

# Disintegration and recycling possibility of selected abrasives for water jet cutting

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## Abstract

This paper presented a study of abrasive disintegration in a 400 MPa Abrasive Water Jet (AWJ). Abrasive particle size and distribution play a major role in machining and cutting efficiency of abrasive water jets. Tested garnet abrasive, commonly used in the abrasive water jet treatment, and corundum. It is of scientific interest to observe the disintegration of these particles which have been interactive with uncommonly used abrasive materials. Time impact of abrasive grains on the workpiece is very short and not all the grain in the stream of being able to do the work of cutting, you should expect the possibility of recovering the abrasive treatment. Considerable importance is the increase in cutting capacity crushed grains due to reveal new cutting edges. Based on a feasibility study this paper will present some results on achieved cutting data and shows also wear of the used focusing tube - the main part responsible for the formation of the jet.

*Keywords:* Abrasive; water jet; grain size; recycling.

# Valoración de la desintegración y reciclaje de los componentes abrasivos en procesos de cortes con agua

## Resumen

Este trabajo presentó un estudio de la desintegración abrasiva en un chorro de agua abrasivo de 400 MPa (AWJ). El tamaño y la distribución de partículas abrasivas juegan un papel importante en el mecanizado y la eficacia de corte de los chorros de agua abrasiva. Abrasivo de granate probado, comúnmente utilizado en el tratamiento con chorro de agua abrasivo y corindón. Es de interés científico observar la desintegración de estas partículas que han sido interactivas con materiales abrasivos poco comunes. El impacto del tiempo de los granos abrasivos en la pieza de trabajo es muy corto y no todo el grano en la corriente de poder hacer el trabajo de corte, debe esperar la posibilidad de recuperar el tratamiento abrasivo. Considerable importancia es el aumento en la capacidad de corte de granos triturados debido a revelar nuevos bordes de corte. Con base en un estudio de factibilidad, este documento presentará algunos resultados sobre los datos de corte obtenidos y muestra también el desgaste del tubo de enfoque utilizado, la principal parte responsable de la formación del chorro.

*Palabras clave:* Abrasivo; chorro de agua; tamaño de grano; reciclaje.

## 1. Introduction

Among the methods of machining special attention they deserve environmentally friendly. This is mainly plastic processing [8,9] and high pressure water jet technology [15].

Cutting by high-pressure water jet is one of advanced methods of materials machining. This technology has many advantages: wide range of options [18], including the processing of complex shapes, cutting of a large variety of materials [5,6,17], and high effectiveness under extreme conditions (hazard of

explosion or fire, underwater works up to a depth of 6000 m, etc.) and the environmental friendliness [7].

Treating materials using a high pressure abrasive water jet is more complex than conventional treatments. Therefore, optimization of the machining is the subject of many studies [4,14,21]. High pressure water is converted to a high speed jet inside a nozzle (Fig. 1a.) and flows out of the nozzle at a speed of several hundred meters per second, seizes abrasive particles and accelerates them to large kinetic energies.

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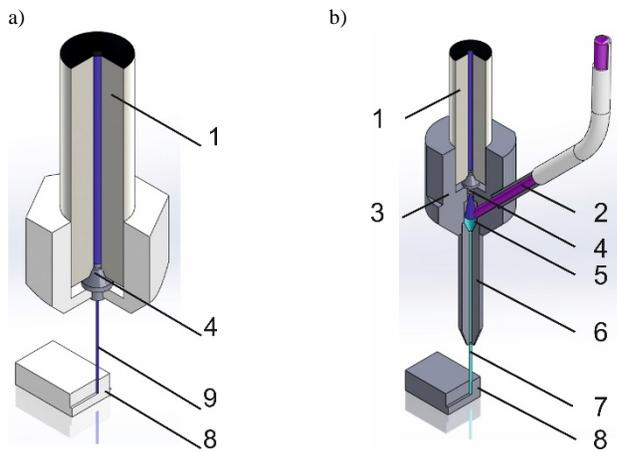


Figure 1. Schematic diagram of: a) Water Jet cutting; b) Abrasive Water Jet cutting: 1. High pressure water inlet, 2. Abrasive inlet, 3. Cutting head body, 4. Water nozzle, 5. Mixing chamber, 6. Focusing tube, 7. High Pressure Abrasive Water Jet, 8. Machining sample, 9. High Pressure Water Jet. Source: The author.

Adding to the water jet the dry abrasive in a special mixer injector (Fig. 1b), causes increase cutting efficiency. As a result, it becomes possible to almost any material cutting with low roughness of cutting surface [13,16,20]. The most commonly used pressure in the system, called AWJ, ranges from 400 to 600 MPa and common abrasive is garnet [2,11]. Its popularity in the processing stream as an abrasive garnet is caused by achieving high performance at relatively low wear focusing tube [3].

The cost of abrasive is the main cost of processing an abrasive water jet [15] therefore purposeful work aimed towards the use of the cheapest abrasive materials and their recycling.

The roughness of the cut surface is comparable with the surface of the rough grinding and reaches a value  $R_a$  equal 2  $\mu\text{m}$  [1,19].

## 2. Materials and methods

### 2.1. Abrasive materials

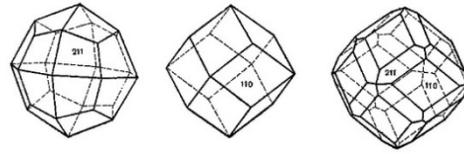
#### 2.1.1. Garnet

The study used GMA Garnet abrasives supplied by GMA Garnet Pty Ltd, Western Australia. Almandine is the iron aluminum garnet. Almandine, like other garnets, forms rounded crystals with 12 rhombic or 24 trapezoidal faces or combinations of these and some other forms. This crystal habit is classic for the garnet minerals. Almandine is the most common of the garnets but seldom occurs in specimens worthy of collections or fit for gems. Almandine is usually found either as rocks forming mineral in magmatic and metamorphic acid rocks (such as migmatites, garnet-biotite gneisses, granulites, micaschists, pegmatites, diorites, etc.) or as heavy mineral sand from weathered hard rocks, secondary concentrated in present-day and/or pre-existing streams and other alluvial deposits or in present-day and/or pre-existing

Table 1. Garnet (almandine) properties.

Crystal system	Cubic
Twinning	None
Unit cell	$a = 11.53 \text{ \AA}$
Habit	Crystals usually dodecahedrons or trapezohedrons; also in combination or with hexocathedron; massive; granular
Cleavage	1; $\{110\}$ parting sometimes distinct
Fracture	Conchoidal to uneven
Tenacity	Brittle
Color	Deep red to reddish-brown, sometimes with a violet or brown or brownish black hue
Hardness (Mohs)	6.5-7.5
Density	4.1-4.3

Source: Adapted from [10]



beaches and other shore line marine deposits. Only selected few localities are mentioned. Industrial abrasive made from garnet almandine is prevalent abrasive used in AWJ cutting. Degree of damage of big crystals of garnet almandine (porphyroblasts) in rocks (i.e. number of individual particles limited by cracks in one porphyroblast (crystal)) plays an important role in determination of suitability of the almandine for production of industrial abrasive concentrate for AWJ cutting [10].

The properties of abrasives and view of crystal shape are shown in Table 1.

#### 2.1.2. Corundum ( $\alpha\text{-Al}_2\text{O}_3$ )

Corundum is a very hard, tough, and stable mineral. It is the second hardest mineral after diamond. It is also unaffected by acids and most environments.

Natural corundum occurs as contact metamorphic rocks (emery) and precious stones (sapphire, ruby). Translucent brown corundum and emery are the most common forms of corundum. These are fairly common and when ground up, they are the most favorable abrasives. The industrial term "emery" describing corundum abrasives is derived from the variety emery, which is mined for abrasive use.

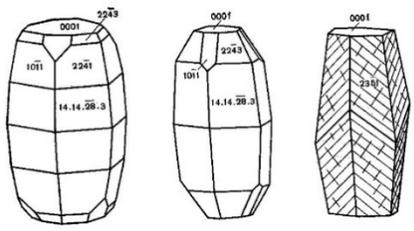
Corundum is easily synthesized, and many corundum abrasives are synthetic. Corundum abrasives are produced in various grades of purity and chemical composition.

Industrial abrasive products based on corundum are used mainly for air blasting and cleaning (cleaning of metals, paint removal, etc.). High level of focusing tube wear limits their usage in AWJ cutting. Corundum based abrasives are available at many grain size fractions with different mineralogical and chemical purity. Corundum is stable abrasive material with a good recycling possibility; it is relatively cheap in case that industrial corundum is used as secondary raw material (product of waste recycling).

For research was used white fused alumina supplied by LKAB Minerals. It is white in color, a dense mineral and has predominantly large crystals of alpha corundum.

The properties of abrasives and view of crystal shape are shown in Table 2.

Table 2.  
Corundum properties.

	
Crystal system	Hexagonal (Trigonal)
Twinning	Common on {10-11}, lamellar; rare on {0001}
Unit cell	$a = 4.76 \text{ \AA}$ ; $c = 12.99 \text{ \AA}$
Habit	Crystals often well-developed, steep-pyramidal, prismatic, tabular; barrel-shaped; massive
Cleavage	2; {0001} and {10-11} parting
Fracture	Uneven, conchoidal
Tenacity	Brittle
Color	Many colors, including blue, red, violet, pink, green, yellow, orange, gray, white, colorless, and black
Hardness (Mohs)	9
Density	4.0 – 4.1

Source: Adapted from [10]

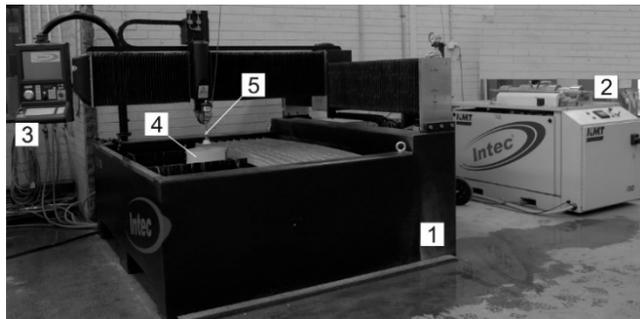


Figure 2. Testing rig: 1) Cutting table, 2) Intensifier, 3) Control Unit, 4) Catcher, 5) Cutting Head.  
Source: The author.

## 2.2. Focusing tubes

In research was used focusing tubes made from unique, patented materials that are literally changing the definition of wear resistance ROCTEC100. The ROCTEC process enables the combination of these advanced ceramic materials without the need for a soft metal binder, as is the case with tungsten carbide/cobalt using traditional sintering technology.

The ROCTEC process enables focusing tubes to be formed using very short consolidation cycles to minimize the natural tendency of ceramic particles to grow in size, when exposed to high heat for long periods. Eliminating a metallic binder and maintaining extra-fine grain size both contribute to optimum focusing tube performance. The result is an extremely durable material that fiercely resists abrasive and erosive wear.

## 2.3. Apparatus

The equipment used was a KMT Intensifier type I50, 2 axis CNC table type ILS55 by Techni Waterjet with computer control system (Fig. 2).

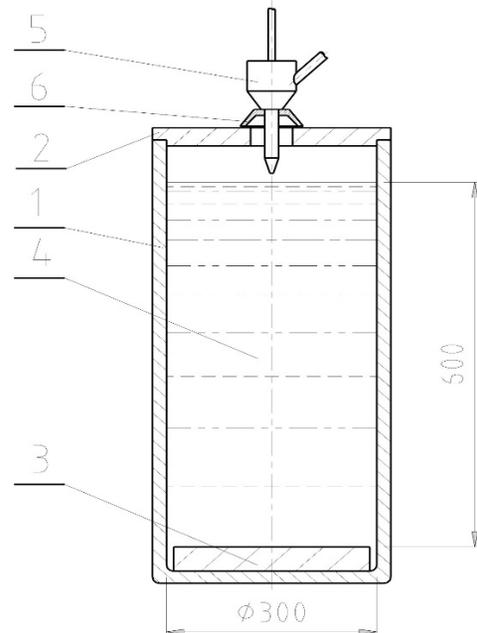


Figure 3. Catcher for abrasive jet: 1) Tank, 2) Tank Cap, 3) Mild Steel Shield, 4) Water, 5) Cutting Head, 6) Rubber Head Cap.  
Source: The author.

To capture abrasives after its exit from the focusing tube, a special receiver was used (Fig. 3). The receiver was designed to collect the abrasives and to prevent any further particle disintegration after leaving the focusing tube. The bottom PVC receiver was covered by a steel plate to prevent perforation. No signs of wear were observed on the protective plate after conclusion of testing [12].

For establishing the particle size distribution of the abrasive, Retsch sieving equipment was used and the mass of abrasive remaining on the sieves was weighed on the digital lab scales (Fig. 4).

Microscopic photos of abrasive particles were taken on a microscope Olympus SZ-40 equipped with a digital camera MD1800 Am Scope type with 8MB CCD



Figure 4. a) Retsch sieving equipment, b) digital lab scale  
Source: The author.

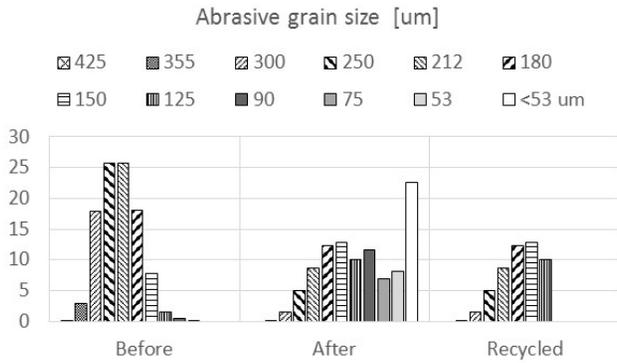


Figure 5. Disintegration of garnet after passing through cutting head with water nozzle ID 0.25 mm and focusing tube ID 0.76 mm. Pressure 390 MPa Source: The author.

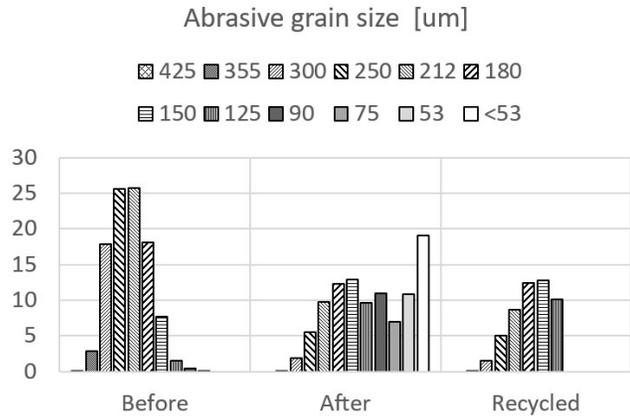


Figure 7. Disintegration of garnet after passing through cutting head with water nozzle ID 0.33 mm and focusing tube ID 1.02 mm. Pressure 390 MPa Source: The author.

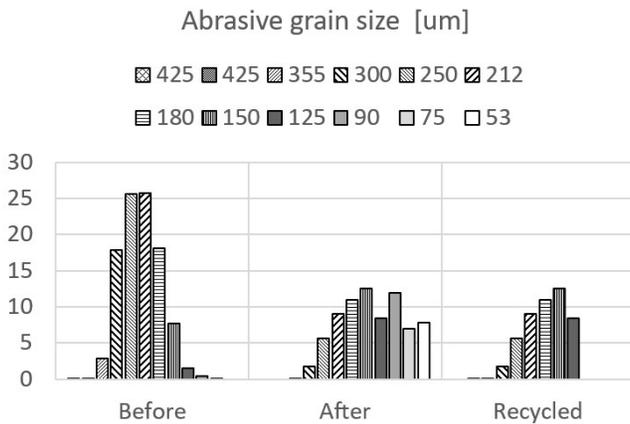


Figure 6. Disintegration of garnet after passing through cutting head with water nozzle ID 0.33 mm and focusing tube ID 0.76 mm. Pressure 390 MPa Source: The author.

#### 4. Tests results and discussion

##### 4.1. Abrasive grain disintegration

###### 4.1.1. Garnet

The results of the study of GMA80 abrasive fractured during formation of jets at a pressure of 390 MPa through a 0.25 mm orifice, 0.76 mm ID focusing tube and average of abrasive flow rate are shown in Fig. 5.

The largest fraction (almost 25%) was smaller than 53  $\mu\text{m}$ . Overall a significant particle size decrease was observed. Abrasive mass flow rate (concentration of abrasive in the stream) had almost no impact on particle fragmentation [11].

The results of disintegration of GMA80 abrasive at a pressure of 390 MPa and 0.33 mm orifice, 0.76 mm ID focusing tube and average of abrasive flow rate are shown in Fig. 6.

The largest fraction (almost 13%) was equal 150  $\mu\text{m}$ . Overall a significant particle size decrease was observed. Abrasive mass flow rate (concentration of abrasive in the stream) had also almost no impact on particle fragmentation.

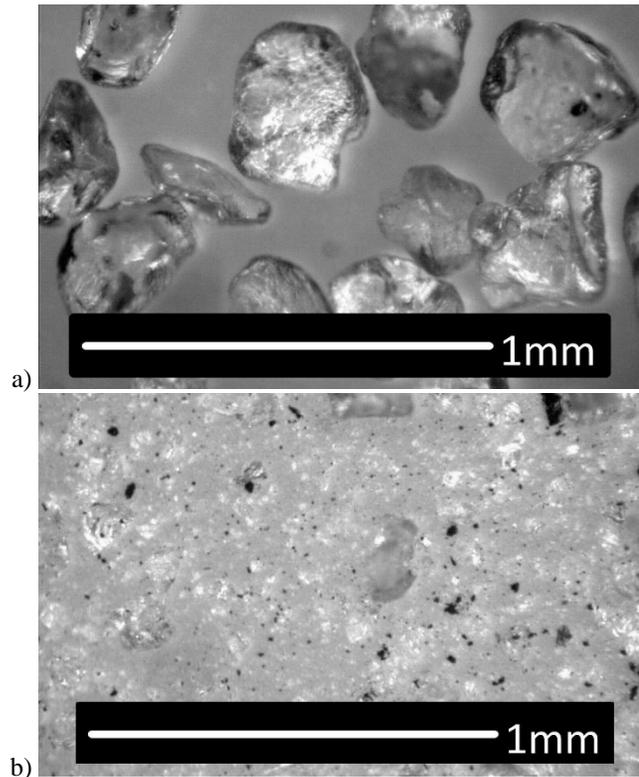


Figure 8. Abrasive grains garnet 80 Mesh a) before, b) after forming in cutting head. Magnification 60x. Source: The author.

In Fig.7 are shown the results of breakage of GMA80 abrasive at a pressure of 390 MPa and 0.33 mm orifice, and 1.02 mm ID focusing tube and average of abrasive flow rate. The largest fraction (almost 20%) was smaller than 53  $\mu\text{m}$ . Overall a significant particle size decrease was observed. Abrasive mass flow rate had almost no impact on particle fragmentation

Fig. 8 shows sample abrasive particles before and after leaving the focusing tube. One can observe different size

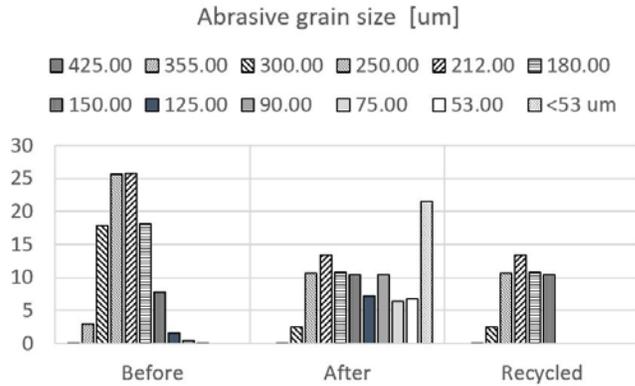


Figure 9. Disintegration of Corundum 60 Mesh after passing through cutting head with water nozzle ID 0.25 mm and focusing tube ID 0.76 mm, Pressure 390 MPa.  
Source: The author.

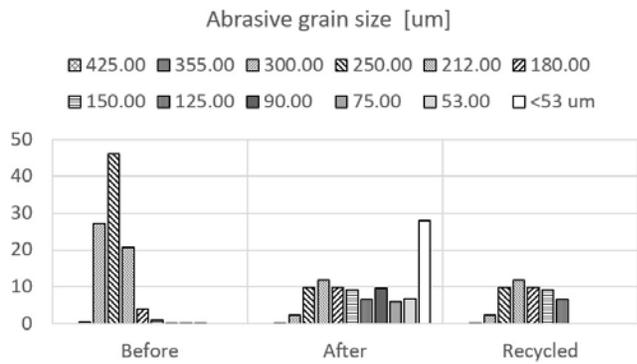


Figure 10. Disintegration of Corundum 60 Mesh after passing through cutting head with water nozzle ID 0.33 mm and focusing tube ID 0.76 mm, Pressure 390 MPa.  
Source: The author.

grains, mostly isometric in shape, but with sharp edges. Most grains are fine. Among them, you can see a few grains with larger dimensions.

#### 4.1.2. Corundum

The results of the study of corundum abrasive fractured during formation of jets at a pressure of 390 MPa through a ID 0.25 mm. Orifice and 0.76 mm ID focusing tube are shown in Fig. 9.

The largest share (22%) belonged to the abrasive grains size smaller than 53  $\mu\text{m}$ . Overall a very significant particle size decrease was observed.

The results of disintegration of corundum abrasive at a pressure of 390 MPa and 0.33 mm orifice, 0.76 mm ID focusing tube and average of abrasive flow rate are shown in Fig. 10.

The largest fraction (almost 30%) was below 53  $\mu\text{m}$ . Overall a significant particle size decrease was observed. Abrasive mass flow rate had almost no impact on particle fragmentation.

In Fig. 11 are shown the results of breakage of corundum abrasive at a pressure of 390 MPa and 0.33 mm orifice, and

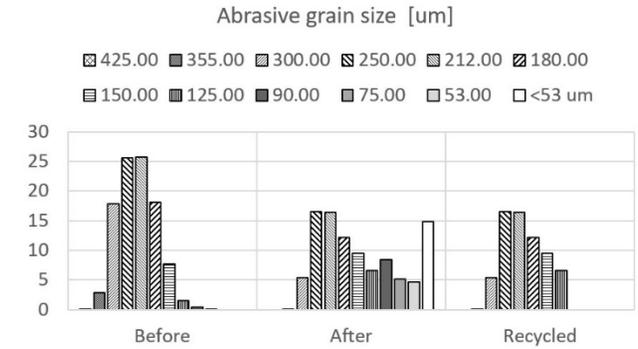


Figure 11. Disintegration of Corundum 60 Mesh after passing through cutting head with water nozzle ID 0.33 mm and focusing tube ID 1.02 mm, Pressure 390 MPa.  
Source: The author.

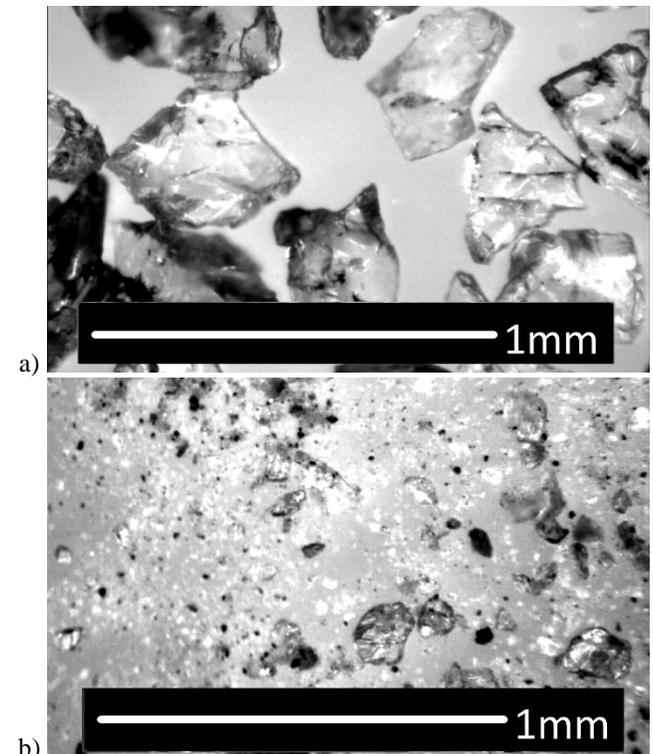


Figure 12. Abrasive grains Corundum 60 Mesh a) before, b) after forming in cutting head. Magnification 60x.  
Source: The author.

1.02 mm ID focusing tube and average of abrasive flow rate. The largest fraction (almost 15%) was smaller than 53  $\mu\text{m}$ . Overall a significant particle size decrease was observed.

Fig. 12 shows sample abrasive particles of corundum before and after leaving the focusing tube. One can observe a large number of very small grains. Also seen are medium-sized and large-sized corundum grains.

#### 4.2. Recycling potential

After abrasive catching and drying sieve analysis was carried out and the analysis the amount of the individual fractions was

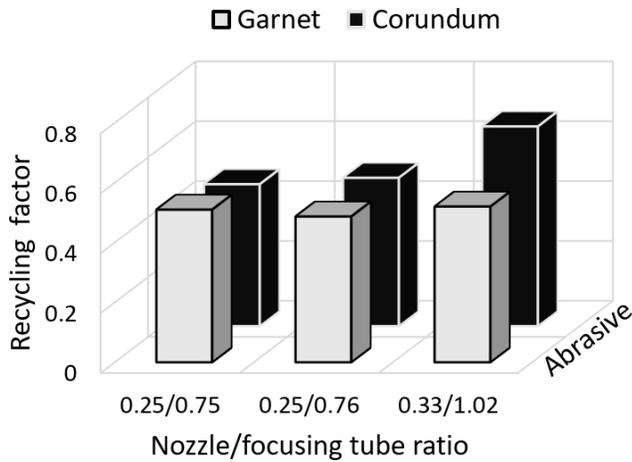


Figure 13. Recycling rate for tested abrasives  
Source: The author.

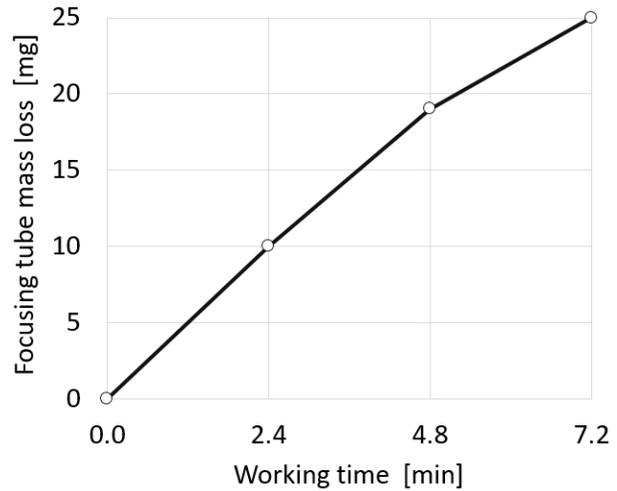


Figure 14. Relation of focusing tube mass loss and working time for garnet.  
Source: The author.

determined. For test abrasive size 80 Mesh size range is from 300 to 125  $\mu\text{m}$ . To determine what fraction of the original range found in the mass of particulate after treatment, all of the fractions smaller than the lower limit of the particle distribution, were rejected. It is illustrated in Figs. 5, 6, 7 for garnet and Figs. 9, 10, 11 for corundum.

The recycling rate was calculated on basis equation:

$$R_f = \frac{m_r}{m_t} \quad (1)$$

Where:

$R_f$  is abrasive recycling factor,  
 $m_r$  is mass of recycled abrasive  
 $m_t$  is total mass of abrasive

Specific results for tested abrasives are presented in Fig. 13. The even recycling factor, amounting near 0.5 was observed for the garnet. This means it can be expected that half of the spent abrasive is possible to re-use. The other abrasive was corundum, with the recycling factor in range from 0.47 to 0.67.

### 4.3. Wear of focusing tube

Erosive properties have an effect not only on the parameters of cut material but also on the durability of focusing tube [1]. On the studies basis, it's have identified the ability of erosion abrasive wear rates by calculating the focusing tube.

On Fig. 14 presented relation of focusing tube mass loss and abrasive flow for garnet and on Fig. 15 for corundum. The biggest focusing tube weight loss was observed for corundum. After the maximum test time, equal 7.2 min., the weight loss to almost 1600 mg. For garnet loss in weight after 7.2 min. amounted 25 mg.

Focusing tube mass loss factor  $M_f$  is calculated based on the equation:

$$M_f(t) = \frac{\Delta m_t}{\Delta t} \quad (2)$$

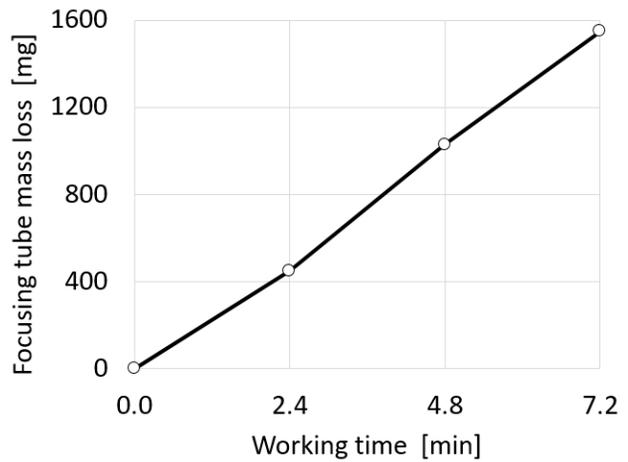


Figure 15. Relation of focusing tube mass loss and working time for corundum.  
Source: The author.

Where:

$\Delta m_t$  is mass loss of focusing tube [g],

$\Delta t$  is working time [s].

Illustrations of this equation for the tested abrasives shows Fig. 16. The highest focusing tube mass loss factor, equal to 3.51 is characterized by corundum abrasive. For the garnet abrasive  $M_f$  factor is smaller and reaches value of 0.06.

Measurements of the focusing tube internal geometry were carried out on the microscope. To determine the shape of the nozzle were made of special casting a two-component silicone material, Silastomer P50, which have a high elasticity when solidified, and low shrinkage.

In Fig. 17. shows an example of the effects of wear Focusing tube. After 5 minutes (Fig. 15a) will wear only the beginning of a cylindrical hole in which passes the cone. After 20 minutes of operation, the inner opening is increased, while the central part can be observed erosion effects as a strong deterioration of the focusing tube.

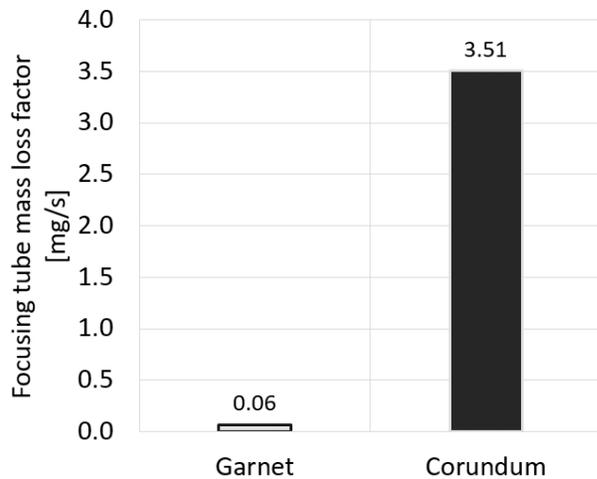


Figure 16. Focusing tube mass loss factor  $M_f$  for tested abrasive.  
Source: The author.



Figure 17. Shape of focusing tube wear with corundum after: a) 5 min, b) 10 min. c) 20 min.  
Source: The author.

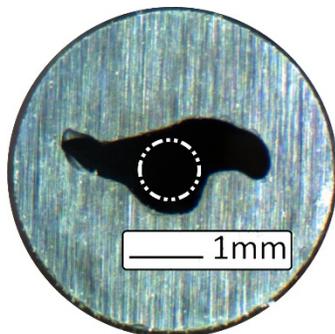


Figure 18. Focusing tube outlet after 20 min. work with corundum. Dash-dot-dot line – original focusing tube ID = 0.76 mm.  
Source: The author.

Also, at the outlet of the nozzle showing intense wear in form of flattened cone, which confirms Fig. 18.

## 5. Conclusions

Based on the research following conclusions were drawn:

- The biggest recycling potential, near 50% characterized garnet.
- Recycling potential of corundum is from 47-67% range, but abrasive wear of focusing tube is 60 time bigger then garnet.

- Maximal working time of focusing tube with corundum abrasive not exceed 20 min.
- Further studies should test the cutting ability of recovered abrasive.

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Área Curricular de Ingeniería Mecánica

Oferta de Posgrados

Maestría en Ingeniería - Ingeniería Mecánica

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