EVALUATION OF EROSION PERFORMANCE OF ABRASIVE PARTICLES IN ABRASIVE WATER JET CUTTING PROCESS

PETR HLAVACEK, LIBOR SITEK, JOSEF FOLDYNA

Institute of Geonics of the Czech Academy of Sciences, Ostrava,
Czech Republic

DOI : 10.17973/MMSJ.2020_03_2019140

e-mai: petr.hlavacek@ugn.cas.cz

Abrasives are an integral part of the abrasive water jet (AWJ) technology and have a significant impact on the efficiency and economy of the cutting process. The abrasive particles are accelerated by the water jet and transported to the point of their interaction with the cut material. There are many factors influencing the determination of the abrasive type to be used in the AWJ process.

In this study, series of experiments were performed with the aim to evaluate the erosion performance of abrasive particles in an abrasive water jet cutting process. Three types of abrasives were used in the process of cutting of several types of materials by the abrasive water jet. The wear of a focusing tube due to the action of abrasive particles during their acceleration was also evaluated. The paper presents a methodology for evaluation of abrasives with respect to their use in the abrasive water jet cutting process.

KEYWORDS

abrasive water jet, erosion performance, focusing tube

1 INTRODUCTION

Only suitable abrasive material should be used for abrasive water jet (AWJ) machining. Various abrasive materials in required grain sizes are available on the market at different prices. Experience has shown that products of individual manufacturers can vary considerably. This is often caused by different composition of products, origin of mineral concentrates, insufficient separation of fine fractions, possible presence of defects in individual grains and the like.

2 MATERIALS AND METHODS

Three different types of abrasive materials were selected for testing: Norwegian olivine, Australian garnet and artificial corundum.

Olivine is a natural mineral with various proportions of forsterite (Mg_2SiO_4) and fayalite (Fe_2SiO_4) components. Forsterite-rich olivine is commonly used in metallurgy as moulding sand. It can also be used as an abrasive in the AWJ cutting and blasting [Martinec 2002b]. Fig. 1 shows the used Norwegian olivine.

Figure 1. Grains of Norwegian olivine (mean grain size of 208 μm)

Australian garnet is a natural mineral with main proportions of almandine ($Fe^{2+}{}_3Al_2[SiO_4]_3$) and pyrope ($Mg_3Al_2[SiO_4]_3$). Almandine is an iron-aluminum garnet and pyrope is a magnesium-aluminum garnet. Pure forms of almandine and pyrope are rare in nature and most specimens are compositions of both minerals. Industrial abrasive made from almandine garnet is the prevalent abrasive material used in the AWJ cutting [Martinec 2002a]. Fig. 2 shows the Australian garnet used in our experiments.

Figure 2. Grains of Australian garnet (mean grain size of 288 μm)

Corundum (Al_2O_3) is the second hardest mineral on the Mohs hardness scale. Corundum is produced by melting bauxite (alumina) at a temperature higher than 1800 °C and its subsequent slow cooling. It is taken out of the furnace in a rough state. Then, it is crushed and sorted according to the grain size. Due to its hardness, corundum is used in the abrasive industry for production of grinding wheels. The wheels can grind all other minerals except diamond. In addition, corundum is an important material in the surface treatment industry. It is used as an abrasive for blasting. In the AWJ technology, it can be used, for example, for accelerated tests of the focusing tube wear [Nanduri 2000]. Fig. 3 shows the tested artificial corundum.

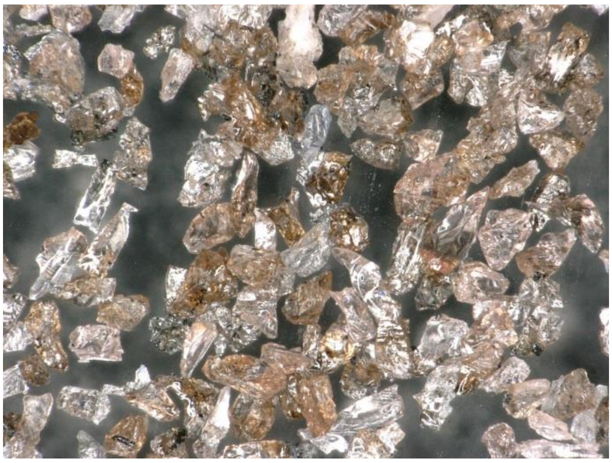

Figure 3. Grains of artificial brown corundum (mean grain size of 226 µm)

All tested abrasives were of 80 MESH grain size according to manufacturers´ specifications. Laser particle size analysis was used to determine the exact grain size distribution of tested abrasives. Results of the analysis are presented in Fig. 4.

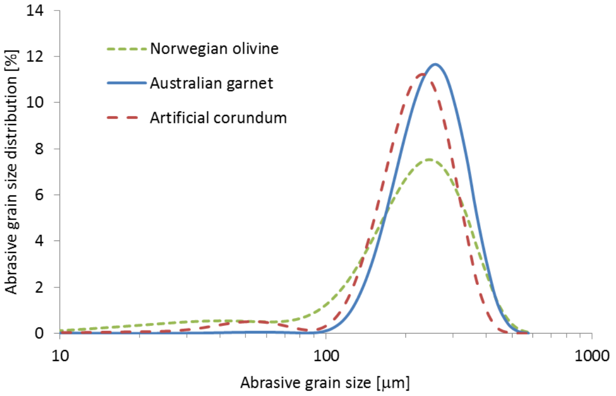

Figure 4. Grain size distribution curves of the used abrasive materials in a logarithmic scale. Abrasive grain size distributions were measured using the laser particle size analyzer Fritsch ANALYSETTE 22 NanoTec

It is shown that the peak of the grain size distribution curve of all abrasives is in the range from 200 to 300 µm (see Fig. 4). Norwegian olivine contains the largest proportion of fine fractions (below 100 µm). This is an undesirable property because it reduces the cutting performance. On the other hand, Australian garnet contains virtually no particles below 100 µm. Tab. 1 provides basic information on the abrasive materials used.

Type of abrasives	Mean grain size [µm]	Mohs hardness [-]	Specific density [g·cm^{-3}]
Norwegian olivine	208 ± 95	7.5	3.23
Australian garnet	288 ± 68	7.5	4.1
Artificial corundum	226 ± 63	9	4.05

Table 1. Basic properties of the used abrasive materials

Based on previous experience, we know that the cutting performance of abrasives varies considerably when cutting materials of various hardness. Therefore, three types of materials with different hardness were selected in the presented experiments. Cutting performance of the tested abrasives was determined using the following materials: stainless steel AISI 304, aluminum alloy EN AW 6060 and corundum ceramics with 92% of Al_2O_3.

3 TESTING OF CUTTING PERFORMANCE OF ABRASIVES

The test procedure consists of creating non-through cuts in the selected materials and evaluating their weight loss. The cutting performance of the tested abrasive is then expressed as a percentage of the cutting performance of the reference abrasive. Australian garnet was chosen as the reference abrasive for its high purity and stable properties.

Tests were performed using a commercially available “Slice I” (DTI) cutting head for the abrasive water jet generation. The traversing velocity for stainless steel and aluminum alloy was 800 mm·min^{-1} and 200 mm·min^{-1} for corundum ceramics. All other cutting parameters were constant during experiments: water pressure of 400 MPa, nozzle diameter of 0.33 mm, focusing tube diameter of 1.02 mm, focusing tube length of 76.2 mm, stand-off distance of 2 mm, abrasive mass flow rate of 400 g·min^{-1}. The relative cutting performance C_P was calculated using the following formula:

$$C_P=(\Delta m/\Delta m_{ref})\cdot 100\ [\%] \qquad (1)$$

where Δm is the weight loss of cut material caused by the tested abrasive, Δm_{ref} is the weight loss of cut material caused by the reference abrasive.

4 WEAR OF FOCUSING TUBE

Focusing tube wear is a complex phenomenon influenced by the AWJ system parameters, and nozzle geometric and material parameters [Nanduri 2002]. One of the most imortant parameter is a type of used abrasive. Certain types of abrasives may not be suitable for the abrasive water jet cutting due to their significant wearing effects on the focusing tube.

Several methods can be used to evaluate the focusing tube wear. The most commonly used method is the measurement of the output diameter of the focusing tube over time [Prijatelj 2017]. However, the disadvantage of this method is the time consumption of the test because the output diameter of the focusing tube usually changes after several hours of its use. Another frequently applied method is based on monitoring the weight loss of the focusing tube over time [Foldyna 2000]. This method was chosen for our experiments. Using very accurate analytical weights, it is possible to evaluate the weight loss of the focusing tube after only a few minutes of use. To compare the effects of a particular abrasive material on the focusing tube, the wear rate of the focusing tube w was defined as:

$$w = (w_0 - w_1) / t\ [\mathrm{mg\cdot min^{-1}}] \qquad (2)$$

where w_0 is the initial weight of the focusing tube in mg, w_1 is the final weight of the focusing tube in mg, t is the duration of experiment in min.

The focusing tube wear was tested under standard operating conditions: water pressure of 400 MPa, nozzle diameter of 0.33 mm, focusing tube diameter of 1.02 mm, focusing tube length of 76.2 mm and abrasive mass flow rate of 400 g·min^{-1}. Tests were performed using two commercially available focusing tubes made by various manufacturers, marked as the focusing tube I and II. The short term wear test of focusing tubes lasted

15 minutes for Norwegian olivine and Australian garnet and 5 minutes for artificial corundum.

The lifetime of the focusing tube can be predicted from the wear rate of the focusing tube. The criterion of the focusing tube wear was determined as 5 % loss of its initial weight. The focusing tube lifetime T_l can be calculated using the following formula:

$$T_l = m_{5\%}/(60 \cdot w) \text{ [hour]} \tag{3}$$

where $m_{5\%}$ is 5% of the weight of a new focusing tube in mg (for the focusing tubes used in our experiment it is approximately 2000 mg).

5 RESULTS AND DISCUSSION

The relative cutting performances of Norwegian olivine, Australian garnet and artificial corundum in stainless steel AISI 304, aluminum alloy EN AW 6060 and corundum ceramics under above specified testing conditions are shown in Fig. 5.

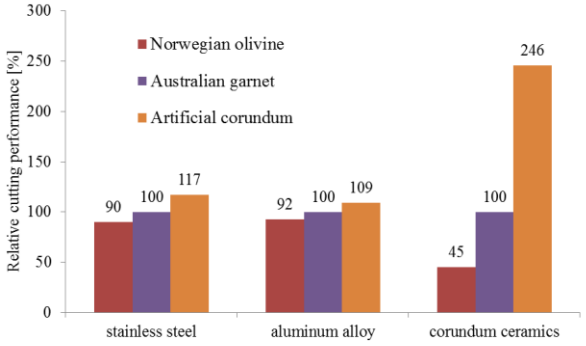

Figure 5. Comparison of the relative cutting performances of three tested abrasives in stainless steel, aluminum alloy and corundum ceramic.

The smallest differences in the relative cutting performance were found when cutting aluminum alloy (less than 10 % for all tested abrasives). The highest differences were found in corundum ceramics, where the relative cutting performance of olivine was about 55% lower compared to the cutting performance of Australian garnet. On the other hand, the relative cutting performance of artificial corundum represented 246% of the cutting performance of the reference abrasive.

Significant differences in the relative cutting performance of individual abrasives examined during disintegration of testing materials show that the type of abrasives used has a vital effect on the overall efficiency of the abrasive water jet technology. This fact should be considered when using the technology not only in industrial applications (cutting, machining, removal of degraded concrete layers), but also in further technological development and research activities where the abrasive water jets are used for simulation of real situations (e.g. modeling of the surface resistance of concrete layers against fast flowing liquids) [Sitek 2018].

Type of abrasives	Lifetime of focusing tube I [hour]	Lifetime of focusing tube II [hour]
Norwegian olivine	667	416
Australian garnet	83	68
Artificial corundum	0.97	0.75

Table 2. **Prediction of the focusing tube lifetime**

It was found that the predicted lifetime of the focusing tube I was longer than the predicted lifetime of the focusing tube II for all three tested abrasives. The predicted lifetime of focusing tubes differs by 22 to 60 %.

6 CONCLUSIONS

It is clear from the presented results that the issue of the abrasive material evaluation for the AWJ technology must be dealt with comprehensively. It is not possible to select abrasive materials only according to price. It is important to assess the cutting performance of abrasives in relation to the material to be machined because the differences can be significant. The wear of the focusing tube is also an important parameter. Artificial corundum demonstrates the highest cutting performance of the three tested abrasives. However, this abrasive causes the fastest wear of the focusing tube which is more than 85 times higher than in the case of Australian garnet. Due to this results and high price, the use of artificial corundum is uneconomical in most cases. The cutting performance of Norwegian olivine is considered the worst. However, this abrasive material causes the slowest wear of the focusing tube (6 to 8 times slower than the reference abrasive according to the focusing tube type). Due to lower price, it can be used for cutting softer materials such as aluminum alloys or other metals. For this type of materials, the cutting performance of Norwegian olivine is only about 10% lower.

ACKNOWLEDGMENTS

This work was supported by grant of the Technology Agency of the Czech Republic (TH04020218), by grant of the Czech Science Foundation (18-25035S), by project of the Institute of Clean Technologies for Mining and the Utilization of Raw Materials for Energy Use – Sustainability program, reg. no. LO1406 financed by the Ministry of Education, Youth and Sports of the Czech Republic and by institutional budget RVO 68145535. The authors are very thankful for the support.

REFERENCES

[Foldyna 2000] Foldyna, J., Martinec, P., and Sitek, L. Testing of industrial types of abrasives for abrasive water jet cutting. Proceedings of the 6th pacific rim international conference on water jet technology, 2000, pp. 143-147

[Martinec 2002a] Martinec, P., Foldyna, J., Sitek, L., Scucka, J. and Vasek, J. Abrasives for AWJ cutting. INCO – COPERNICUS No. IC 15-CT98-0821. Institute of Geonics, Ostrava, 2002, ISBN 80-86407-02-0

[Martinec 2002b] Martinec, P., Foldyna, J., Sitek, L. and Bilkova, L. Olivine as industrial arasive for high-speed water jet technology. 16th International Conference on Waterj Jetting Aix-en-Provence, 2002, pp. 287-297

[Nanduri 2000] Nanduri, M., Taggart, D.G. and Kim, J.T. A Study of Nozzle Wear in Abrasive Entrained Water Jetting Environment. Journal of Tribology, 2000, Vol. 122, pp. 465-471.

[Nanduri 2002] Nanduri, M., Taggart, D.G. and Kim, J.T. The effects of system and geometric parameters on abrasive water jet nozzle wear. International Journal of Machine Tools and Manufacture, 2002, Vol. 42, pp. 615-623.

[Prijatelj 2017] Prijatelj, M., Jerman, M., Orbanic, H., Sabotin, I., Valentincic, J., and Lebar, A. Determining focusing nozzle wear by measuring AWJ diameter. Journal of Mechanical Engineering, 2017, pp. 597-605.

[Sitek 2018] Sitek, L., Hlavacek, P. and Bodnarova L. Use of high-speed water flows for accelerated mechanical modelling of erosive wear of concrete surfaces. 3rd Innovative Technologies in Engineering Production, 2018, article number 02007

CONTACTS:

Ing. Petr Hlavacek, Ph.D
Institute of Geonics of the Czech Academy of Sciences,
Studentská 1768, Ostrava, 70800, Czech Republic
+420 596 979 312, petr.hlavacek@ugn.cas.cz, websites www.ugn.cas.cz