Applicability Assessment of the Resource-Saving Method for Recovering Garnet Sand Abrasivity

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Abstract. Hydroabrasive treatment technology is widely used for cutting semi-finished products, products, cleaning contaminated surfaces, etc. The main disadvantage of the technology is the high cost of cutting. The abrasivity recovery and recycling used abrasives for cutting process is subject matter of foreign researchers, however, no one deals with this problem in Russia due to its low tonnage. The possibility of recovering garnet sand waste after hydraulic cutting is evaluated and a semi-industrial installation for recovering garnet sand waste is presented in this paper.

1. Introduction
The most popular devices for cutting workpieces and products are: guillotine, bandsaw, oxy-fuel, plasma, laser and waterjet cutting (LWC). Each device has its own advantages and disadvantages, limitations on the thickness and type of metal being cut, and ways to ensure a certain level of surface quality. Materials that have a high coefficient of thermal conductivity or a low melting point (for example, copper, tin, lead, etc.) cannot be cut using laser, and in the case of plasma cutting thermal deformations and large losses of material in the cutting area appear. Therefore, waterjet cutting is a universal method, however, it involves contact with water, which can be critical for metals susceptible to corrosion.

Waterjet cutting is a method of obtaining given product size by using directed flow of a liquid abrasive mixture. A numerically controlled (CNC) waterjet machine cuts the material with high speed and accuracy, while the cutting process is almost independent of the material type. Waterjet cutting has become the main material processing technique due to its high efficiency, ease of operation and high productivity and is widely used in engineering, aerospace, automotive, shipbuilding and other industries. The catalytic fines are loaded to increase the cutting process efficiency into a high-speed jet (300 - 900 m / s) of a high-pressure water stream (200 - 600 MPa) [1].

Advantages of waterjet cutting:
- absence of thermal deformations and mechanical stresses in finished workpiece [2];
- ease of programming;
- minimization of material losses of in-process parts;
- ease of placement and fastening of in-process parts;
- minimization of expensive reprocessing operations;
- absence of toxic gases.
The abrasive used to cut all material types must have an extremely high hardness and an acute-angled particle shape. At the same time, it is necessary to maintain a balance between the abrasive material type and mixing tube durability. Currently, garnet sand is mainly used as an abrasive in industry, having parameters such as high hardness (7–7.5 on the Mohs scale), the sharpness of the particles, while having a high cost (about 40 thousand rubles / t).

Garnets are an extensive group of minerals related in chemical composition to the so-called orthosilicates. Different mineral species exist in the garnet group. Iron-aluminum garnet - almandine is used for waterjet cutting. This is a cherry-red mineral with a high density of 4.1 ... 4.3 g / cm3, very high resistance to destruction, and the absence of toxicity to humans and the environment [14]. The main producers of garnet sand are China, India, Australia, and the USA. In 2015, India produced about 47% of total world production, followed by China with 31%, Australia with 15%, and the remaining 7% of production belongs to the USA and other countries [3].

Along with the advantages of this cutting technology, there are also the following disadvantages:

- a large amount of garnet sand is consumed (sand consumption exceeds 50 kg cutting 1 rm of carbon steel with a thickness of 50 mm) [4];
- environmental pollution by silt waste.

Garnet sand is destroyed as a result of collisions between the material being cut and sand itself during the cutting process. Particles of the material being cut are mixed with partially disintegrated garnet sand and form a slurry, which is currently discharged into the environment. Used garnet sand obtained due to industrial waterjet cutting is taken out for disposal, and in rare cases it is used as construction sand and in road engineering [5-7].

According to the data studied, it follows that interest in the development of methods for processing garnet sand waste is fairly low in Russia, which leads to the loss of useful resources [20]. For example, in 2016-2019, 210 tons of garnet sand were used for waterjet cutting in the Tomsk enterprise (Tomsk Electric Drives Plant JSC), while in 2017-2018, 180 tons of garnet sand, the slurry of which were then taken into a disposal area, were used for waterjet cutting in the Novosibirsk enterprises (Akvakat LLC and Sibrez LLC).

Recycling these costly abrasive materials minimizes environmental damage and will also save resources and lower the cost of waterjet processing.

When processing any industrial waste, if the cost of the target product, as garnet sand in the present case, is lower than the product obtained from natural raw materials, from the almandine deposit in the present case, then such a technology will sooner or later find its investor.

There are three alternative schemes for managing the resulting garnet sand waste, namely:

1) waste processing and recovery of a part of the raw materials, recycling for hydraulic cutting of this part or the whole mass, and disposal of non-recoverable and not suitable for reuse fraction;
2) transportation of all waste to the waste deposit;
3) waste recycling in the construction and road industries (Figure 1).

The choice of the best management scheme depends mainly on the costs associated with each scheme, as well as on local environmental standards [18]. Waterjet cutting waste treatment is necessary regardless of the chosen managerial scheme, if it is proved that the waste is an environmental problem (for example, if beryllium bronze or stainless steel with a high nickel or chromium content is processed).

Based on the composition and properties, waterjet cutting waste can be characterized as follows: very fine, almost mono-fractional heavy sands with a high content of dust fraction, the chemical composition of which is dominated by iron, silicon, and aluminum oxides. Waterjet cutting waste is classified as the 5th hazard class waste products, that is, non-hazardous.

The authors [8] conduct research on the possibilities of using garnet sand waste after hydraulic cutting as an additive in the production of building ceramics. It makes sense to use used garnet sand after sandblasting as a substitute for river sand in geopolymer self-compacting concrete [9, 13]. Studies have shown satisfactory performance with high compressive strength. The garnet sand 25% (wt) showed optimal characteristics both in terms of self-compaction and strength properties. The high
content of silicon dioxide, aluminum oxide and iron in the used garnet, as well as the high specific surface area, porosity positively affect the production of high-quality geopolymer self-compacting concrete.

![Diagram of garnet sand waste management schemes.](image)

**Figure 1.** Garnet sand waste management schemes.

Lawrence Livermore National Laboratory investigated waterjet cutting waste to assess the possibility of recycling used garnet sand as a trench backfill and concrete aggregate [10]. In both cases, garnet waste replaces quartz sand. The results confirmed the possibility of recycling used garnet sand as a concrete aggregate, but did not confirm its proposed use as a trench backfill. Used sand stabilized in a concrete matrix, as expected, does not pose a risk to metal leaching, however, unconsolidated sand in trenches can potentially leach metals at concentrations high enough to threaten groundwater quality.

Familiarization with domestic and foreign literature on the waste use does not provide sufficient information on the recycling of waterjet cutting waste in Russia and CIS countries; it can be caused, in particular, by the lack of interest in waste generated in small quantities. Abroad, namely, in the Czech Republic, Malaysia and the USA, sand recycling is carried out, but this activity is more theoretical than practical in nature [15-17, 19].

A method for recovering garnet sand abrasivity was proposed and tested at the Tomsk Polytechnic University to reduce the cost of waterjet cutting. The method is based on the sand cleaning from particulate impurities of the material being cut on the concentrating table and the subsequent use of the specified sand as an abrasive during waterjet cutting.

About two tons of used garnet sand after hydraulic cutting was received at Tomsk Polytechnic University from the company Hydrez LLC (Tomsk). The entire sand volume was carefully averaged by repeatedly mixing the mass to level out fluctuations in the chemical and particle size distribution. Sample preparation was carried out for laboratory studies, consisting in the selection of 50 kg of sand from the average mass and its natural drying (layer thickness is 5-10 mm) at the indoor site, after drying, large particle aggregates were disaggregated by grinding, then the sand was passed through
sieve with a mesh diameter of 0.5 mm. 5 kg of used sand were selected for laboratory tests by quartering.

A JEOL JSM 6000 scanning electron microscope was used to determine the abrasiveness and graininess of the used sand. For comparison, we used new sand from the supplier (Fig. 2), the manufacturer is an enterprise from China, the declared fraction is 80 mesh. Figure 3 presents sand from the same supplier, but already disintegrated after hydraulic cutting.

As can be seen from fig. 2, in new sand from the supplier all particles are the same size. In fig. 3 it is noticeable that the fine fraction is quantitatively prevailing, but coarse particles with a diameter of more than 70 microns are at least 60%.

In a point of fact, particles are disintegrated into several large and many small pieces. If a particle breaks up into two large and many smaller parts, a round particle will usually break up into two elongated particles, and a long particle will break up into two round particles [11]. This means that cutting with alluvious (river) cheaper supplier’s sand can lead to the formation of long sharp recycled abrasives and the cutting efficiency rate will be significantly improved, while new long particles will be crushed mainly to a spherical shape with low sharpness.

The laser particle size analyzer SALD-7101 from SHIMADZU (Japan) was used to determine the particle size of the powders. Its operational principle is based on static scattering of laser light with a wavelength \( \lambda = 375 \) nm. The SALD-7101 analyzer helps to determine the content of powder particles, the size of which is in the range from 0.01 to 300 \( \mu \)m. Conducting particle size analysis by laser diffraction, a sample of the studied powder was placed in a mixer bath with distilled water and dispersed for several minutes using an ultrasonic unit (40 W, 40 kHz). Measurements were performed in a flowcell. The one-dimensional parameter was used to characterize the granulometric composition of the powder under study, namely, the average volumetric-weight diameter \( d_{V\text{p}} \). When conducting laser scanning used 1 g of the same powder. The granulometric composition determination time was 10 min. The granulometric composition of powdered garnet sand obtained by laser scanning is presented in Table 1. A decrease in the average diameter occurs with an increase in the dispersing time (analysis time), and a peak appears in the region of smaller sizes. This is due to the fact that aggregates of particles are present in the initial powder, which are destroyed by ultrasound and mixing.

As can be seen from Table 1, the quality of the used sand is satisfactory, it is advisable to recycle particles from 70 to 270 \( \mu \)m, as the volume amount is 71.9%. The volume content of coarse particles depends not only on the initial particle size, but also on the type of material being cut.
Table 1. Garnet sand volume distribution.

| Size, µm | Volume, % | Size, µm | Volume, % | Size, µm | Volume, % | Size, µm | Volume, % | Size, µm | Volume, % |
|---------|-----------|---------|-----------|---------|-----------|---------|-----------|---------|-----------|
| 3.564   | 0.77      | 11.078  | 0.518     | 34.429  | 0.627     | 107.006 | 7.562     |         |           |
| 3.951   | 1.177     | 12.28   | 0.696     | 38.168  | 0.619     | 118.626 | 8.531     |         |           |
| 4.38    | 1.506     | 13.614  | 0.783     | 42.312  | 0.626     | 131.508 | 9.082     |         |           |
| 4.856   | 1.749     | 15.092  | 0.849     | 46.907  | 0.514     | 145.788 | 9.443     |         |           |
| 5.383   | 1.883     | 16.731  | 0.92      | 52.001  | 0.173     | 161.62  | 8.717     |         |           |
| 5.968   | 2.001     | 18.548  | 1.029     | 57.648  | 0.172     | 179.17  | 6.819     |         |           |
| 6.616   | 2.231     | 20.562  | 1.017     | 63.908  | 0.169     | 198.626 | 4.985     |         |           |
| 7.334   | 1.966     | 22.795  | 0.889     | 70.847  | 0.96      | 220.195 | 2.461     |         |           |
| 8.131   | 1.077     | 25.27   | 0.783     | 78.541  | 2.548     | 244.106 | 1.03      |         |           |
| 9.014   | 0.686     | 28.015  | 0.626     | 87.07   | 4.126     | 270.614 | 0.359     |         |           |
| 9.992   | 0.554     | 31.057  | 0.572     | 96.525  | 6.194     | 100     |           |         |           |

Laboratory studies showed that when the garnet sand content is not less than 50% in the slurry of coarse particles (from 70 µm or more) after hydraulic cutting, it is advisable and cost-effective to recycle this slurry for almandine selective extraction.

The employees of Tomsk Polytechnic University have developed a semi-industrial installation for recovering garnet sand waste after waterjet cutting of pomegranate sand, shown in Figure 4, where 1 - storage location of source material, 2 - vibrating screen, 3 - oversize fraction collecting box, 4 - target waste fraction collecting box, 5 - lifter tank, 6 - lifter, 7 - metering screw hopper, 8 - spiral classifier, 9 - concentrating table, 10 - drying oven, 11 - vibrating screen, 12 - oversize collecting box, 13 - regenerate collecting box, 14 - scales, 15 - nutsch filters, 16 - hydrotrap (the minus fraction is the fraction that passes through the given sieve, and the oversize fraction is the fraction that remains on this sieve).

Figure 4. Hardware configuration of a semi-industrial installation for recovering garnet sand waste after waterjet cutting.

The technological process is that the used (waste) abrasive, consisting of garnet sand, water and mulch, which is a mixture of the smallest particles of the material subjected to hydraulic cutting, such as stainless steel, carbon steel, glass (mirror was cut), plastic (polypropylene), enters the processing area, first getting to the vibrating screen 1 removing large material cutoffs. The operator transfers the
target waste fraction from the collecting box 4 into the tank 5 of the lifter 6, and then into the hopper 7, the volume of which is calculated taking into account the daily productivity of the semi-industrial installation. The material is uniformly replaced from the hopper by a spiral classifier 8, equipped with an irrigation system based on S: W (sand: water, wt) - 1: 2, to a concentrating table 9, on which the material is separated into mass flows, differing in size, density and shape of the particles, by reciprocating table vibrations and flushing water pressure (S: W - 1: 5 (wt)). The used garnet sand on the concentrating table is divided into three fractions according to the density and size of particles: heavy, light and target fractions. The heavy fraction is the remnants of cut materials with a density of more than 4 g / cm³ (usually steel) after waterjet cutting. The light fraction is a mixture of used garnet sand with a particle diameter of less than 70 µm and material residues with a density of less than 4 g / cm³ after waterjet cutting. It is well defined visually for its color from light brown to pale-yellow. About 50% of the starting material for recovering goes into the light fraction and then transfers from the concentrating table to the water circulation unit. The target fraction is used garnet sand with a particle diameter of more than 70 µm [12]. It is well defined visually for its light-cherry color.

After separation on the concentrating table, the material is placed into the drying oven 10 for achieving a moisture content of not more than 1-2%, after which it is transferred to a vibrating screen 11 for control cleaning, and then sent for packing onto the scales 14.

The main unit of the used garnet sand recovering unit is the SKO-0.5 concentrating table, which is a metal channeled area of 0.5 m², driven into oscillatory horizontal movements by radial gear with an oscillation range of 4 to 16 mm and a frequency of 280 up to 400 vibrations per minute and a transverse inclination angle from 0 to 5 °.

The main criteria were identified during semi-industrial tests determining the difficulty of the recovering technological process:

В ходе полупромышленных испытаний были выявлены основные критерии, определяющие трудность технологического процесса регенерации:

1. Waterjet cutting machines using home-made collector boxes for storing abrasive waste are not equipped with a grating separating large cutoffs from the used abrasive, therefore large cutoffs (metal, ceramic, plastic, wood, etc.) with a diameter of up to 50 mm are periodically seen in garnet sand waste.

2. A variety of cut parts and semi-finished products by density: copper - 8.9 g / cm³, stainless steel - 8.0 g / cm³, almandine - 4.19 g / cm³; aluminum - 2.7 g / cm³, glass - 2.5 g / cm³, fiberboard - 0.82 g / cm³, etc.

3. A significant content of fine fraction, approximately ~ 30% of particles are less than 70 µm.

4. Humidity content of garnet sand waste varies from 0 to 20%.

2. Conclusions

1. The fraction of garnet sand recovered after hydraulic cutting contains particles in the range from 70 to 270 µm in the developed recovering installation;

2. The developed method for cleaning used garnet sand on a concentration table falls into the category of energy and resource-saving technologies due to the garnet sand recycling for hydraulic cutting.

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