Abrasive Water-Jet Technology Waste and Its Processing Possibilities

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Abstract

The paper is dealing with the environmental research of waste material rising from abrasive water-jet cutting. On the occasion of disposal of the slurry from the overfull collector tank in the Laboratory of the Liquid jet of the Department of Physics at the Technical University of Ostrava the waste material was studied. Samples from different points of the catcher were collected into the beaks, dried up and consequently their elemental and structural composition has been analyzed. The results were primarily evaluated from the viewpoint of effectiveness of further abrasive recycling and usage (either as an abrasive - for this reason the residual cutting ability of the grains was discussed, or as a fine powder material for other applications – the size and shape of the grains was considered). Second viewpoint which was discussed was potential environmental hazard arising from the normal disposal of the waste material. The analysis of dried slurry samples was carried on by electron microprobe. Twenty one samples of waste mixture from various parts and depths of the tank were analyzed and compared with samples of non-used abrasive material. It was proved that abrasive material which had undergone the process of cutting was significantly impaired. It should be recycled in some cases but careful economic calculation taking into account all additional costs connected with separation of suitable abrasive fraction and its drying should be necessary.

X-rays analysis provided information about chemical composition of the waste material. Most of the sludge was from abrasives, namely almandine. Higher contents of magnesium oxide, lower contents of aluminum oxide and higher contents of iron oxide, however, was probably caused by presence of other abrasive materials, such as olivine or zirconium which had been also used for cutting during the working period of the system. No potentially harmful material was detected by the X-ray analysis. It can be therefore stated that waste material from the water-jet cutting can be disposed on a common landfill without any restrictions.

Keywords: high-energy water jet, abrasive water jet, abrasive material, recycling, separation

Introduction

High pressure liquid jet represents one of the common cutting technologies, which is, due to its unique attributes, often used in many sectors of human activity, both in industry and research. While the pure water jet can be used in the processing of soft materials, dealing with harder materials it is necessary to increase the abrasive effect of water by adding small particles called abrasives. Wide range of materials can be used as abrasive, from ice crystals (Shishkin, 2005), salt, sugar (Pude, 2003), to various minerals (Hlaváč, 1998), depending on the application. In industrial applications, both outdoor and indoor ones, garnets (Fig. 1) from various resources are used most often, namely due to its low price and relatively easy accessibility. At the research departments, such as the Laboratory of the Liquid Jet of the Department of Physics at the FMG Technical University of Ostrava extensive research with other abrasives is being executed, such as the research of cutting effectivity of olivine, corundum, chromite and zircon in the years 2012–2013 (Geryk, 2013).

In the indoor applications the used mixture of water and abrasive is captured in the water catcher, which is placed under the cut material. The catcher represents the equipment serving to absorb residual water and abrasive energy, for this purpose water tank is used most often today.

In abrasive water jet cutting the most commonly used abrasive mass flow rate is around 200 g per minute, so the consumption of abrasive is quite significant and the abrasive costs constitutes abound 50% of operating costs. Abrasive, unlike water that passes through a multistage cascade of sedimentation tanks into the sewer, in most cases settles in the catcher and sooner or later it does limit its functionality.

Therefore, some suppliers of the liquid jet technology offer also abrasive recycling equipment (Recyklace abraziva. PTV [online]. 2006

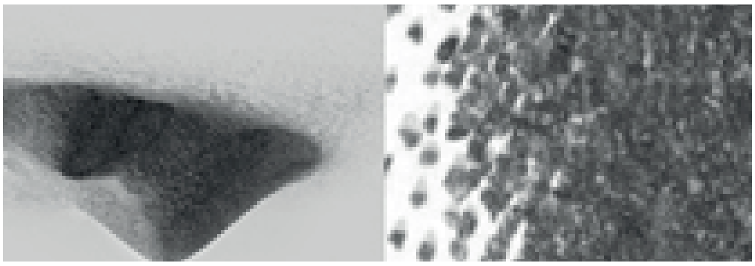

Fig. 1. a) samples of abrasive on carbon ribbon; b) abrasive embedded into resin (polished sections)

Rys. 1. a) próbki materiału ściernego na tasmie węglowej; b) materiał ścierny w zywicy (szlif)

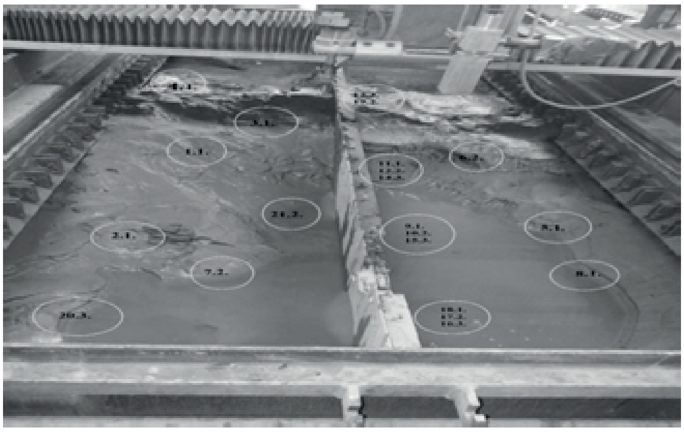

Fig. 2. Sampling scheme; first number indicates the sample ranking and second the sample depth

Rys. 2. Schemat opróbowania; pierwsza cyfra oznacza pozycje próbki, druga głębokość

Fig. 3. left) samples of abrasive on carbon ribbon; right) abrasive embedded into resin (polished sections)

Rys. 3. Lewa) próbka materiału ściernego na taśmie węglowej; prawa) materiał ścierny w żywicy (szlif)

[cit. 2015-20-03]. Available at: http://www.ptv.cz/abraziva/index.html), however, users do not look for such equipment; also in the literature it is impossible to find serious information about their placement in a larger scale. No reports about the sludge disposal methods are available it is possible that the waste is automatically considered as harmless.

Waste processing in Laboratory of the Liquid Jet

In summer 2013 the condition of collector tank in the Laboratory of the Liquid Jet matured to necessity to solve disposal of used abrasives. On this occasion, samples of sludge were taken from pumped tank and consequently their elemental and structural composition has been analyzed. The results were evaluated from the viewpoint of effectiveness of further abrasive recycling and usage (either as abrasive or as a fine powder material for other applications) and from the viewpoint of potential environmental hazard rising from the waste removal to a landfill.

The research began by pumping the water out of the tank and consequent sampling, see Fig. 2.

Twenty one samples of waste mixture from various parts and depths of the tank were collected into the beaks and dried up. Dried abrasive was fixed on carbon tapes (see Fig. 3 left) and analyzed in vacuum at the Electron Microprobe Laboratory. The samples of unused abrasive needed to be evaluated from polished sections (see Fig. 4) since they have contained grains with too different heights (see Fig. 3 right).

Tab. 1. Comparison of the abrasive chemical composition

Tab. 1. Skład chemicznego materiału ściernego

chemical composition	sample no.3	sample no. 4	mean value	**almandine** composition [%]	difference
Na_2O	0.27	0.37	0.32		0.32
MgO	11.70	10.20	10.95	6.00	4.95
Al_2O_3	11.61	12.27	11.93	20.00	-8.07
SiO_2	35.09	34.82	34.96	36.00	-1.04
CaO	3.31	3.01	3.16	2.00	1.16
TiO_2	2.01	1.74	1.88	1.00	1.88
Cr_2O_3	0.40	0.40	0.40		0.40
MnO	1.26	1.20	1.23	1.00	0.23
FeO	33.55	35.98	34.765	30.00	4.77
ZrO_2	0.85		0.85		0.85
Fe_2O_3				2.00	-2.00

Tab. 2. Element analysis

Tab. 2. Analiza składu chemicznego

Element	O	Fe	Si	Al	Mg	Ca	Ti	Mn	Cr	Zr	Na	P
Average At %	61.6	13.1	11.2	7.6	3.0	1.4	0.9	0.4	0.3	0.2	0.2	0.2
Average Wt %	39.8	29.9	12.5	8.5	3.1	2.1	1.6	0.7	0.6	0.7	0.2	0.2

Sample analysis was executed on a scanning electron microscope FEI QUANTA 650 FEG by standard measuring procedures (Reed, 2005). The equipment enables to carry out local analysis of percentage ratio of individual elements in a sample, evaluation of total element contents of researched sample and analysis of percentage ratio of individual oxides. The oxides analysis program was used on two samples in order to compare probable chemical contents with chemical contents of abrasive stated by supplier.

Results and discussion

The aim of sludge element analysis was to answer a question if it includes some materials hazardous for the environment both from the used abrasive and the cut material. The mass concentration analysis of individual oxides was performed on two samples, the mean value was calculated, and was rounded to the nearest whole percentage and it was consequently compared with the chemical contents stated by the supplier, see Table 1.

From the last column of Table 1 it is evident that most of the sludge is from abrasive, namely almandine. Higher contents of magnesium oxide, lower contents of aluminum oxide and higher contents of iron oxide suggest that other abrasive materials, such as olivine had been used for cutting. Zirconium is also found in the tank due to the executed cutting experiments with zirconium.

Higher portion of calcium oxide is probably caused by the presence of residues of cut rocks or other materials the same reason has also the presence of titanium and chromium (it can be found in stainless steel). The absence of ferric oxide is probably only ostensible since the software instruments evaluated all the iron present as ferrous oxide. Although the iron forms a considerable part of the waste it is not present in a form which would allow the magnetic separation.

All samples were evaluated by weight and the atomic concentration of each element. Average values are summarized in Table 2, the first line shows average atomic (molar) concentration and the second line shows average mass concentration.

Contents of oxygen and silicon, same as with iron and aluminum corresponds to the expectations, since almandine which is used most often as abrasive, has chemical composition $Fe^{2+}{}_3Al_2$

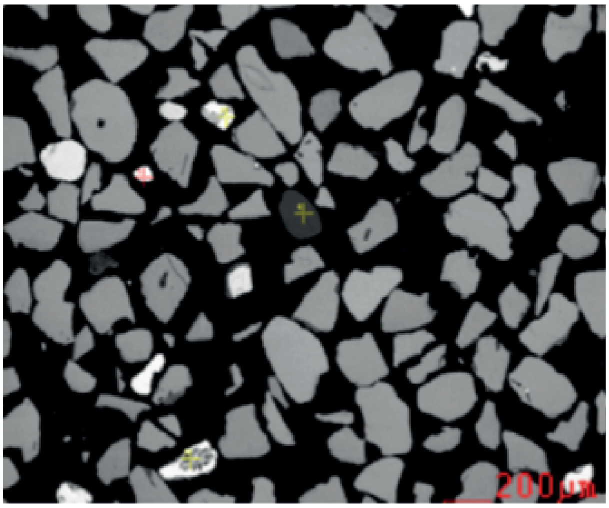

Fig. 4. Unused abrasive

Rys. 4. Nieuzywany materiał ścierny

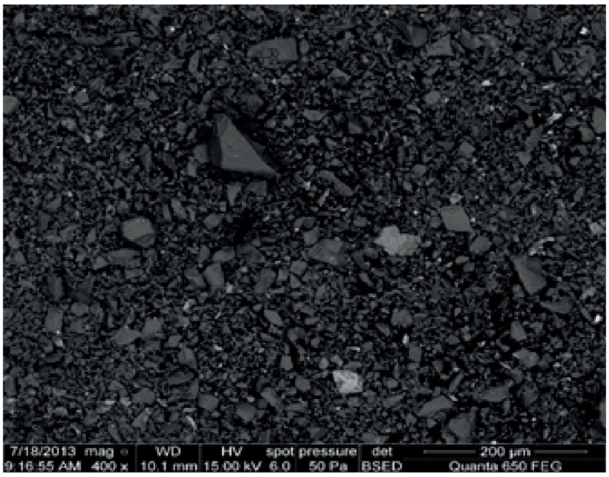

Fig. 5. Sample no. 1

Rys. 5. Próbka nr 1

$[SiO_4]_3$. Also other elements are found in the sludge predominantly in the form of oxides.

The explanation of the presence of individual elements can be summarized as following:

Iron 29.9% – an essential part of most used abrasives, mostly cut material, silicon 12.4%, aluminum 8.5%, 3.1% magnesium, calcium, 2.1% and 1.6% titanium. During the spot analysis other elements: manganese, zirconium, chromium, sodium and phosphorus were also found in some samples. In the total sample evaluation, however, their presence was negligible (below 1%), an individual grain of non-common material was therefore probably involved in these results.

Morphological analysis of sludge was carried out by evaluating pictures from electron microscope. Individual samples differed significantly according to which part of the tank they have settled in. In the evaluation it was necessary to take into consideration at what enlargement the picture had been taken.

Figure 5 – enlarged 400 times – contains larger grains around 50 µm, rarely up to 200 µm.

A significant proportion of the sample is formed by dust component, which cannot be recycled. After removing the dust it would be possible to use this type of waste for recycling, however the question remains what should be the economic advantage of such procedure.

Figure 6 – enlarged 308 times – contains larger grains with dimensions around 100–150 µm.

The sample seems to be appropriate for recycling if it is possible to separate the dust components from larger grains. Due to high material adhesion this will not be an easy task.

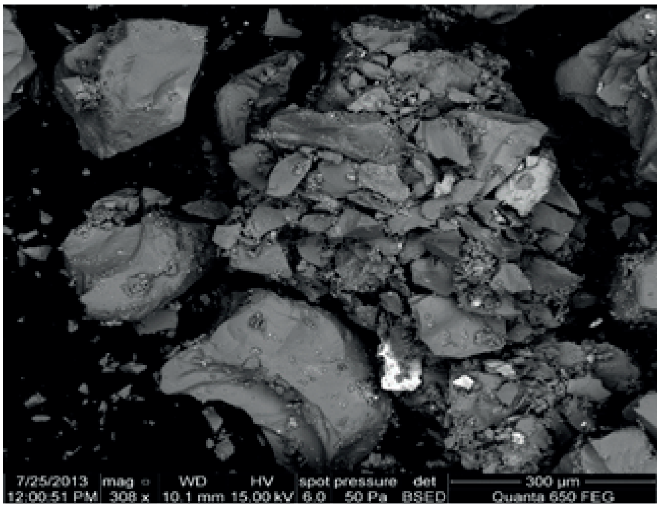

Fig. 6. Sample no. 10

Rys. 6. Próbka nr 10

Acknowledgements

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Conclusion

The analysis of waste material chemical contents executed by X-ray did not prove the occurrence of elements with harmful attributes that could negatively influence environment or human health. The waste can be, without other limitation taken to the landfill.

Electron micrographs showed that grains of used abrasive have neither the same size nor shape. In the comparison with unused abrasive it was found that the abrasive grains having passed through the cutting process are not as strong as new abrasive. Moreover, used abrasive also contains significant volume of soft particles, which are completely unsuitable for recycling. Grains smaller than 90 µm should not be recycled. This part of waste must be completely removed before possible recycling; however, reduced strength of remaining grains can lead to increased consumption of recycled abrasive in comparison with a new abrasive. When considering possible abrasive recycling it is also necessary to consider the fact that in abrasive recycling, namely in the drying process, increased consumption of water and energy is involved.

On the contrary, the utilization of abrasives in other technologies, such as construction, could be promising. Handling this material proved that it is a very soft adhesive material therefore it could be used in combination with a suitable binding material.

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Technologia obróbki Water-Jet i możliwości jej zastosowania

Praca traktuje o badaniu środowiskowym odpadów powstałych po cięciu strumieniem wodno-ściernym (water-jet). Materiał przebadano przy okazji czyszczenia zawiesiny z przepełnionego zbiornika kolektora w laboratrium prowadzącym badania nad ciekłym strumieniem na Uniwersytecie Technicznym w Ostrawie. Próbki zostały pobrane z różnych punktów zbiornika do zlewek i osuszone. Następnie przeanalizowano ich skład pierwiastkowy i strukturalny. Wyniki przede wszystkim były oceniane pod kątem skuteczności dalszego recyklingu i użytku odpadów ściernych (zarówno jako materiał ścierny – z tego powodu badano zdolności tnące resztek ziaren oraz inne zastosowania tego materiału w postaci drobnego proszku, brano pod uwagę wielkość i kształt ziaren). Drugim aspektem badań było ryzyko środowiskowe wynikające z dotychczasowego sposobu usuwania odpadów.

Analizę próbek osuszonej zawiesiny dokonano przy użyciu mikrosondy elektronowej. Poddano analizie 21 próbek mieszaniny odpadów z różnych części i głębokości pojemnika i porównano je z próbkami niezużytego materiału. Wykazano, że materiał ścierny, który był użytu do procesu cięcia został znacząco zniszczony. W niektórych przypadkach powinien zostać poddany recyklingowi, jednakże nalezy przeprowadzić dokładne wyliczenia ekonomiczne uwzględniające dodatkowe koszty dotyczące separacji części materiału oraz osuszania. Analiza rentgenowska dostarczyła informacji na temat składu chemicznego odpadu. Większość osadu pochodziła z materiałów ściernych, dokładniej almandynu. Niemniej jednak, zwiększone zawartości tlenku magnezu oraz tlenku żelaza i niższe zawartości tlenku glinu były prawdopodobnie spowodowane obecnością innych materiałów ściernych, tj. oliwinu czy cyrkonu, które również zostały wykorzystane do cięcia w czasie pracy. Analiza rentgenowska nie wykazała występowania żadnych potencjalnie niebeziecznych materiałów. Można zatem stwierdzić, ze odpady powstałe z cięcia strumieniem wodno-ściernym (watrer-jet) można składować na standardowym wysypisku bez żadnych ograniczeń.

Słowa kluczowe: water-jet wysokoenergetyczny, ścierny water-jet, materiał scierny, recykling, separacja