storage/ln2-dewars-liquid-storage/#:~:text=Liquid%20Nitrogen%20DewarsCryogenic%20Dewars,times%20even%20under%20rugged%20conditions. [Access Date: 05.05.22]

Louis, H., Von Rad, C.H. 2000. Cutting of hollow structures with abrasive water suspension jets, Proc. 15th International Conference on Jetting Technology, Ronneby, Sweden, 59-67.

MBA, 2017. 8 Rules for Recycling Abrasive Media in Blast Cabinets. Available at: https://www.mediablast.com/blog/2017/07/06/8-rules-for-recycling-abrasive-in-blast-cabinets/ [Access Date: 04.05.22]

Natarajan, Y., Murugesan, P.K., Mohan, Khan, M.S.A.L.A. 2020. Abrasive Water Jet Machining process: A state of art of review, Journal of Manufacturing Processes 49, 271-322.

Orbanic, H., Junkar, M. 2008, Analysis of striation formation mechanism in abrasive waterjet cutting, Wear, 265, 821-830.

Wang, J. 2003. Abrasive Waterjet Machining of Engineering Materials, Trans Tech Publications Ltd. Switzerland.