Numerical simulation of diamond powder separation by particle shape and size

A V Kurnenkov*, A Yu Shurigin and V V Glebov
Arzamas Politechnical Institute the branch of Nizhniy Novgorod State Technical University n. a R.E. Alekseev, 607227, Arzamas, Russia

*mexkev@mail.ru

Abstract. The paper presents the finite-element modeling results of classifying diamond microgrit grains, using a rotary type separator in software ANSYS Fluent. The authors obtained the following results: distribution of air flow velocities, grain motion trajectories in the liquid film and in the air when ejecting from liquid, depending on their size and shape for synthetic diamond powder grit size 80/63.

1. Introduction
Grinding is one of the main machining methods. Nowadays, tools based on synthetic diamond grains are widely used in grinding various materials (glass, ceramics etc.). One of the promising ways to improve the quality of the tool is the use of diamond grains, classified not only by size, but also by shape. Grains within a given grit size are significantly different in linear dimensions and durability, which results in different strength of the working layer of the tool and its chaotic wear [1, 2]. Current vibration methods of classifying by the shape of grains have low productivity.

To implement the process of classifying diamond microgrits according to the shape and size of grains, the separator was developed [3]. It has the following components: a mixing funnel, a curved rotor, and receiving sections for diamond grain fractions. The main technological parameters of the separator are rotor angular velocity, and flow rate which is determined by the diameter of the supply hole of the funnel.

The process of classifying based on this separator is complex; it includes the flow of a liquid film over the rotor surface in centrifugal force field, as well as grain dynamic in a fluid and air.

The aim of the work is to study the process of classification of diamond microgrit grains by size and shape (by the example of synthetic diamond powder grit size 80/63) in centrifugal force field using computational fluid dynamics.

The grain-size composition of diamond powder grit size 80/63 according to GOST 9206-80 are given in the table 1.

The ratio of grains linear dimensions is shown in the table 2.

Assuming that the geometric model of the grains is an ellipsoid, the equivalent diameters for each grain shape were determined, taking into account the linear dimensions from Table 2, based on the equality of the volumes of the ellipsoid and its equivalent sphere. The equivalent diameters obtained for each grain shape are shown in the table 3 and the diamond grains shape factors are shown in the table 4.
Table 1. The grain-size composition of diamond powder grit size 80/63.

| Size range, µm | Intermediate size, µm | Ratio of fraction mass to total mass of microgrit |
|---------------|----------------------|-------------------------------------------------|
| 100÷80        | 90                   | < 13 %                                          |
| 80÷63         | 72                   | > 75 %                                          |
| 63÷50         | 57                   | > 10 %                                          |
| 50÷40         | 45                   | < 2 %                                           |

Table 2. The ratio of grains linear dimensions.

| Grain shape | Isometric | Intermediate | Lamellar | Needle |
|-------------|-----------|--------------|----------|--------|
| Length, l   | 1,2       | 1,2          | 1,2      | 1,2    |
| Width, w    | 1         | 1            | 1        | 0,6    |
| Height, h   | 0,8       | 0,6          | 0,4      | 0,36   |

Table 3. The equivalent diameters of grains.

| Intermediate fraction size, µm | Shape-based equivalent diameters of grains, µm |
|-------------------------------|-----------------------------------------------|
|                               | Isometric | Intermediate | Lamellar | Needle |
| 90                            | 89        | 81           | 70       | 58     |
| 72                            | 71        | 65           | 56       | 46     |
| 57                            | 57        | 52           | 45       | 37     |
| 45                            | 45        | 41           | 36       | 30     |

Table 4. The diamond grains shape factors.

| Grain shape | Isometric | Intermediate | Lamellar | Needle |
|-------------|-----------|--------------|----------|--------|
| Shape factor | 0,97      | 0,89         | 0,73     | 0,55   |

2. Computational Model

At the first stage of modeling, a two-dimensional axisymmetric model was created. It consists of three main regions:

1 - the region of the mixing funnel where the grains of the diamond microgrit are mixed with the fluid. The minimum mesh size is 250 µm.

2 - the region of liquid film flow over the rotor surface. The second region layer thickness located over the entire surface of the rotor is 500 µm; the minimum mesh size is 5 µm.

3 - the region of ejected from the liquid grains moving in air. The minimum mesh size is 250 µm.

The finite element model presented on figure 1 contains 70150 nodes with an average orthogonal grid quality of 0.99.

To implement the numerical simulation, the computational fluid dynamics software package ANSYS Fluent was chosen, it allows simulating the hydrodynamics of multiphase flows by the finite element method in Euler's formulation. When choosing an algorithm for solving the task, the Pressure-Based Coupled Solver was used, as it is more stable for a large class of problems. The problem was solved in a transient formulation with the time step of $10^{-5}$s.

When simulating the flow dynamics with a free surface, Volume of Fluid technique was taken, as well as the explicit sampling scheme [4, 5], the two-parameter turbulence model Realizable k-e was chosen as a viscosity model. Water with the following properties: surface tension 0.072 N/m, kinematic viscosity $1.006 \times 10^{-6}$ m$^2$/s, density 998 kg/m$^3$ was chosen as a working fluid.

To simulate the dynamics of diamond grains in fluid and air, Discrete Phase Model was used; it allows displaying the grains trajectories at a given point in time in accordance with steady state.
hydrodynamic conditions. The grains injection points were uniformly distributed over the entire width of the funnel. The density of the diamond grains was assumed to be 3500 kg/m³.

The scheme of boundary conditions is presented on figure 2. The external pressure equal to atmospheric was set at inlet and outlet. The rotor angular velocity was set as 400 rad/s and flow rate of fluid was set as 2.5 l/min, the rotor surface roughness was 6.3μm, the contact angle of fluid on the rotor surface was assumed to be 60°.

The grain distribution by size and shape is ensured by their getting into the corresponding sections that are located below the low boundary of the computational domain.

**Figure 1.** The finite element model.

**Figure 2.** The scheme of boundary conditions.

3. Results and discussion

The simulation results of the grain dynamics in accordance with their sizes in Table 3 at the rotor angular velocity 400 rad/s are presented in figure 3.

**Figure 3.** The grains motion trajectories: a - isometric grains; b - intermediate grains; c - lamellar grains; d - needle grains.
According to figure 3, it can be concluded that almost all grains will not get into the sections. The following patterns are observed: particles with equivalent diameters more than 55 μm move in straight-line trajectories, and trajectories of particles with diameters less than 55 μm deviate from straight-lines, presumably due to the influence of circulating air flows.

To analyze the air flow dynamics, the distribution of their radial velocities field was calculated (figure 4). It allows to determine the regions of the velocity fields, as well as the concentration region of the highest velocities (red zone), located closer to the bottom of rotor.

Based on the result analysis, the following solutions were proposed:

- to set the flow cutoff in order to eliminate the influence of air flow at the bottom of the rotor on the grain motion trajectory;
- to raise the upper limit of the sections, because grains ejected from the liquid at the top of the rotor.
- to reduce rotor angular velocity.

The simulation results of the grain dynamics in accordance with the above changes at the rotor angular velocity 250 rad/s are presented on figure 5.

4. Conclusion
The simulation results show that the changes allow correcting the hydrodynamics of diamond grains classifying process and ensure its stability. The analysis of the obtained grain motion trajectories allows set the boundaries of concentric receiving sections for abrasive grain fractions. The bulk of
isometric and intermediate shaped grains get into the section distant from the rotor, and lamellar and needle-shaped grains get into the section located closer to the rotor.

This classification gives the opportunity to improve the quality of the initial synthetic diamond microgrit by ensuring the uniformity of its grain composition by shape.

References
[1] Baydakova N V 2006 Avtoreferat dissertatsii na soiskaniye uchenoy stepeni kand. tekhn. nauk: 05.03.01 (Saratov)
[2] Novikov N V, Nikitin YU I and Bogatyreva G P 2008 Porodorazrushayuschij i metalloobrabatvayushchij instrument – tekhnika i tehnologiya ego izgotovleniya i primeneniya: Sb. nauch. tr. vol 11 (K.: INM im. V.M. Bakulya NAN Ukraini) pp 141-50
[3] Glebov V V, SHurygin A YU, Sorokin V M and Pomelov N A 2014 Pat. 2513936 (RF)
[4] Yuhua Pan, Peter J Witt and Dongsheng Xie 2010 CFD simulation of free surface flow and heat transfer of liquid slag on a spinning disc for a novel dry slag granulation process Progress in Computational Fluid Dynamics vol 10 pp 292-99
[5] Tejas J Bhatelia, Ranjeet P Utikar, Vishnu K Pareek and Moses O Tade 2009 Characterizing liquid film thickness in spinning disc reactors Seventh International Conference on CFD in the Minerals and Process Industries CSIRO (Melbourne)