ANNALS of Faculty Engineering Hunedoara
– International Journal of Engineering
Tome XIII [2015] – Fascicule 4 [November]
ISSN: 1584-2673 [CD-Rom; online]
a free-access multidisciplinary publication of the Faculty of Engineering Hunedoara

[1.] Lydia SOBOTOVA, [2.] Monika KARKOVA

PROCESSING OF WASTE OF ABRASIVE IN WATER JET TECHNOLOGY

[1-2.] Technical University of Kosice, Faculty of Mechanical Engineering, Departmenet of Process and Environmental Engineering, Letna 9, 042 00 Kosice, SLOVAKIA

Abstract: The cutting of materials by using of recykling abrasive water jet (AWJ)belongs to one of clean technologies, which utilize the possibility to divide or cutting the materials that are sensitive to pressure and temperature in material processing. At the same time there is also a need to decrease of waste process after finishing of cutting operation. The contribution deals with the recycling opportunities, possibilities and influence on the working environment.
Keywords: water jet technologies, recycling of material, waste

1. INTRODUCTION
Over the past five years, the number of waterjet (WJ) cutting machines sold worldwide, both abrasive and pure water, has increased by an average of 18 percent annually. That growth is projected to continue for the foreseeable future. Fabricators are showing more interest in the technology as they realize it can cut metals of various thicknesses and different materials, but the question with the waste is still important.

Workshop environment may not tolerate any deterioration of working, safety and hygienic conditions which do not meet European standard requirements. Partial targets are:
- to lower an exploitation of abrasive natural sources, water and energy,
- to reduce import of abrasive into EU countries,
- to improve quality of life and health by preserving the environment.

2. PROPERTIES OF ABRASIVES FOR AWJ CUTTING
WJ cutting technology has found a variety of applications world over as it offers wide ranging benefits. The type of abrasive used in AWJM can have a large impact on the performance of cutting. The more difficult the cut, the more important the abrasive selection becomes. The natural characteristics like hardness, shape, particle size, purity, specific gravity of abrasives will affect their effectiveness in cutting. The analyses of physical properties and chemical properties of abrasive materials are very important before using of cutting process. The cutting speed and surface quality of material influence on the selection of abrasives. Cost of operation of AWJM will be influenced by abrasives, too. High quality abrasives cost more but must be weighed against the performance.

3. ABRASIVE WATERJET PROCESS
An abrasive water jet (AWJ) system typically consists of a high pressure pump, abrasive cutting head, abrasive delivery system, nozzle, motion system, control unit, spent abrasive catcher unit and settling tank, Figure 1. High pressure water flows through a sapphire or diamond orifice into the mixing chamber of the cutting head and creates a partial vacuum that draws in a metered flow of abrasive.

The use of mineral particles as abrasive material causes negative environmental impacts that involve additional processes for manufacturers. Waste is produced by both the mixture of abrasive particles and water used for jet generation and the material spills mixed with particles produced during material cutting. Thus, managing the waste produced during the AWJ implies complicated additional processes.

The abrasive combines with the water jet to create the AWJ cutting stream that exits through the nozzle. Typical operating conditions are 200 – 400 MPa water pressure, mesh #50 – #120 abrasive, 0.24 – 0.40 mm orifice diameter, 0.76 – 1.70 mm nozzle diameter and 3.8 – 15.0 g/s abrasive flow rate.

In an AWJ company with an average of 3 machines, approximately 24 tons of abrasive are spent every 3 or 4 weeks. That is equivalent to a consumption of 360 t per year, with an economical cost of 95.400 €. The total amount of water consumed by WJ technology is also significant. In Europe 2.409.523 m3 of water per year (average of three machines) are consumed, equivalent to a domestic consumption of 16.063.486 inhabitants.

When abrasive is new, there is a certain percentage of other minerals or "filler" that is found. After going through the cutting process, these softer minerals are shattered into extremely small particles that are filtered out at the first stage of the recycling process. In fact, comparing at the same volume, recycled abrasive weighs more than new abrasive.

Two types of abrasive (Garnet, Mesh 80) is shown in the Figure 2 and Figure 3:

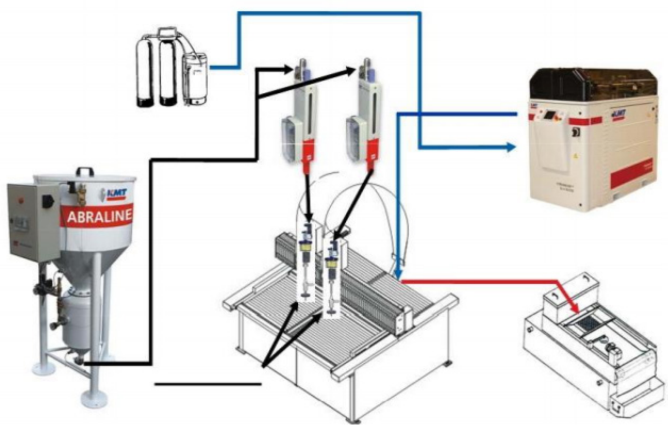

Figure 1: Water jet cutting workplace [8]

- preliminary crushed;
- preliminary not crushed (it was only extracted from fluvial deposit).

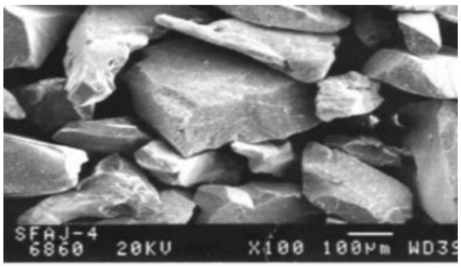

Figure 2: The SEM picture of preliminary crushed abrasive before first using [1]

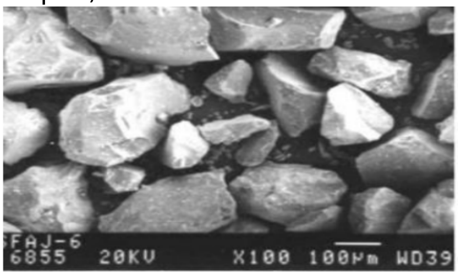

Figure 3: The SEM picture of preliminary crushed abrasive after first using [1]

As you can see from the chart below, both new and recycled abrasive are composed of certain percentages of various abrasive mesh sizes, Figure 4. What we find is that recycled abrasive tends to be composed of slightly finer mesh abrasive than new. Conventional wisdom would dictate that a finer mesh means you need to cut at a slower speed or increase your abrasive feed rate. However, in recycling of abrasive, this is not the case.

The Figure 5 shows the distribution of abrasive amount (relative density of abundance in volume units) in the dependence to grain size of preliminary crushed abrasive. Three column plots represent this distribution:

- New abrasive – maximum abundance of mean Mesh 80 of the "Garnet 80 ™ is confirmed. The occurrence of other-size components is found regularly but in lessen amount.
- After cut process abrasive (ACPA) - maximum abundance of mean Mesh 95 is occurred. The shape of distribution plot is more flat and it is inclined to smaller grain-size. Dusty components are plentiful.
- Recycling abrasive - recycling process includes drying, sorting, separation and selection.

Mean Mesh 90 is obtained. The occurrence of other-size components is eliminated. Dusty components are separated.

During of cutting of materials, starting with an abrasive flow of zero pounds per minute, there would be absolutely no penetration of the material except for maybe a very light etching of the top surface of the material. Cutting speed increases as more and more abrasive is added. In the Figure 6 is shown abrasive amount in the dependence of feed rate.

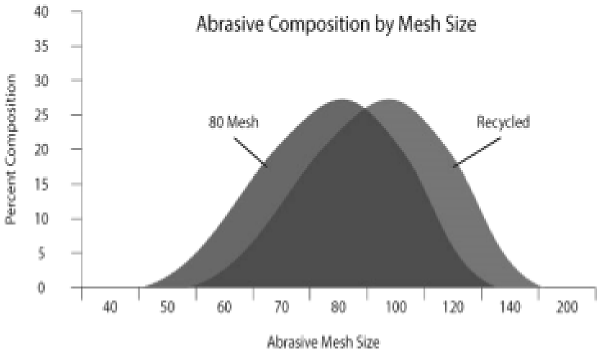

Figure 4: Abrasive composition by mesh size [2]

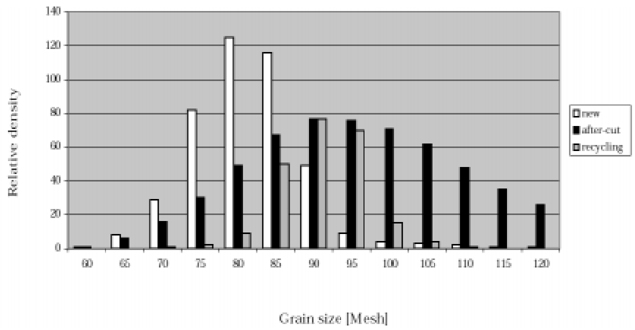

Figure 5: Distribution of abrasive amount in the dependence to grain size of preliminary crushed abrasive [2]

The optimum cost point may be slightly below what looks to be the apex of the speed curve. In the Figure 7 is shown the cost changing in dependence of feed rate and abrasive amount. Smaller orifice / nozzle combinations are more efficient though in their use of water and abrasive. The available power of the waterjet is concentrated into a smaller area, so more power is directed to the cut.

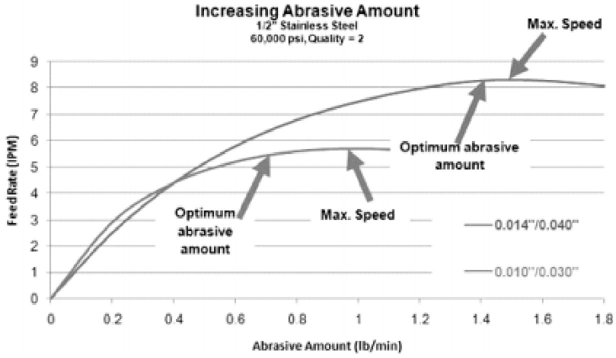

Figure 6: Abrasive amount in the dependence of feed rate [8]

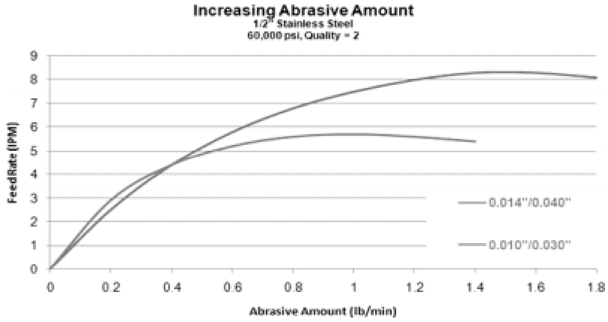

Figure 7: The cost changing in dependence of feed rate and abrasive amount [8]

4. ABRASIVE RECYCLING SYSTEMS

During scientific research in the area of recycling abrasive materials in AWJ technologies and reducing the amount of waste from the manufacturing, various methods of material recycling and design of recycling machines were created. We can mention, for example: WARD Jet abrasive removal system, WARD Pro-waterjet abrasive recycling, TECHNI water jet system, OMAX solids removal system, WATING mechanical system.

In the world exist more types of separating and recycling methods of abrasives depends on technology:

- magnetic separation,
- floating,
- setting of used abrasive material,
- recycling under water flow.

The most famous abrasive recycling system are realized by the firms WARD – Waterjet Abrasive Removal Only System (AROS), Flow-WaterVeyor™ Abrasive Removal System, TECHNI-waterjet, KTM and others.

In the Slovakia is used mechanical system **WATING** – the entire development system is based on the patented technology, which during the first separation phases the effluent, is discharging (launched) from the table battle. In the next phase the abrasive material is picked out on the metal palettes and can pass to following washing process. In sedimentation process in the first part the maximum of 94% of used abrasive grains are separated and only 4 % can be caught. Of course in the second sedimentation part about 2% and in the third part it is not important for optimal performance because there is only water with slime.

In experiments, different materials for the recycling were used. The optimum of regeneration is 53 % of whole abrasive grains.

WARD Pro – Water Jet Abrasive Recycling System is environmentally friendly, because it saves and minimalizes the working space, see Figure 8. The Drum Abrasive Recycling System is designed specifically to process recycled abrasive into the WARD Pro system. The waste material into the DART can be load, which removes large particles such as material drops, off cuts, or tools that may have fallen into the tank. A recycling removal nozzle is placed at the bottom of the DAR, the content is agitated and the materials are processed through the recycling unit. The DAR will empty completely when used.

TECHNI waterjet system was designed to take the hard work out of tank cleaning, Figure 9. The abrasive waste removal system collects used abrasive from the cutting stream via a tray fitted to the bottom of the waterjet tank. The abrasive slurry is then pumped to a heavy duty tipper bin mounted on a steel frame by an abrasive resistant diaphragm pump, designed specifically to handle the harsh abrasive environment.

Figure 8: WARD Pro - Waterjet Abrasive Recycling [5]

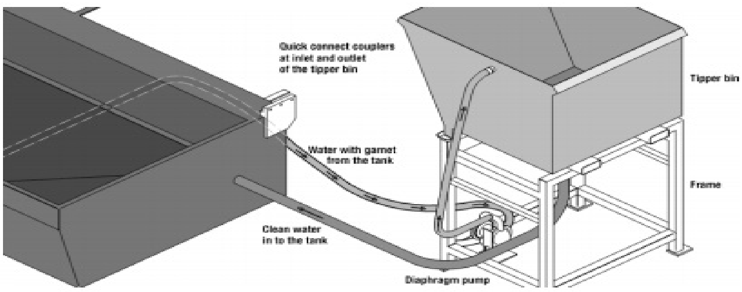

Figure 9: TECHNI waterjet system[11]

The pump includes hardened steel manifolds and long lasting santoprene bearings to withstand the abrasive slurry pumping action. The waste garnet abrasive settles to the bottom of the bin while the water is returned to the waterjet tank. The tipper bin can then be easily emptied by a forklift as required.

In **OMAX Solids Removal System** the garnet is removed from the retaining tank and deposited into a hopper, see Figure10. The water from the hopper flows back to the tank without the use of a pump (gravity return).

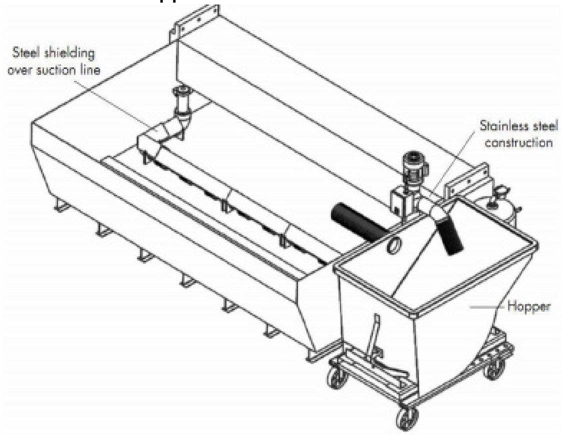

Figure 10: OMAX SRS shown on Model 55100[10]

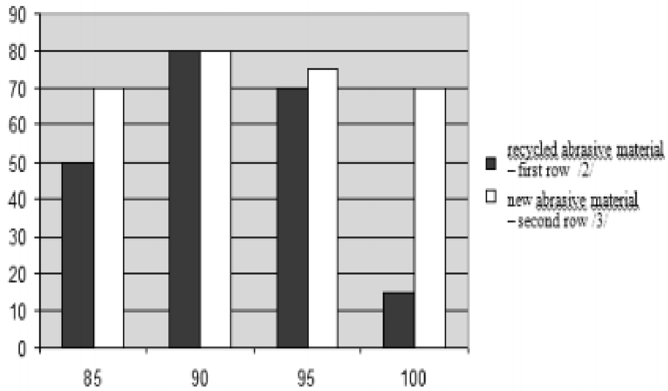

Figure 11: Relation between grain dimensions and grind density[2]

Were used the different materials for the recycling. Optimal results were achieved and WATING technology of recycling abrasive material could be used as the new one in the next process. The possibilities of using these recycled materials were performed on the WATING solution. The optimum of regeneration is 53% of whole grains, Figure 11.

For the answer to the question how much abrasive manufacturers can save by recycling depends on a number of factors is most important a quantity of used abrasive and its cur- rent price. With the recycling system, there is possibility to recover varying amounts of the abrasive. The more it can be recovered, the more it can be saved. As the recovery rate in- creases, also a little decrease of hourly recycled abrasive can be observed.

5. WATER SPECIFICATION

The water supplied to the intensifier is critical to waterjet cutting due to its direct influence on the service life of the equipment components such as control valves, seals and orifices. A high concentration of Total Dissolved Solids (TDS) causes accelerated wearing of any components that come in contact with the high pressure water because of the increased abrasiveness of the water from the TDS.

As a part of the installation planning, a water quality analysis should be performed by a commercial company that is specialized in water conditioning. The minimum information that should be provided by this analysis is:

- total dissolved solids TDS,
- silica content,
- pH value.

Table 1: Water treatment guidelines[11]

Criteria	Values	Recommended Treatment
Total Dissolved Solids TDS	Low TDS (<100 ppm) Moderate TDS (100 - 200 ppm) High TDS (>200 ppm)	Good water, requires only softening Can be treated by softening, DI or RO Poor water, should be treated with RO or DI
Silica Content	High content (>15 ppm)	Dual Bed Strong Base DI
pH Value	Treated water must have a value of 6 - 8	

The best treatment process for a specific application is a function of the original water quality and the desired service life of the affected components. 60 to 70 ppm of TDS is optimum. Any water treatment producing TDS content of less than 0.5 part per million (ppm) should be avoided since the aggressiveness of such purified water will damage pump components.

6. CONCLUSION

Reducing abrasive consumption decreases direct part cost. It also decreases the amount of work required to empty the abrasive out of the machine's tank and the cost of disposal. We can make some basic conclusion about consumption, recycling of abrasives:

- Smaller Nozzles. Using a smaller water/abrasive nozzle combination can reduce abrasive consumption dramatically.
- Utilization of more cutting heads. Most producers hesitate to change because a smaller water/abrasive nozzle combination results in fewer parts per hour. While this is true for cutting with a single head, two-head cutting with the smaller nozzle

combination produces more parts per day at a lower abrasive cost per part. But not all parts are suitable for two-head cutting because of part size.

- Using two heads and smaller nozzle. The small-nozzle combination is a 16 % savings per inch of cutting. Considering the number of inches you will cut in a year, these fractions of a penny add up dramatically.
- Pump Sizing for Two-head Cutting. If you find that two-head cutting with a smaller nozzle combination is most cost-effective for your application, then you must determine the optimum pump size.
- CNC Abrasive Metering. It takes less abrasive to make a quality cut than a production cut. A quality cut might require 0.8 lb.min^{-1} of abrasive, while a production cut might require 1.0 to 1.2 lbs.min^{-1} With CNC abrasive metering, the amount of abrasive used during piercing can be reduced by 50 percent or more without increasing piercing time. Since it can take several seconds to pierce through thick material, reducing the amount of abrasive used during those seconds can save several pounds of abrasive per day.
- CNC abrasive metering allows the programmer to choose the appropriate abrasive feed for varying part quality requirements within a single program.
- Abrasive Removal Systems. Abrasive removal systems can reduce part cost by eliminating the downtime that is required to remove abrasive from the machine's catcher tank; the abrasive is removed automatically throughout the cutting process. Anyone who has had to do the back-breaking work of shoveling out the sludge from a waterjet will appreciate an abrasive removal system.
- Water Recycling Systems. Closed-loop water recycling systems can help save on water costs. Recycling systems separate abrasives from the water, leaving cleaner water for disposal and also improving the quality of the water going into the pump, which helps increase the life of the pump and cutting components.

Acknowledgements

The work was supported by Ministry of Education of Slovak republic KEGA 048TUKE - 4/2015.

LITERATURE

[1.] Krishnaiah Chetty, O.V., Ramesh Babu, N., Some investigations on abrasives in abrasive waterjet machining, in: 10-th American Waterjet Conference, August 14-17, 1999, Houston, Texas, USA.

[2.] Summers, D.A., Fossey, R.D., Newkirk, J.W., Galecki, G. et al., Results of comparative nozzle testing using abrasive water jet cutting. In: 2001 WJTA American Waterjet Conference, August 18-21 2001, Mineapolis, Minesota, USA.

[3.] Kmec, J., Sobotova, L. et al.: Categories of hydroerosion factors - 1. ed. - Lüdenscheid: RAM - Verlag, Germany 2012. - 153 s. ISBN 978-3-972303-11-8.

[4.] Vasek, J., Martinee, P., Foldyna, J., Hlavac, L., Influence of properties of Garnet on cutting process, In: Proceedings of 7th American waterjet conference, pp.375-387, Waterjet Technology Association, Seattle, Washington, 1993.

[5.] www.wardjet.com/02-waterjet-relationship-parameters.html

[6.] Kmec, J., Sobotová, L., Demeč, P., Safety of the waterjet, in: MM science journal - no. 4, pp. 278-280, Praha, 2011. www.mmscience.eu, ISSN 1803-1269.

[7.] Kmec, J. et al: Technical and technological factors affecting hydro erosion surface topography. In: Annals of Faculty engineering Hunedoara – international journal of engineering - Vol. 10, no. 3, pp. 485-488, Romania , 2012. - ISSN 1584-2673.

[8.] www.ktm-waterjet.com

[9.] Waterjet Abrasive Removal Only System (AROS), www.wardjet.com/aros.html

[10.] WaterVeyor™ Abrasive Removal System, www.flowcorp.com

[11.] Abrasive Waste Removal System, www.techni waterjet.com

[12.] Badida, M., Sobotova, L., Kmec, J., Environmental approach to abrassive recycling for AWJ. In: SGEM 2012: 12th International Multidisciplinary Scientific GeoConference: conference proceedings: Volume 4: 17-23 June, 2012, Albena, Bulgaria. - Sofia: STEF92 Technology Ltd., 2012, pp. 693-700. - ISSN 1314-2704.

[13.] Badida, M., Kmec, J., Sobotová, L., Bičejová, Ľ., Gombár, M., Hydroerosion and environment, 2013, first edition, 153 p. ISBN 978-3-942303-20-0.

[14.] Juračka, B. & Rusnáková, S. & Letko, I. & Koštial, P. & Ružiak, I. & Jurčiová, J. Study of thermoelastic properties of acrylate composites in automotive industry-Part I. (2011) Chemicke Listy, 105, (15 spec. issue), pp. 297 – 299.

[15.] Fojtl, L., Rusnáková, S., Žaludek, M., Influence of honeycomb core compression on the mechanical properties of the sandwich structure. (2014) Applied Mechanics and Materials, 486, pp. 283 – 285, doi: 10.4028.

[16.] Rusnáková, S., Žaludek, M., Fojtl, L., Rusnák, V., Design and verification of sandwich structures for high speed trains. (2014) Key Engineering Materials, 586, pp. 72 – 75, doi: 10.4028/www.scientific.net/KEM.586.72.

[17.] Gombár, M., Bičejová, Ľ., Kmec, J., Vagaská, A. Experimental analysis of the effect of cutting conditions on microgeometry of the machined surface - 2013. In: Academic Journal of Manufacturing Engineering. Vol. 11, no. 1 (2013), p. 38-43. - ISSN 1583-7904.

[18.] Kmec, J., Bičejová, Ľ., Gombár, M., Vagaská, A., Category factors for AWJM - 2013. In: Academic Journal of Manufacturing Engineering. Vol. 11, no. 1 (2013), p. 60-65. - ISSN 1583-7904.

[19.] Kmec, J., Safe working conditions for the water jet technology. 2013. In: Acta Technica Corviniensis: bulletin of engineering. Vol. 6, no. 2 (2013), p. 113-116. - ISSN 2067-3809.

ANNALS of Faculty Engineering Hunedoara – International Journal of Engineering