A new generation of structural materials is required that can operate under high dynamic (shock or explosion) loads, at high temperatures, under nonuniform thermal loads, or in aggressive media. Such materials should excel the currently available materials in terms of strength and hardness by 20%, in fracture toughness by 50%, and in wear resistance by a factor of 2.

The principal advantage of ceramics over metals is that all of the main parameters characterizing their performance and structural properties (density, strength, thermal conductivity, resistance, etc.) are variable in a wide range. Superplastic ceramic nanomaterials make it possible to produce complex-shaped pieces with a high dimensional accuracy for aerospace applications. Because of the importance of ceramic materials (oxides, nitrides, and carbides), their proportion in the total output of nanomaterials is continuously growing, being approximately 75% at the moment.

Ceramic nanomaterials are based on regular-sized fine powders of refractory compounds (nitrides, carbides, borides, and oxides), which determine, to a large extent, their properties. The grinding and classifying of submicron powders in amounts that are sufficient to ensure the profitable production of new functional or structural materials presents a separate, challenging scientific and engineering problem. Here, we report experimental and theoretical data concerning a new crushing technique for ceramic materials, specifically, circulation pneumatic crushing using high-velocity submerged gas jets. In this technique, particles are crushed through intensive collisional interaction.

CIRCULATION PNEUMATIC CRUSHING OF CERAMICS

None of the present-day methods for obtaining nanopowders (sol–gel processing, plasma spraying, condensation, electrical explosion of conductors, etc.) allows low-cost large-scale production, because all of them are complicated and laborious, include many steps, and require high-tech special equipment.

Current advances in crushing technology demonstrate that pneumatic crushers using compressed gas at a pressure of 0.4–1.0 MPa are the most advantageous for obtaining submicron powders [1]. It is of fundamental importance that it is only pneumatic methods that can ensure the crushing of superhard materials with minimum milling. The same principle is successfully utilized in circulation pneumatic apparatuses, where a bulk solid is subjected to underexpanded submerged gas jets [2]. The operation of such an apparatus (Fig. 1) is based on the controlled circulation of gas–solid flows in a closed space. The important features of this technique are that product fractions are continuously withdrawn from the crushing zone and that the uncrushed material is multiply recycled. Repeated collisional interaction between particles is thus made possible, which finally leads to particle breaking.

Processes of the Collision Interaction between Ceramic Particles Being Crushed in a Circulation Pneumatic Crusher


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Abstract—A new circulation pneumatic crusher capable of producing submicron powders of refractory materials is presented. A mathematical model is constructed for the dynamic breaking of ceramic macro particles. This model allows the basic laws of shock-wave crushing in the circulation pneumatic apparatus to be analyzed.

Fig. 1. Schematic of the circulation pneumatic apparatus: (1) rotor, (2) circulation tube, (3) nozzles, and (4) exhaust gas directed to a dust collector.
Figure 2 shows a photograph of the crushing zone of the pneumatic apparatus. One can see the tapered bottom of the apparatus, the lower part of the circulation tube, the bed of a material, and the working zone of a jet coming out of a nozzle in the cone vertex (the nozzle is not shown). Particles interact intensively at the jet/bed boundary owing to the large velocity gradient, since their relative velocities in a narrow boundary zone are as high as ≈100–300 m/s. At the same time, the particles do not interact with apparatus walls, which almost rules out milling.

Controllable circulation of the heterogeneous medium makes it possible to combine crushing and classifying and to control these processes independently. Built-in separating elements of various designs and the circulation of the two-phase medium in circuits allows the gas–solid flow dynamics in the separation zone to be adjusted so as to intensify the counterflow centrifugal separation of particles and to control the separation boundary. In circulation pneumatic crushers, the well-timed withdrawal of desired size fractions and the return of coarser particles into the crushing zone raise the energy efficiency of crushing.

The crushing of refractory materials was studied experimentally on alumina, silicon carbide and nitride, and other compounds. Pilot batches of submicron powders were obtained for all materials examined. This confirms the high efficiency of circulation pneumatic crushing. By performing special-purpose experiments and processing a large body of experimental data, we revealed some specific features of the new method of particle diminution and separation.

We studied the dependence of the weight yield of desired fractions on the rotational speed of the rotor at a varied gas flow rate (Fig. 3). We found that the weight yield of all desired fractions falls as the rotational speed is increased to ~4000 rpm and grows slightly as the rotational speed is further raised. Furthermore, both particle size and the weight yield of desired fractions are almost independent of gas flow rate. This finding suggests that some flow restructuring occurs in the apparatus under the conditions examined. Measuring the recovery of particles smaller than 5 µm demonstrated that this restructuring favors the formation of fine fractions. In order to relate these facts to the flow pattern produced by the rotor, we carried out an empirical estimation of the circulation flow rate in the free space of the apparatus. It was found that, as the rotational speed of the rotor is increased, multiple recycling of the entire batch becomes progressively less necessary. Accordingly, progressively less working gas is required for the separation of desired fractions.

In Fig. 4, we compare the amounts of gas (compressed air) necessary for obtaining desired fractions in the circulation pneumatic crusher and in an AFG mill (Hosokawa Micron Corp.) [3]. For fine fractions (e.g., for a particle size of 10 µm), the circulation pneumatic apparatus provides for 30% energy saving. These