ISSN 1062-7391, Journal of Mining Science, 2017, Vol. 53, No. 2, pp. 259–264. © Pleiades Publishing, Ltd., 2017.
Original Russian Text © Yu.M. Grogor'ev, V.P. Mironov, P.P. Tarasov, 2017, published in Fiziko-Tekhnicheskie Problemy Razrabotki Poleznykh Iskopaemykh, 2017, No. 2, pp. 52–58.

ROCK FAILURE

Laboratory Selective Disintegration of Kimberlite

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Received January 15, 2017

Abstract—For the selective disintegration of kimberlite and dissociation of diamond crystals preserving their natural integrity undisturbed, the authors have designed a tool with cutters having hardness lower than diamonds but higher than binding minerals in kimberlite. The article gives the test results on the prototype of the heterogeneous material disintegrator on soft kimberlite extracted from Manchary pipe. The prototype includes disc brushes made of high-strength steel wire. The prototype realizing selective disintegration is a preproduction model of lab, semi-commercial and commercial disintegrators. The method is applicable to recover hard particles from geological samples.

Keywords: Kimberlite, diamond, Manchary pipe, crushing, grinding, disintegration, attrition, granulometric analysis, mineral, mineralogical analysis, laboratory prototype.

DOI: 10.1134/S1062739117022092

INTRODUCTION

In Russia the priority research trends in integrated comprehensive processing of natural minerals and mining waste cover high efficient energy-saving ore preparation processes, selective disintegration of complex ores, development of dry mineral processing techniques, including diamond ore treatment [1]. The research works on mastering of conventional techniques to open diamonds [2, 3], to modify available grinding facilities [4], development of new high-frequency crushing machines [5], application of UHF energy [6], and chemical processing of kimberlites [7] are governed by the need to gain higher efficiency and better economy of mineral processing in the diamond industry. Much attention is paid to preservation of natural wholeness of crystals, large-size crystals, in particular [8]. The use of attrition in rock grinding circuits allows essential improvement of energy efficiency of disintegration process with indestructibility of mineral grain structure [9].

Analysis of publications on mechanical properties of basic minerals and binding components of kimberlites revealed that an essential portion of kimberlites (up to 90%) can be ground to a damped size by applying the selective milling of relatively soft binding components with their subsequent rejection from kimberlite processing circuits [10]. In selective destruction of binding mass and its rejection a number of undamaged minerals are concentrated with a solid fraction which can be readily separated by screening. Mathematical modeling made it possible to demonstrate feasibility of the selective kimberlite disintegration, namely, failure of binding components with preservation of natural wholeness of hard minerals. The mathematical model implied the use pf an instrument designed for selective destruction of the binding mass of kimberlite. However among a wide range of instruments capable to destruct, to crush an ore, to grind down to coarse and fine size fractions there was no instrument for the selective destruction of binding mass in ore [11], the cutting process was selected as the most promising way to disintegrate heterogeneous rocks.

To realize the selective destruction (disintegration) required an instrument with cutters which hardness was lower than diamond hardness, but higher than hardness of binding mass of kimberlite components. The prime condition was the cutters should stand at contact with hard kimberlite minerals, including diamond. The first version of such an instrument was a set of steel cable sections mounted on a rotary shaft [12]. Later industrial disk brushes designed to clean concrete and steel surfaces in construction industry were used in these instruments [13]. Laboratory tests of the simplest prototypes on concrete specimens justified efficiency of the method and served the base to develop an actual laboratory pilot disintegrator [14].

1. TEST RESULTS AND DISCUSSION

Disintegrator model (Fig. 1a) consists of lined working chamber *1*, rotary rotor with a destructive tool *2*, mounted on it and actuated by motor *3*, and receiving bin *4*. All the modules are fixed on frame *5*. I the model the rock destructing tool (Fig. 1b) is mounted on rotary vertical shaft and placed into working chamber *1*, which is rigidly fixed on frame *5*. The working chamber is a blunt-nose cone with downward-directed little base (Fig. 1a). The size of outlet depends on the diameter of cone base; the latter is selected with account for diameter of the destructing tool, and an expected size class of hard fraction. In the model outlet width was 10 mm. Internal surface of working chamber was lined with relatively soft, but wear-resistant polypropylene material.

Disintegration tests were performed on relatively soft non-diamond kimberlites originated from Manchary pipe, explored in the Central Yakutia in в 2007. Under [15], rocks of Manchary Pipe, Yakutia kimberlite province, present porphyry kimberlite of serpentine−phlogopite−apatite composition. Porphyry components−inclusions of serpentine and xenolyths of sedimentary rocks are from 0.1 up to 0.5–0.7 cm in size, fractured, with displacement traces, irregularly distributed in rocks. Their structure varies from fine- to course-porphyry one with domination of the second (Fig. 2).

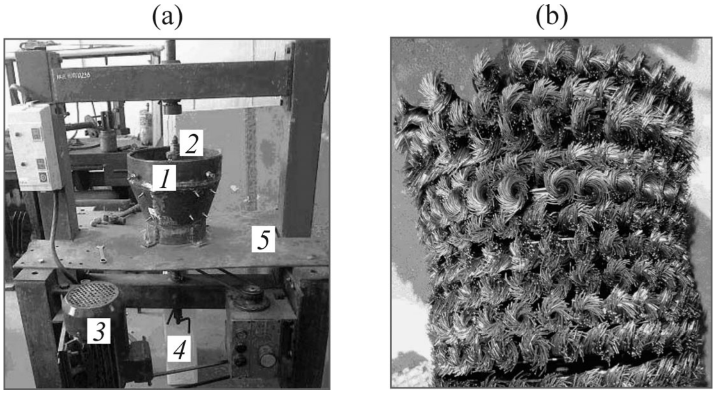

Fig. 1. (a) General view of the model and (b) rock−destructing tool: *1*—working lined chamber; *2*—rotor with active destructive tool; *3*—electromotor; *4*—receiving bin; *5*—frame.

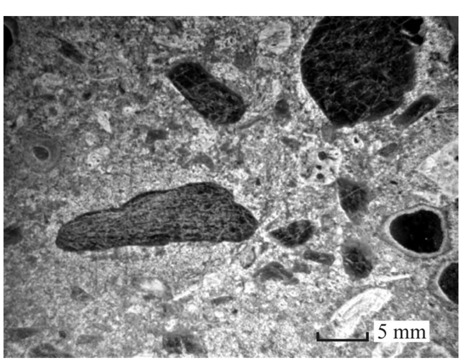

Fig. 2. Kimberlite structure.

Characteristic feature of Manchary pipe rocks is the commonly developed carbonatization: the rocks are crook-veined with carbonates. Veins are featured with bulges, their structure is microcrystalline and microcryptocrystalline. They used to form crusts, edges and aggregates differing in shape and size.

Analysis of published evidence on mineralogical composition of kimberlites revealed that their hardness ratio after Protod'yakonov's scale f is relatively low [10]. This suggestion was verified experimentally. Hardness ratio is calculated according to Standard procedure based on the uniaxial compression tests of material hardness (GOST 21153.2−84) at IP-500 press with CI-2 measurement system. Rock hardness ratio for kimberlite averaged based on tests of 15 specimens was 1.4 units after Protod'yakonov's scale at volumetric rock density ranging from 2.37 to 2.43 g/cm^3. Thus, it is found that Manchary pipe kimberlite is a heterogeneous rock wit a relatively soft binding component. This material is good for material grinding tests after the attrition procedure.

The disintegration tests were conducted on kimberlite core specimens of 95 mm in diameter and 150−300 mm in length, total weight of the material was 31 kg. Test time values were 5, 10, and 25 min.

Course fractions (concentrate) and granulometric analysis were produced at Fritsch Analysette 3 screen, Germany. Screen mesh sizes were 1, 2, 6, and 10 mm. Masses of disintegrated material and non-ground material were determined by weighing, disintegration time was measured by a second meter.

Specific energy consumption was calculated from:

$$W = \frac{N_1 - N_2}{Q}, \quad Q = \frac{m}{t},$$

where W—specific energy consumption, kW·h/t; N_1— operation capacity of the facility, kW; N_2— idle capacity of the facility, kW; Q—productivity of the facility, t/h; m— mass of disintegrated material, t; t—disintegration time, h.

Power consumed by the facility was measured by a wattmeter and it amounted to 2.376 kW for an idle stroke. Data for energy consumption calculations at different disintegration modes and specific energy consumption values are summarized in the Table below. Relationships of disintegrated product yield classified by size fractions versus time of disintegration are shown in Fig. 3.

Calculation data on energy consumption at different disintegration modes

Disintegration time, min	Mass of disintegrated material, kg	Operation capacity, kW	Specific energy consumption kW·h/t
5	1.760	2.640	12.5
10	1.685	2.706	32.6
20	3.572	2.838	53.9

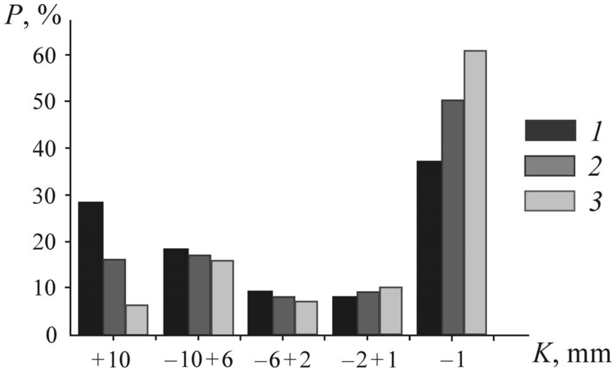

Fig. 3. Yield of disintegration products P in size classes K. Treatment time: *1*—5 min; *2*—10 min; *3*—25 min.

As it follows from the table and Fig. 3, disintegration runs until the minimal size of every of material particles under grinding in one of three projections gains a size equal or less than disintegrator outlet (10 mm). In general, disintegration products are fractions of more than 1 mm in size; the yield of this product is increasing with reduction in the yield of + 10 mm fraction. The yield of – 2 + 1 mm fraction is growing in much less proportion. Disintegration of – 10 + 6 mm and – 6 + 2 mm fractions is not efficient at the test model under consideration due to the governing factor of outlet size in the disintegrator. As soon as kimberlite lumps reach size of less than 10 mm they fall into the product receiving bin with no further disintegration. The test specimens contained a certain amount of hard minerals (garnet, ilmenite) of – 10 + 6 mm in size, in the disintegration process these minerals were detected as bulged irregularities on specimen surface (Fig. 4). Cutting of discrete oval course lumps of + 10 mm in size revealed that the lumps can not be specified as a monomineral fraction, they present the rounded kimberlite particles with hard inclusions which disintegration can be realized in further processing.

The tests on production capacity of the facility at the continuous feeding mode were not practiced on the grounds of the limited number of available kimberlite core specimens, but disintegration results make it possible to suggest that performance of the prototype facility was approximately 21 kg/h at the experimental prototype specifications and kimberlite hardness. Figure 5 demonstrates disintegration products, graded into size fractions.

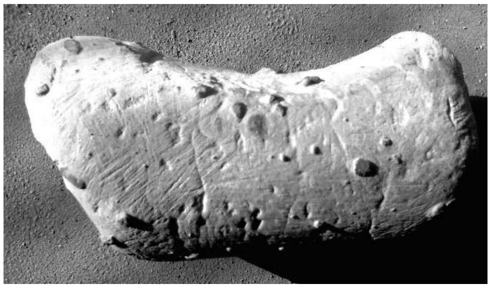

Fig. 4. Core specimen after 5 min disintegration.

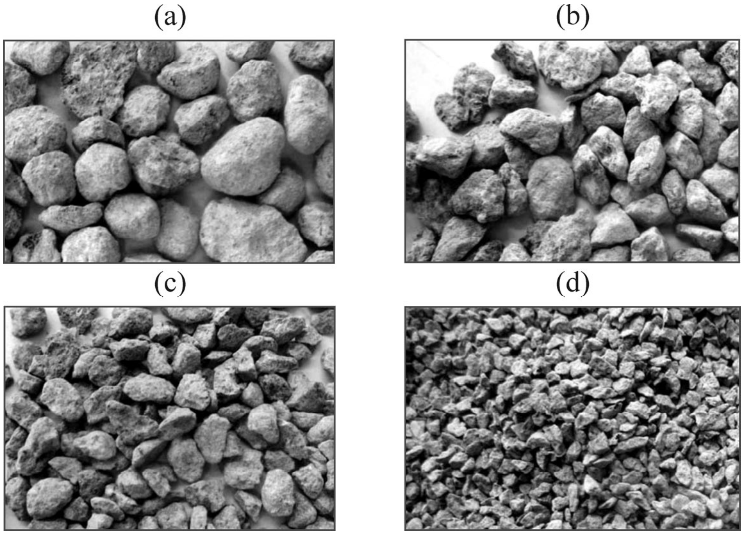

Fig. 5. Disintegration products graded into size fractions, mm: (a) (+ 10); (b) (– 10 + 6); (c) (– 6 + 2); (d) (– 2 + 1).

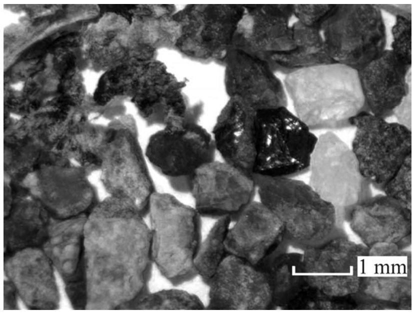

Fig. 6. Mineral grains in – 2 + 1 mm size fraction.

As it follows from the relationship between granulometric composition and treatment time, it is feasible to single out a number of regularities in the material disintegration process under consideration. Say, the data in the table and Fig. 3 are readily approximated with relation:

$$m = m_0\left(1 - \exp\left(-\frac{t}{\tau}\right)\right),$$

where m_0—mass of material feed to disintegration; m—summarized mass of disintegrated material; t—disintegration time; τ—constant with time measurement unit depends on both strength and hardness of the material and prototype structure, including outlet dimensions and a general disintegrator design.

According to the mineralogical analysis of disintegration products at Nikon SMZ745T, stereoscopic microscope among – 2 + 1 mm fraction there are rock aggregates of basic fine-crystalline mass, grains of minerals like picroilmenite, garnet, discrete porphyry inclusions like serpentine, and crusts of carbonate compounds (Fig. 6). As it was expected serpentine is strongly damaged, garnet grains are free of damages, some picroilmenite grains preserved wholeness, the rest picroilmenite is met in fragments with shell-like fractures because of its fragility and secondary changes in the mineral. It is important to state that open minerals had no traces of damage, specific for minerals which opening was gained in autogenous mills. Integrity degree of natural wholeness tends to higher with the mineral hardness growth.

Starting from – 6 + 2 mm size, the grains or fragments of discrete minerals (monomineral fractions) are not detected. This can serve a reason to narrow an outlet gap down to 5 mm

Let consider the shape of course (+ 10 mm) and fine (– 2 + 1 mm) size fractions of disintegration products (Fig. 5). The shape of course disintegrated particles is close to spherical. With reduction in size fraction a shape of particles changes and approaches to angular one (Fig. 5). Alteration of the shape can be considered as a criterion for mineral opening in the hard fraction. The closer the mineral shape to spherical shape, the less is opening degree of hard fraction minerals. Therefore, spherical–shaped particles are subject to further disintegration.

CONCLUSIONS

A device for selective kimberlite disintegration is designed, where attrition instrument is disc brushes made of high-strength steel wire. Test specimens are Manchary pipe kimberlite, rock hardness factor by Protod'yakonov scale is 1.4, volumetric density varies within 2.37–2.43 g/cm^3, the structure is distinguished for the developed carbonatization. The tests were conducted at different disintegration time from 5 till 25 min; granulometric analysis of the obtained product allowed establishment of the relation of the ground material mass versus treatment time.

It is found that among $-2+1$ mm fraction the grains of some minerals (picroilmenite and garnet) are opened without damage traces, specific for minerals subjected to opening in autogenous mills. Integrity of natural mineral wholeness tends to grow with increase in mineral hardness.

The new-proposed process is recommended to prepare geological samples with the yield of a hard fraction or to process alluvial materials rich in clayey components, frozen rocks containing the basic icy binding component.

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