

Abrasives in water jet cutting systems

G.R. Martín C, C.T. Lauand & W.T. Hennies

Mining Engineering Department, Polytechnic School, University of São Paulo, Brazil

R. Ciccu

DIGITA, University of Cagliari, Italy

ABSTRACT: Abrasives used in high velocity water jet cutting systems are one of the most important elements for kerf opening. The most commonly used product as an abrasive is mineral garnet. Many of its technological characteristics are very important. The common characteristics that influence the cutting system were defined as abrasive power and among these features there are grain size distribution, abrasive hardness, geometrical form of the particles, and other features that will be presented. Different grain sizes are available to provide best cutting features for different materials. Operation with softer materials such as wood and rubber do not require the use of abrasives, but for cutting hard rocks, as well as steel, other metals and ceramics, the use of abrasives is mandatory. Garnet is the most commonly used abrasive, but there are other natural and man made abrasives such as slag, aluminium oxide and carborundum that may be used. Careful selection of the abrasive material is recommended to achieve a compromise between nozzle durability and the part to be machined.

1 INTRODUCTION

Abrasives are sharp, hard materials used to wear away the surface of softer less resistant materials. Included within the term are both natural and synthetic or manufactured substances that range from the relatively soft particles used in household cleansers and jeweller's polish to the hardest known material, the diamond. Abrasives are indispensable to the manufacture of nearly every product made in modern industry with high precision components as automobiles, aeroplanes and space vehicles, mechanical and electrical appliances, and machine tools.

The history of abrasive usage is very old. The earliest man's rubbing one hard stone against another made use of abrasives to shape his first weapon or tool. Natural abrasives were used during the first industrial revolution in the early stages of large scale mechanisation.

An interesting story of those days is the event from 1873 in the United States, when Swen Pulson, working in the Norton and Hancock Pottery, Worcester, Massachusetts, won a jug of beer by betting that he could make a grinding wheel by combining emery with potter's clay and firing them in a kiln. Just before the turn of the century man discovered the manufacturing process to obtain aluminium oxide and silicon carbide with the use of electric

furnaces. In 1955 the General Electric Company succeeded in manufacturing synthetic diamond.

Most recently, industry mechanisation evolved into full automation, with the development of computer controlled systems for cutting a range of modern materials, and the use of abrasives is critical for machining hard materials.

In modern automated systems with computer controlled operation by a Cad/Cam software, it is possible to make precision parts for industrial applications. The new abrasive water jet system installed as a Module of the Rock Mechanics Laboratory at EPUSP and the Brazilian aims for the following years are described in a paper presented this year at Calgary (Lauand et al., 2000), Canada, during the SWEMP'2000, in May.

Manufacturer's instructions indicate the use of garnet, 80 mesh grain size, for effective operation of the water jet system.

Unfortunately, garnet as a quality abrasive for water jet application is not available in Brazil, and we need to import the product. The price of the imported product is R\$2.00/kg (about US\$1/kg).

On the other hand, in Brazil there other suppliers of synthetic or manufactured abrasives, generally aluminium oxide and silicon carbide. The prices of manufactured abrasives are R\$1.13/kg for aluminium oxide and R\$1.86/kg for silicon carbide, for 80

mesh grain sizes, which are cheaper than imported garnet.

Complete technological characterisation of abrasive materials used in the new abrasive water jet cutting system will here presented below.

2 TECHNOLOGICAL CHARACTERISTICS OF ABRASIVE MATERIALS

The main technological characteristic of an abrasive as defined to be used as grains in abrasive water jet systems (Agnus et al., 1995 & 1996) is its power that can be calculated by the following mathematical expression:

$$P_{Abr} = H_p^{a1} \cdot S^{a2} \cdot \rho_p^{a3} \cdot d_p^{a4} \cdot \dot{m}_A^{a5} \quad [1]$$

In equation [1] H_p is the Knoop abrasive material hardness, S is a particle shape factor, ρ is the abrasive material density, d is the abrasive particle diameter, and \dot{m} abrasive mass flow rate.

To better understand their features, the powder materials were evaluated according to their abrasive power as determined in equation [1].

The mineralogical composition of the samples was determined in a semi-quantitative determination by Spectrometry with an Xray apparatus.

Then, the shape of the particles was measured by a method suggested by Ayres da Silva & Hennies, 1983, to determine the mean roundness of the abrasive grains.

Additional chemical analyses of the abrasives were also performed.

Abrasive grain hardness was determined from microhardness indentation tests on polished grain section samples.

Abrasive material density was another physical characteristic that we measured or evaluated from available data provided by the manufacturer.

Grain size distribution was measured with a laser beam measuring apparatus (Malvern) to evaluate the mean diameter of grains for every abrasive sample.

3 EXAMINED SAMPLES

As mentioned above, different kinds of abrasives were examined. First, we examined two artificial powder abrasives from Alcoa, identified as aluminium oxide and silicon carbide or carborundum, 80 tyller mesh grain size.

Additionally, Flow brand garnet samples imported from the USA were also examined, 80 and 120 tyller mesh grain size, as well as another sample used in the preliminary testing of the equipment, also 80 tyller mesh grain size.

Finally, a Brazilian garnet sample, from the tailing product of the monazitic sands processed at

the Nuclemon, the State Nuclear Agency of Brazil, was also characterised.

Eletrostatic separation of this Brazilian garnet was performed at the mineral processing laboratory of the mining engineering Department of EPUSP, providing a good concentration of this abrasive material for the characterisation study. Initial tests were performed with a 5kg sample that resulted in 20% of good concentration garnet.

Summarising, our study evaluated the physical characteristics of 6 different samples, as follows: 2 artificial abrasives (aluminium oxide and silicon carbide or carborundum), and 4 garnet samples (3 imported and 1 from the domestic market).

4 ASSAYNG RESULT

Most of the tests were performed at the Laboratory of Technological Characterization of the Mining Engineering Department of EPUSP, as follows: Mineralogical characterisation; Grain size distribution; Particle shape characterisation; Chemical analysis; Abrasive grain hardness; Abrasive grain density; Abrasive grain scanning.

4.1 Mineralogical characterization

Abrasive powder samples were submitted to an Xray to obtain a diffractogram.

The resulting interpretation of these diffractograms determined the mineralogical constituents of the abrasive grain crystals.

The interpretation demonstrates that the mineral content in all four garnet samples corresponds to Almandine and Almandite. There is also some Quartz content in all of the samples.

The Flow brand garnets also include small amounts of Goethite in the 80# kind and Allophane and Pseudobrookite in the 120#.

The Omax 80# samples include some Quartz content as well as a small amount of a mineral known as Ulvospinel.

Finally, the Brazilian garnet sample included some Ilminite as well as Allophane and Pseudobrookite.

The diffractogram of Aluminum oxide artificial abrasive indicates the presence of synthetic Corundum as the major component and minor amounts of some Goethite and Silimanite. There was also a diffractogram of Silicon Carbide or Carborundum samples.

4.2 Grain size distribution on Malvern

The grain size distribution of all the six abrasive powder samples was determined in a Malvern laser apparatus and the results are presented in a theoretical mesh size distribution in μm .

These results are shown in the figure 1.

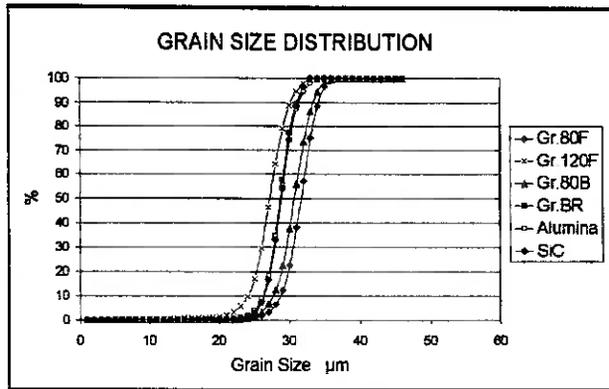


Figure 1. Grain size distribution of the six kinds of abrasive.

4.3 Particle shape characterization

The shape characteristics of the various abrasive grains was determined according to a method suggested by Ayres da Silva & Hennies (1983), presented at the 6th International Rock Mechanics Congress of Melbourne, Australia.

The results of this determination on the six studied kind of abrasives are presented at table 1.

The results of this determination on the six abrasive samples are displayed at table 1.

Table 1 Results of the particle shape characterization

Abrasive	value
Aluminium oxide 80#	0.38
Silicon Carbide 80#	0.35
Flow garnet 80#	0.55
Flow garnet 120#	0.48
Omax garnet 80#	0.62
Brazilian garnet	0.73

4.4 Chemical analysis

The chemical analysis of the abrasives were also performed at the Technological Characterisation Laboratory of EPUSP.

The results of these test are shown in table 2.

These data provide a chemical composition of the abrasive and identify the minerals of the natural abrasives or garnets.

4.5 Hardness of abrasive grain

Polished slices were prepared for Vickers micro-hardness determination and then submitted to an indentation test with a tetragonal prism of diamond.

The Vickers hardness values were then correlated to Knoop hardness. The results of these tests are shown in table 3.

4.6 Density of abrasives

Finally, the determination of density of the abrasives was performed according to standard procedures de-

scribed in the literature. The results are presented in table 4.

Table 2. Chemical analysis of the abrasives

Abrasive	Al2O3	SiC	FIG80	FIG120	OG80	BFG
SiO2	3.44	98.5	20.7	20.0	21.7	28.3
TiO2	8.61	0.02	0.25	0.24	0.81	3.44
MnO2	0.30	---	2.81	3.00	1.38	1.17
Al2O3	82.1	0.12	8.38	7.96	8.09	13.9
Fe2O3	0.56	0.15	64.3	65.7	54.8	35.3
CaO	0.67	0.21	1.52	1.47	9.99	1.79
MgO	---	---	0.47	0.44	1.84	3.41
Na2O	0.20	0.05	---	---	---	---
K2O	0.48	---	0.31	0.14	0.06	0.06
P2O5	1.90	0.89	0.74	0.68	0.97	1.88
SO3	0.65	tr.	---	---	0.25	0.06
V2O5	---	0.03	---	---	---	---
ZnO	---	---	0.19	0.12	0.04	0.08
Y2O3	---	---	0.27	0.17	---	0.31
ZrO2	0.59	---	---	---	---	4.02
CeO2	0.49	---	---	---	---	3.36

Table 3 Results of the hardness of the abrasives

Abrasive	Vicker hardness	Knoop hardness
Aluminium oxide 80#	274	2,100
Silicon Carbide 80#	323	2,480
Flow garnet 80#	172	1,320
Flow garnet 120#	170	1,310
Omax garnet 80#	177	1,360
Brazilian garnet	175	1,340

Table 4. Results of the the specific gravity of the abrasives.

Abrasive	Specific gravity (g/cm ³)
Aluminium oxide 80#	3.98
Silicon Carbide 80#	3.19
Flow garnet 80#	4.12
Flow garnet 120#	4.11
Omax garnet 80#	4.08
Brazilian garnet	4.04



Figure 2. The grains of 80# Flow garnet.

4.7 Scan of the abrasive grains

Figures 2 to 7 display photo of the abrasives.

In figure 2 we can see the shape roundness and other details of the 80# Flow garnet in a 200 times magnification. Figure 3 corresponds to 400 times magnification of 120# Flow garnet.

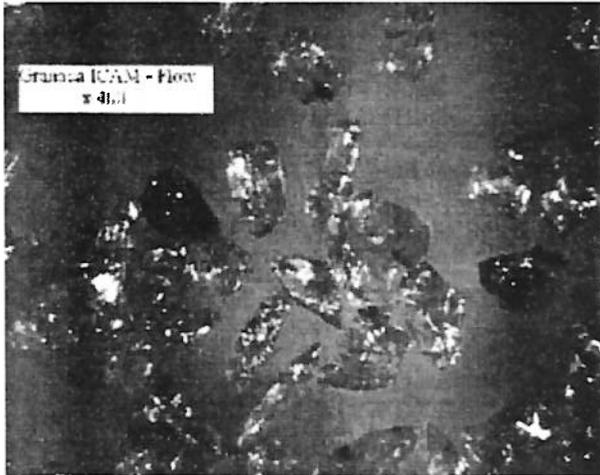


Figure 3. The grains of 120# Flow garnet.



Figure 4. The grains of 80# Barton garnet.

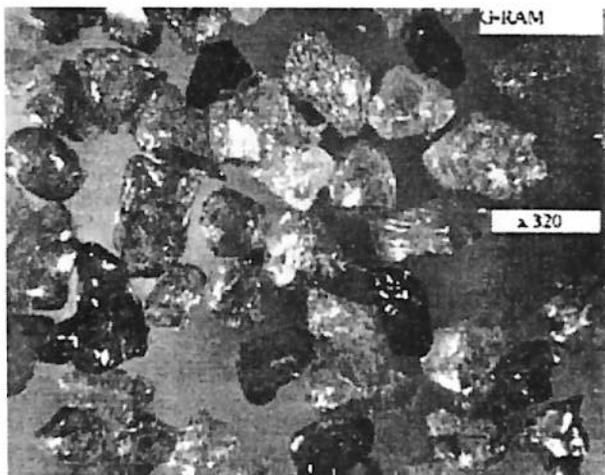


Figure 5. The grains of the Brazilian garnet.

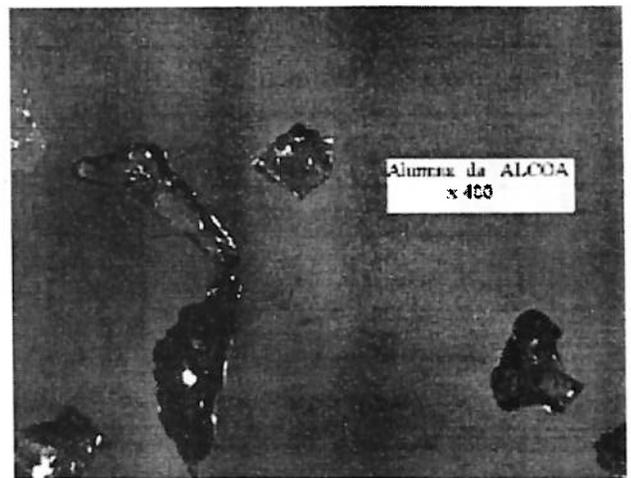


Figure 6. The grains of 80# Alcoa Aluminium oxide.



Figure 7. The grains of 80# Alcoa Silicon carbide.

In figure 4 the grains 80# Barton garnet used by OMAX is presented at 200 times magnification.

Finally, figure 5 corresponds to the Brazilian garnet in 320 magnification, and figures 6 and 7 to artificial abrasives from Alcoa amplified at 400 times magnification (Aluminium oxide and Silicon carbide samples).

5 MAIN CONCLUSIONS

There are two conclusions from this work as follows:

- 1 The Brazilian garnet demonstrates potential characteristics for use in water jet systems. A significant quantity must be prepared for actual testing with the system.
- 2 The initial tentative to use synthetic abrasive led to some troubles with the grain size and shape. Carefully examination and improvement of the feeding system are required before scheduling new tests.

REFERENCES

- Agus, M.;Bortulussi A.; Ciccu, R. et al. 1995 Abrasive performance in rock cutting with AWJ and ASJ. In Labus T.J. (ed) 1995 *Proc. 8th Amer. Water Jet Conf.*, Water Jet Techn. Ass. St. Louis, pp. 31-48.
- Agus, M.;Bortulussi A.; Ciccu, R. et al. 1996 Abrasive-rock interaction in AWJ cutting. In Gee C. (ed) 1996 *Jetting Technol. Mechan. Engng. Publ. London*, pp. 509-20.
- Ayres da Silva, L. A. e W. T. Hennies 1983 A New Method for Particle shape determination. *Proceedings: International Congress on Rock Mechanics*, 6th. p 245-50. Melbourne, Australia.
- Lauand, C.T.; Martin C., G.R.; Hennies, W. T.; Ciccu, R. 2000 The Brazilian Program of High Pressure Water Jet to Cut Ornamental Rocks. In: SWEMP, 6., Calgary, 2000. *Proceedings*. Calgary, 2000. p. 711-16.

PROCEEDINGS OF THE NINTH INTERNATIONAL SYMPOSIUM ON MINE PLANNING
AND EQUIPMENT SELECTION/ATHENS/GREECE/6-9 NOVEMBER 2000

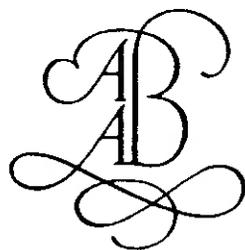
Mine Planning and Equipment Selection 2000

Edited by

G.N. Panagiotou & T.N. Michalakopoulos

National Technical University of Athens, Greece

OFFPRINT



A.A. BALKEMA/ROTTERDAM/BROOKFIELD/2000