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# TREATMENT OF DIFFERENT MATERIALS BY DISINTEGRATOR SYSTEMS

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**Abstract.** First part of the paper focuses on the development of DS-series disintegrators for processing different materials in direct, separative, and selective grinding conditions. The principles of DS-series disintegrators, disintegrator systems design, and kinetic parameters of a small laboratory disintegrator DSL-160 and of a semi-industrial disintegrator DSL-115 are described. The second part of the paper concentrates on the disintegrator milling technology used for mechanical treatment of different metallic (cast iron and stainless steel chips and used hardmetals) and non-metallic (ceramics and rubbers) materials. Main attention is paid to different grinding technologies (direct, separative, and selective grinding), to the grindability of brittle, ductile and composite metallic materials, and to the evaluation of the granulometry and morphology of the ground product. Results of disintegration of ceramic (quartz sand and spar) and polymeric (rubber) materials are presented. Grindability of rubber and the influence of technological parameters (cryogenic grinding, grinding at room temperature) on the product are discussed.

**Key words:** disintegrator, disintegrator milling and grinding, recycling of metals, metal powders, utilization of tyres.

## 1. INTRODUCTION

Grinding by collision is an effective method of materials refining. Rumpf [1] and Primer [2] were the first to use collision for brittle materials. A new type of disintegrators for materials treatment by collision has been developed by the authors [3,4]. Disintegrator is one of the few devices for materials treatment by collision. Materials refining takes place as a result of fracturing the treated material. By the collision of the particle with a grinding element, from the point of contact an intensive pressure wave spreads (Fig. 1). Stresses are approximately an order higher than the strength of the material. In comparison with traditional grinding methods and equipment (jaw crusher, mortar, hand-mill, quern, vibro-

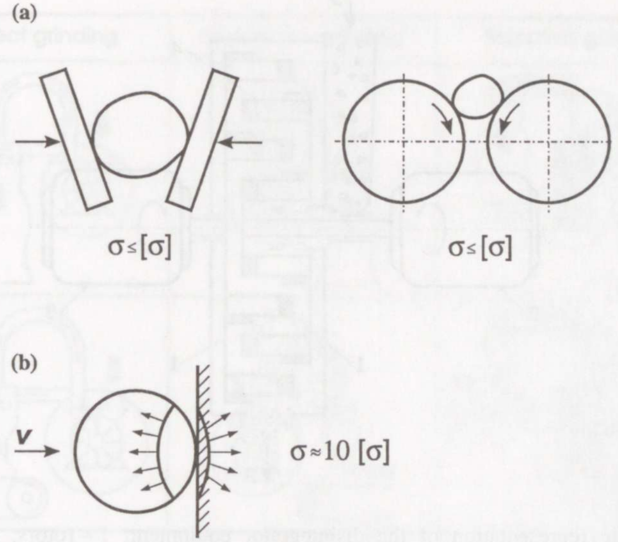


**Fig. 1.** Stresses in the particle: (a) traditional grinding methods; (b) grinding by collision; [σ] – strength of the material.

and ballmill), the parameters of materials treatment in the disintegrator are essentially different (Table 1). The principal scheme of disintegrator equipment is shown in Fig. 2.

**Table 1.** Comparison of the parameters of materials treatment by traditional methods and by collision [5]

| Parameter | Traditional method | Collision |
|---|---|---|
| Loading velocity, m/s | 0.1–10 | 30–200 |
| Loading time, s | $10^{-2}$–$10^{-1}$ | $10^{-6}$–$10^{-5}$ |
| Time spent in active zone, s | 1–10 000 | $10^{-2}$ |
| Ratio of the stresses to material strength, σ/[σ] | ≤1 | ≈10 |

In contemporary industry, the demand and the prices of raw materials are increasing. Thus, economy of the resources and recycling of materials are topical issues. Circulation of metals assumes the formation of metal scrap (metallurgical, industrial, and old) and of waste metal [6]. However, utilization of the industrial scrap (formed during the manufacturing process), in particular the use of metal chips in the metallurgical process, is irrational. Disintegrators can be effectively used for the treatment of the industrial metallic wastes, especially for different kinds of chips [7]. Besides milling, due to high intensity collisions, the ground material is mechanically activated. By disintegration, the grinding of mineral materials, e.g., of the mixture of quicklime, quartz sand and water, the raw materials of silicalcite, activates the materials and strengthens the final product [8].

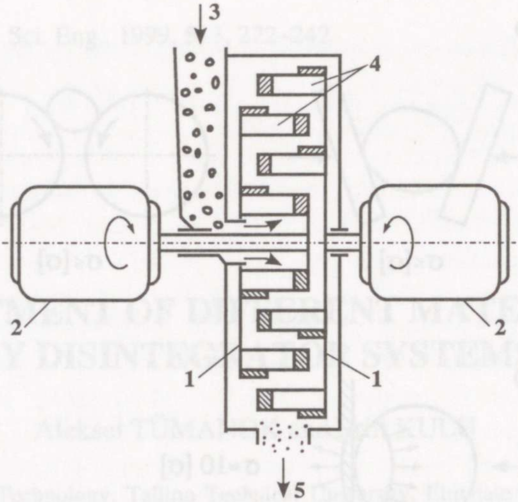


Fig. 2. Schematic representation of the disintegrator equipment: 1 – rotors; 2 – electric drives; 3 – material supply; 4 – grinding elements; 5 – output.

The highest selectivity rate of grinding is observed at treatment by collision [9]. For example, selective grinding of slags and slimes allows separation of valuable components.

Massive polymeric, domestic and industrial, wastes cause pollution. As a result of their burning in furnaces, hazardous gases and organic cancerogenic compounds are formed. Their utilization through disintegration seems more rational. Pretreated plastics may be used to produce new composite plastics and rubber.

## 2. DISINTEGRATOR SYSTEMS FOR MATERIALS TREATMENT

To treat different materials, multifunctional DS-series disintegrators have been developed, operating in three different modes: direct grinding, separative grinding, and selective grinding (Fig. 3) [5]. The DS-series disintegrators include small laboratory disintegrator systems DSL-160 with the capacity of some kilograms per hour, DSL-115 (several hundred kilograms per hour), DS-158 (several tons per hour), DS-104 (10 t/h), and DSA-600 (16 t/h).

DS-series disintegrators and disintegrator systems have been designed on the basis of the following principles:

– convenience of operating and service,

– modular design,

– possibility to use an autonomous and ecologically clean closed gas system,

– possibility to realize direct, separative, selective and selective-separative grinding modes,

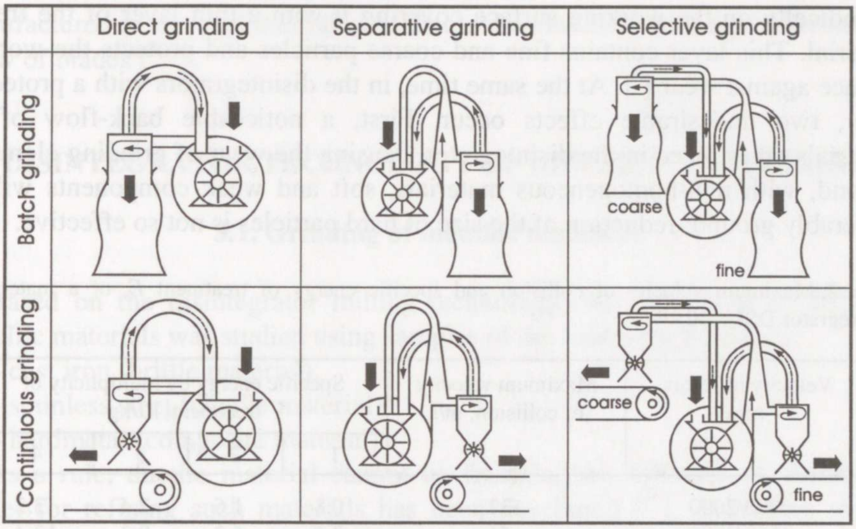


**Fig. 3.** Different modes of disintegrator grinding of materials.

– simplicity of switching from one mode to another,
– elastic support of the motors,
– possibility to use automatic balancing of the rotor system,
– high level of safety.

DS-series disintegrators are intended for different technologies and purposes. That implies designing rotors, classifiers and other auxiliary devices according to the customer demands. With slight modifications, DS-series disintegrators can be adjusted to solve different problems, for example:

– maximum output of a certain size of the ground material,
– maximum volume (bulk) density of the ground product,
– high activation level of the materials, such as catalysators, fertilizers, water,
– micromixing and homogenization of materials (dry-dry, dry-liquid, liquid-liquid),
– technological operations combined with chemical reactions (e.g., polymerization).

The main factor in materials treatment is the specific energy of treatment regarding the grinding effect (grindability) as well as the economic aspects. The results of such an analysis of the disintegrator DSL-160 are described in [10] and in Table 2. The productivity and the specific energy of disintegrator DSL-115 are shown in Table 3. Although in Table 3 data for direct and selective grinding are similar, in the second case the product is different containing fine and coarse fractions.

By the treatment of highly abrasive materials, the working surfaces of the grinding elements are subjected to intensive wear. In this case, rotors with plane working surfaces of the grinding elements are used. Portions of materials fall periodically on the working surface covering it with a thin layer of the treated material. This layer contains fine and coarse particles and protects the working surface against wear [5]. At the same time, in the disintegrators with a protective layer, two undesirable effects occur. First, a noticeable back-flow of the materials takes place in the disintegrator, causing the wear of grinding elements. Second, with non-homogeneous materials, soft and weak components will be preferably ground; reduction of the size of hard particles is not so effective.

**Table 2.** Maximum velocity of collision and specific energy of treatment $E_s$ of a material in disintegrator DSL-160

| Velocity of rotors, rpm | Maximum velocity of collision, m/s | Specific energy by multiplicity of treatment, kJ/kg | | | |
|---|---|---|---|---|---|
| | | 1 | 2 | 3 | 4 |
| 2000/2000 | 32 | 0.8 | 1.6 | 2.4 | 3.2 |
| 4000/4000 | 64 | 3.1 | 6.2 | 9.3 | 12.4 |
| 6000/6000 | 96 | 7.0 | 14.0 | 21.0 | 28.0 |
| 8000/8000 | 128 | 12.4 | 24.8 | 37.2 | 49.6 |
| 10000/8000 | 142 | 15.2 | 30.4 | 42.6 | 60.8 |
| 10000/9000 | 151 | 17.3 | 34.6 | 51.9 | 69.2 |
| 10000/10000 | 160 | 19.4 | 38.8 | 58.2 | 77.6 |

**Table 3.** Productivity of the disintegrator DSL-115 and specific energy of treatment

| Direct grinding | | | Separative grinding | | | Selective grinding | | |
|---|---|---|---|---|---|---|---|---|
| Rotors, number of rows | Productivity, t/h | Specific energy, kJ/kg | Max product size, µm | Productivity, t/h | Specific energy, kJ/kg | Rotors, number of rows | Total productivity, t/h | Specific energy, kJ/kg |
| 2 | 1.0 | 14.0 | | | | 2 | 1.0 | 14.0 |
| 3 | 0.9 | 21.2 | 100 | 0.1 | 180 | 3 | 0.9 | 21.2 |
| 4 | 0.7 | 27.0 | | | | 4 | 0.7 | 27.0 |
| 5 | 0.5 | 31.7 | 250 | 0.25 | 72 | 5 | 0.5 | 31.7 |

In DS disintegrator systems, the ground material ejected from the rotors carries significant kinetic energy which can be used for further transportation of the material [10,11]. This is taken into account in disintegrators of direct grinding (for transportation of the material into the bunker or into the classifier for separative or selective grinding).

The separation systems used in DS-series disintegrators are based on the aerodynamic forces. A special inertial classifier with a closed air or gas system has been developed [12,13]. This system is autonomous and ecologically clean due to the use of the kinetic energy of the output material. The system does not need any additional devices of transportation or fans. For various materials and disintegrator systems, different inertial classifiers have been designed and manufactured as an axial inertial classifier and a classifier with a grid formed by a row of blades [4,13].

## 3. DISINTEGRATOR TECHNOLOGY OF DIFFERENT MATERIALS

### 3.1. Grinding of metallic materials

Based on the disintegrator milling technology, the utilization of different metallic materials was studied using samples of the following materials:
– cast iron (brittle material),
– stainless steel (ductile material),
– hardmetal (composite material).

As a rule, ductile material cannot be fractured by collision. A theoretical model for refining such materials has been developed [14]. According to this model, powder can be produced from ductile materials. That is proved also in practice. Metal chips of stainless steel AISI 316 have been reduced by collision treatment in DSL-160 to metal powder, sized 10–20 μm.

As may be assumed, materials grindability and the properties of the ground product depend on the mechanical properties of the materials.

#### 3.1.1. Experimental

**Grindability.** Metal chips were ground in the disintegrator DSL-160 by direct and separation milling at the rotation velocities from 2000 to 10 000 rpm. The velocities between the impact elements of the disintegrator and the particles of the grinding material ranged from 30 to 160 m/s. The milling step was analysed by the granulometric method [15].

To obtain metal powders with predetermined granulometry, chips were ground at various rotation velocities (2000, 4000, 6000, 8000, and 10 000 rpm). In direct grinding, to achieve the fraction required, multi-stage grinding was used. To estimate grindability, specific energy of grinding, $E_s$, was used [10].

The effect of mechanical activation was estimated on the basis of particle hardening in the milling process, determined by measuring the lattice parameter with the X-ray analyser.

**Granulometry.** The granulometry of a ground product was described by the modified Rosin–Rammler distribution function [15]

$$f_m(x) = \frac{n-1}{m}\left(\frac{x-x_0}{m}\right)^{n-1} \exp\left(-\frac{n-1}{n}\left(\frac{x-x_0}{m}\right)^{n}\right), \qquad (1)$$

where $n$, $m$, and $x_0$ are parameters of the distribution. Logarithmic size of the particle, $x$, is given as

$$x = \log_k \frac{X_0}{X}, \qquad (2)$$

where $X$ is the natural size of the particle of the material, $X_0$ is the upper limit of its size, and $k$ is the coefficient (ratio) of the sieve system used in the experiments (in our experiments $k = 2$).

**Morphology.** To study the morphology of the powder particles, after preparation the powders were investigated by two different methods. In the first method, the powder was placed on a glass plate. For image production, optical microscope (OM) Nikon Microphot-FX was used. Using the transmission regime of the OM, the projections of the powder particles (PPP) were transferred through a video system into the computer. In the second case, the cross-section with polish (CSP) was prepared and the image was obtained by means of the reflecting regime of the OM. Image processing and measurements were conducted by the image analysis system Image-Pro Plus 3.0 with the help of Materials-Pro, a special materials analysis program [16]. The qualitative evaluation of powders was performed by the scanning electron microscope JEOL JSM-840A. The Materials-Pro facilitated the calculation of the following parameters:

– *area* of the object ($A$),
– *mean diameter* ($d_m$), the average length of diameters taken at 5 degree intervals around the mass centre of the blob [17],
– *perimeter* ($P$) (length of the outline) of the object,
– *aspect* ($As$), the ratio of the major and minor axes of the ellipse, equivalent to the object (i.e., an ellipse with the same area and first and second moments); $As > 1$.

*Roundness* ($R$) of the particles is calculated as

$$R = \frac{P^2}{4\pi A}. \qquad (3)$$

Roundness of a disc is equal to one; other shapes have a roundness greater than one.

*Specific surface area* (SSA) of the volume unit of the powder, $S_v$, is calculated from [18]

$$S_v = \frac{4}{\pi} \Sigma P_i, \ \mathrm{m^2\,mm^{-3}}, \qquad (4)$$

where $\Sigma P_i$ is the total perimeter of the particles in the unit of the surface area:

$$\Sigma P_i = \frac{\text{total perimeter of particles}}{\text{total area of particles}}. \qquad (5)$$

In the PPP investigations, the SSA of a volume unit of the powder is calculated as

$$S_v = \frac{3}{2}\Sigma P_i,\ \mathrm{m^2mm^{-3}}, \tag{6}$$

and the SSA of the mass unit, $S_{\mathrm{m}}$, as

$$S_{\mathrm{m}} = \frac{\Sigma S_v}{\rho},\ \mathrm{m^2g^{-1}}, \tag{7}$$

where $\Sigma S_v$ is the SSA, calculated from (4), and $\rho$ is powder density.

### 3.1.2. Grindability of metal chips

**Cast iron chips.** Cast iron chips with initial particle size from 1 to 20 mm were ground by direct milling. As shown in Fig. 4, the granulometry of the ground cast iron GG15 depends on the specific energy of grinding. By the treatment with low specific energy, particle refining depends on the direct fracturing of initial chips because the number of impacts (cycles) is low.

Multi-stage grinding produces a new finer fraction after each grinding. This fine product is the result of the direct fracturing of particles, and it can be used in powder metallurgy. Figure 5 illustrates the shape of the cast iron powder ground at optimal parameters. As can be seen, particle shape is mainly isometric.

The results of the granulometry and morphology studies of the produced cast iron powder of fraction +160–315 μm are illustrated in Fig. 5 and Table 4. The main fraction of the ground powder +60–180 μm, as shown in Table 4, can be used in powder metallurgy. Coarse cast iron powder (from 0.3 to 0.6 mm) can be used, for example, for surface blastering before spraying the coatings.

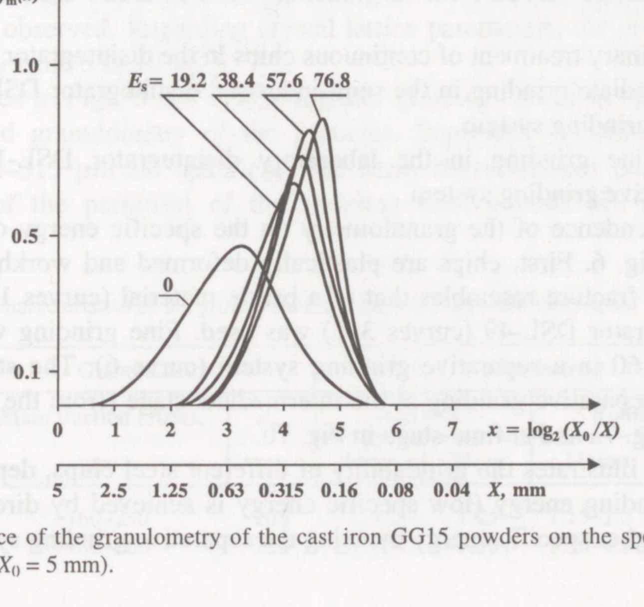


**Fig. 4.** Dependence of the granulometry of the cast iron GG15 powders on the specific grinding energy $E_s$, kJ/kg ($X_0$ = 5 mm).

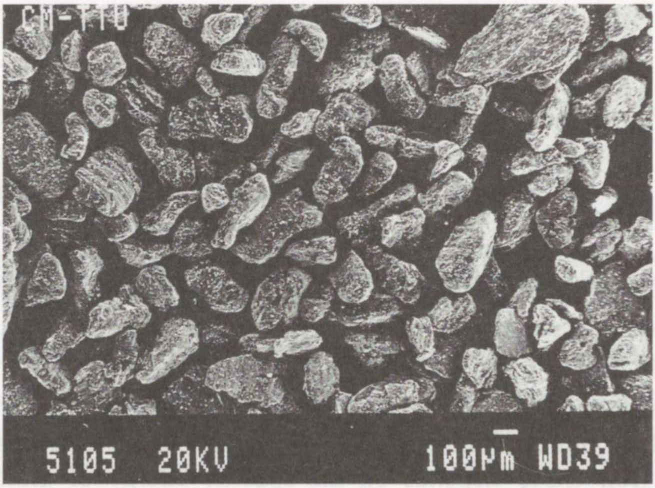


**Fig. 5.** Shape of the particles of the ground cast iron GG15 powder (×40).

**Table 4.** Main characteristics of the ground cast iron with granulometry from 160 to 315 µm

| Method | Granulometry | | Morphology | | | |
|---|---|---|---|---|---|---|
| | Main fraction (70%), µm | $d_m$, µm | Aspect *As* | | Roundness *R* | |
| | | | Main | Mean | Main | Mean |
| PPP | +180–245 | 220 | 1.25–2.05 | 1.8 | 1.45–1.85 | 1.7 |
| CSP | +145–190 | 165 | 1.3–2.3 | 2.05 | 2.35–4.2 | 3.95 |

**Stainless steel chips.** Stainless steel AISI 316 chips were treated in three steps:

– preliminary treatment of continuous chips in the disintegrator DS-158,
– intermediate grinding in the semi-industrial disintegrator DSL-49 using the direct grinding system,
– final fine grinding in the laboratory disintegrator DSL-160 using the separative grinding system.

The dependence of the granulometry on the specific energy of treatment is shown in Fig. 6. First, chips are plastically deformed and workhardened. As a result, their fracture resembles that of a brittle material (curves 1–2) [14]. Next, the disintegrator DSL-49 (curves 3–5) was used. Fine grinding was conducted with DSL-160 in a separative grinding system (curve 6). The structure of the powder of separative grinding at the intermediate stage (from the circulation) is shown in Fig. 7a and at final stage in Fig. 7b.

Figure 8 illustrates the grindability of different steel chips, depending on the specific grinding energy (low specific energy is achieved by direct multi-stage grinding, higher specific energy by using the separative grinding system). By low

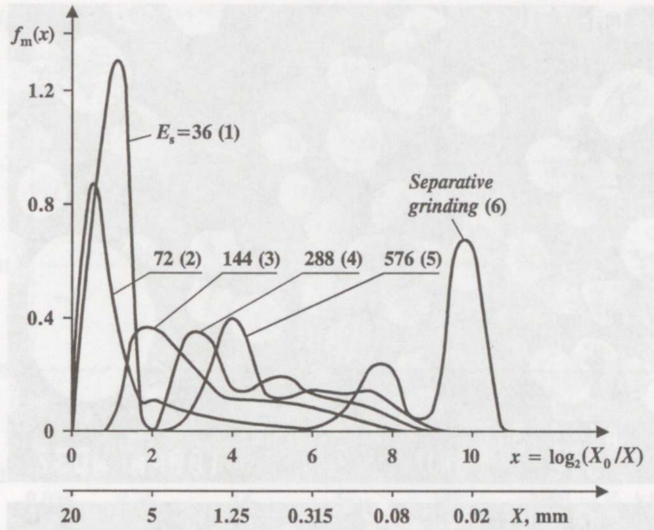


**Fig. 6.** Dependence of the granulometry of stainless steel AISI 316 powders on the specific grinding energy $E_s$, kJ/kg ($X_0$ = 20 mm).

specific energy, as shown in Fig. 8, high speed (HS) steel achieves better refining than stainless and bearing steels, explained by higher plasticity of the latter. At higher specific energy of grinding, after the work hardening of the material, the rate of refining of the bearing and stainless steel chips increases, being higher than for the HS steel. The intensity of grinding of the HS steel chips depends linearly on the specific energy of grinding.

As a result of the X-ray investigations of the non-ground chips and of the ground product, the effect of cold hardening of the particles caused by impact grinding was observed. Regarding crystal lattice parameters, the difference was approximately from 5 to 10% [7].

As it is seen in Figs. 6 and 7, disintegrator grinding results in the changes of the shape and granulometry of the particles. Separately ground particles of fraction +160–315 μm are spherical. The main characteristics (size and form distribution of the particles) of the stainless steel powder are presented in Table 5.

**Table 5.** Main characteristics of the ground stainless steel with granulometry from 160 to 315 μm

| Method | Granulometry | | Morphology | | | |
|---|---|---|---|---|---|---|
| | Main fraction (70%), μm | $d_m$, μm | Aspect $As$ | | Roundness $R$ | |
| | | | Main | Mean | Main | Mean |
| PPP | +160–230 | 200 | 1–1.2 | 1.25 | 1.15–1.3 | 1.25 |
| CSP | +180–260 | 220 | 1.1–1.4 | 1.35 | 1.35–1.8 | 1.7 |

(a)

(b)

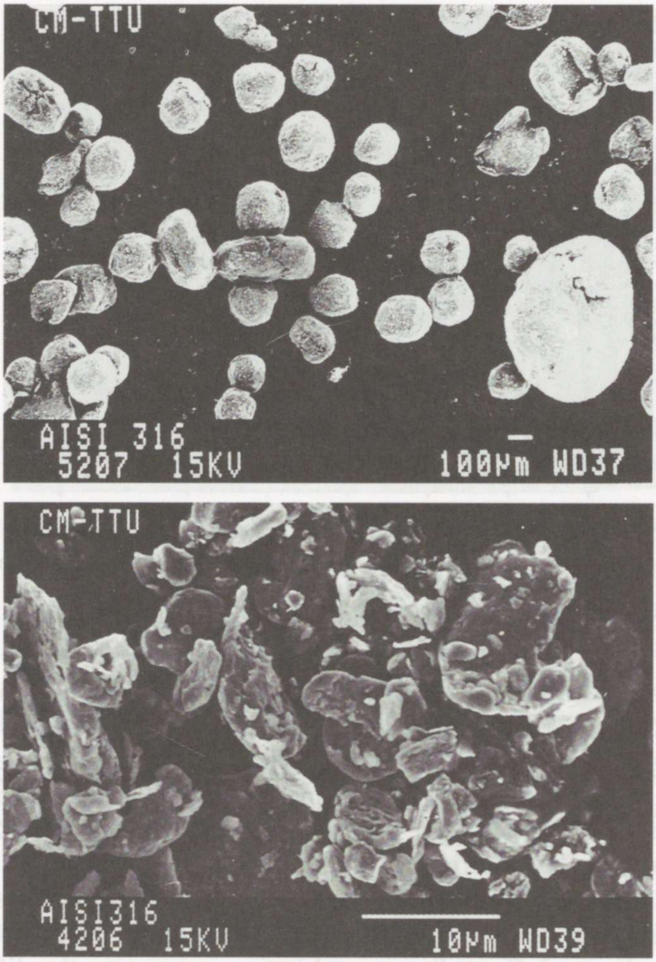


**Fig. 7.** Shape of the particles of stainless steel AISI 316 powders: (a) powder +160–315 µm at the intermediate stage of separative grinding (×40); (b) final product of separative grinding (×250).

### 3.1.3. Grindability of the hardmetal

The technology of producing hardmetal powder from the used (recycled) hardmetal WC-8Co included preliminary thermocyclic treatment and mechanical refining of the worn hardmetal parts and final milling of the pretreated particles by collision in a disintegrator mill. Based on the study of grindability and fracture mechanism of a hardmetal, a brittle material, we can state that hardmetal milling takes place as a result of the direct fracture [19]. The grindability curves of a hardmetal with the initial particle size +1.25–2.5 mm are shown in Fig. 9. The particles were equiaxed in form and their microstructure was a typical tungsten–carbide-based hardmetal structure. Hardmetal particles with their particle size from 60 to 500 µm were used as the hard phase of composite coatings. Figure 10 demonstrates the particle shape of the powder +125–250 µm.

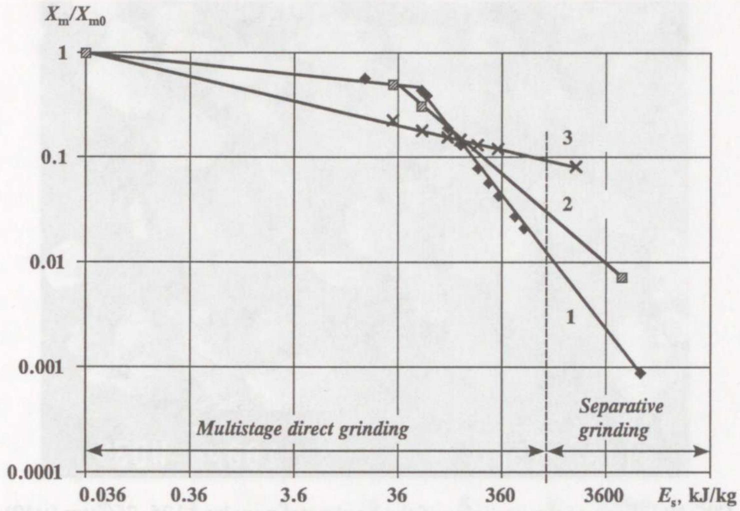


**Fig. 8.** Dependence of the ratio of the medium size $X_m$ of the ground product to the initial size $X_{m0}$ of the material on the specific grinding energy $E_s$: 1 – stainless steel AISI 316; 2 – ball-bearing steel 100Cr6; 3 – high speed steel HS 9-1-2-6.

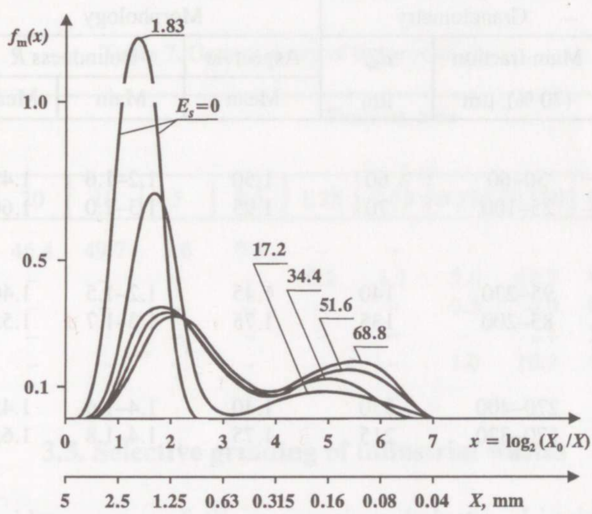


**Fig. 9.** Dependence of the granulometry of the hardmetal powder on the specific grinding energy $E_s$, kJ/kg ($X_0$ = 5 mm).

The main characteristics of the hardmetal powders of different fractions (size and form distribution of the particles) are given in Table 6. As can be seen, the main fraction (70%) of the ground powder +60–125 μm (used as a powder for subsequent detonation spraying) is 30–60 μm, and that of the ground powder +125–250 μm (used as a component of the composite powder for fused coatings) is 95–230 μm [20].

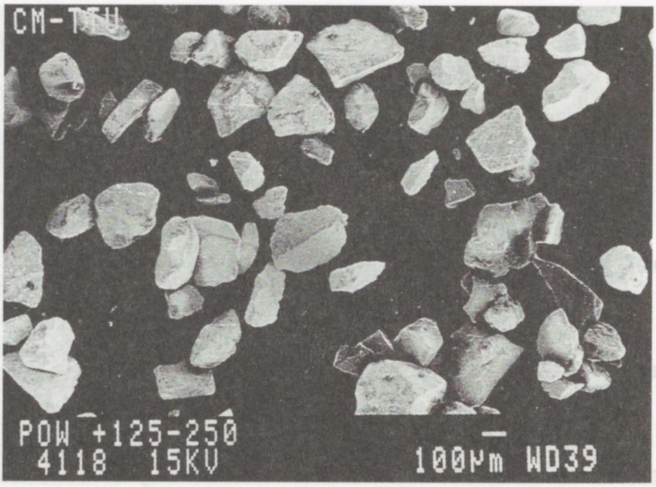


**Fig. 10.** Shape of the particles of the hardmetal powder +125–250 μm (×40).

**Table 6.** Main characteristics of hardmetal powders

| Type of the powder and method | Granulometry | | Morphology | | | Specific surface, $m^2/g$ |
|---|---|---|---|---|---|---|
| | Main fraction (70 %), μm | $d_m$, μm | Aspect $As$ | Roundness $R$ | | |
| | | | Mean | Main | Mean | |
| +60–125 μm | | | | | | |
| PPP | 30–60 | 60 | 1.50 | 1.2–1.6 | 1.45 | 0.0060 |
| CSP | 25–100 | 70 | 1.95 | 1.3–2.0 | 1.60 | 0.0049 |
| +125–250 μm | | | | | | |
| PPP | 95–230 | 140 | 1.45 | 1.2–1.5 | 1.40 | 0.0030 |
| CSP | 85–200 | 135 | 1.75 | 1.3–1.7 | 1.55 | 0.0028 |
| +250–500 μm | | | | | | |
| PPP | 270–400 | 330 | 1.40 | 1.4–1.6 | 1.45 | 0.0014 |
| CSP | 170–320 | 215 | 1.75 | 1.4–1.8 | 1.65 | 0.0018 |

## 3.2. Grinding of ceramic materials

Grinding of glass was investigated to achieve the predicted mean particle size. Figure 11 shows the granulometry of the initial material and its change, depending on the specific grinding energy. The mean size of the ground product by grinding with 75 kJ/kg is about 0.1 mm, similarly to grinding with ball mill. From the granulometry and sieve analysis (Table 7) follows that the material ground by ball mill contains more coarse and more very fine particles in comparison with disintegration by collision. Treatment by collision provides a narrower distribution.

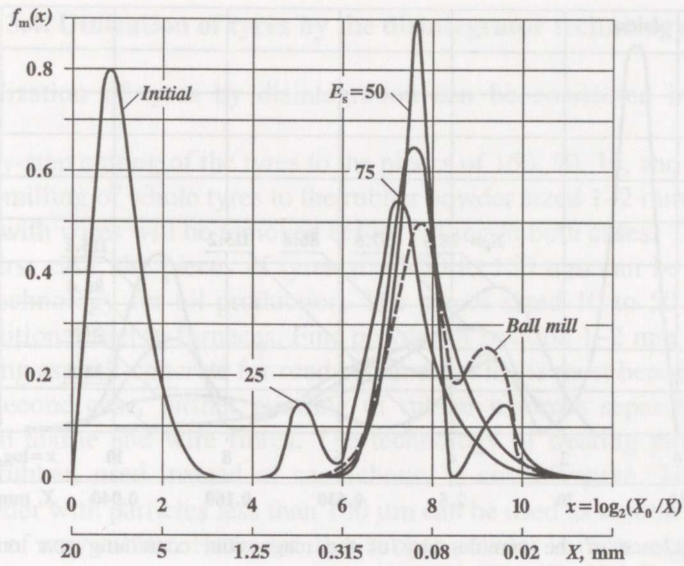


**Fig. 11.** Granulometry of the glass powder, ground by different specific grinding energies $E_s$, kJ/kg ($X_0 = 20$ mm).

**Table 7.** Granulometry of the ground glass

| Specific energy of grinding $E_s$, kJ/kg | Fraction, mm | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | 20 | 10 | 5 | 2.5 | 1.25 | 0.63 | 0.315 | 0.160 | 0.08 | 0.04 | –0.04 |
| Initial | 46.4 | 49.7 | 3.6 | 0.3 | – | – | – | – | – | – | – |
| 25 | – | – | – | – | 0.2 | 1.1 | 5.6 | 17.7 | 40.0 | 23.6 | 11.8 |
| 50 | – | – | – | – | – | – | 0.5 | 6.0 | 62.5 | 20.0 | 11.0 |
| 75 | – | – | – | – | – | – | – | 2.1 | 58.5 | 29.8 | 9.6 |
| Ball mill | – | – | – | – | – | – | 1.0 | 10.2 | 43.9 | 24.5 | 20.4 |

## 3.3. Selective grinding of industrial wastes

Let us consider wastes of the magnesium industry. Liquid magnesium is produced by electrolytic means from the mixture of NaCl and KCl salts. The waste, slim (spar) of liquid salt, is cooled. The slim contains metallic magnesium from 25 to 50%. The problem is how to extract metallic magnesium from the slim.

It appears that the most effective method is treatment by collision. Figure 12 shows the dependence of the granulometry of the feed and that of the spar (25% Mg + 75% NaCl, KCl salt) on the specific energy of treatment. The distribution function of the granulometry is by higher energies multimodal.

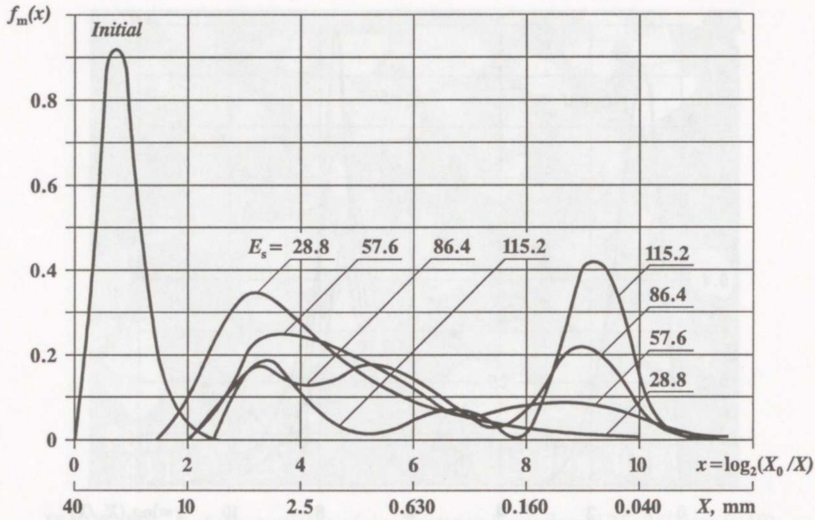


**Fig. 12.** Dependence of the granulometry of the magnesium containing spar on the specific treatment energy $E_s$, kJ/kg ($X_0$ = 40 mm).

Figure 13 shows the same dependence for the metallic magnesium and the salt. Granulometry of the metallic Mg changes little. Granulometry of the salt component changes essentially. From Fig. 13 it follows that when the specific energy is higher than 115 kJ/kg then the metallic Mg can be extracted from the salt simply by screening.

On the basis of our investigations, a disintegrator DS-104 with a productivity of 10 t/h was designed and manufactured for the Solikamsk Magnesium Factory.

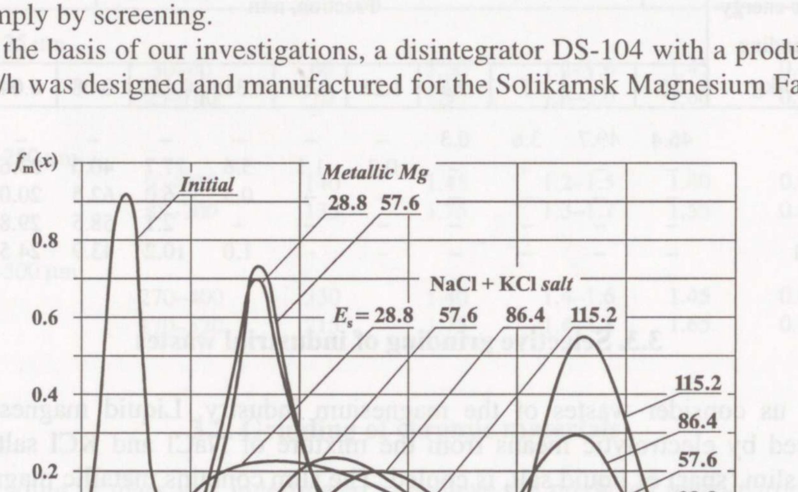


**Fig. 13.** Dependence of the granulometry of the metallic magnesium and salt matrix on specific treatment energy $E_s$, kJ/kg ($X_0$ = 40 mm).

### 3.4. Utilization of tyres by the disintegrator technology

The utilization of tyres by disintegration can be conducted in two ways (Fig. 14):

– step-by-step cutting of the tyres to the pieces of 150, 50, 10, and 2 mm,
– direct milling of whole tyres to the rubber powder sized 1–2 mm.

Collars with wires will be removed before cutting in both cases.

In the first case, the pieces of tyres sized 50 to 150 mm can be used in the pyrolysis technology for oil production. The pieces sized 10 to 50 mm can be used as additional fuel in furnaces. Fine powder of fraction 1–2 mm can be used for producing asphalt-concrete for road pavement. That is most beneficial.

In the second case, further grinding of rubber assumes separation of pure rubber from textile and wire fibres. The technology of treating pure rubber to reclaimed rubber, used instead of caoutchouc, is cost-effective. The ultra-fine rubber powder with particles less than 100 µm can be used as carbon black in the production of new rubber. However, this rubber powder is more expensive than carbon black.

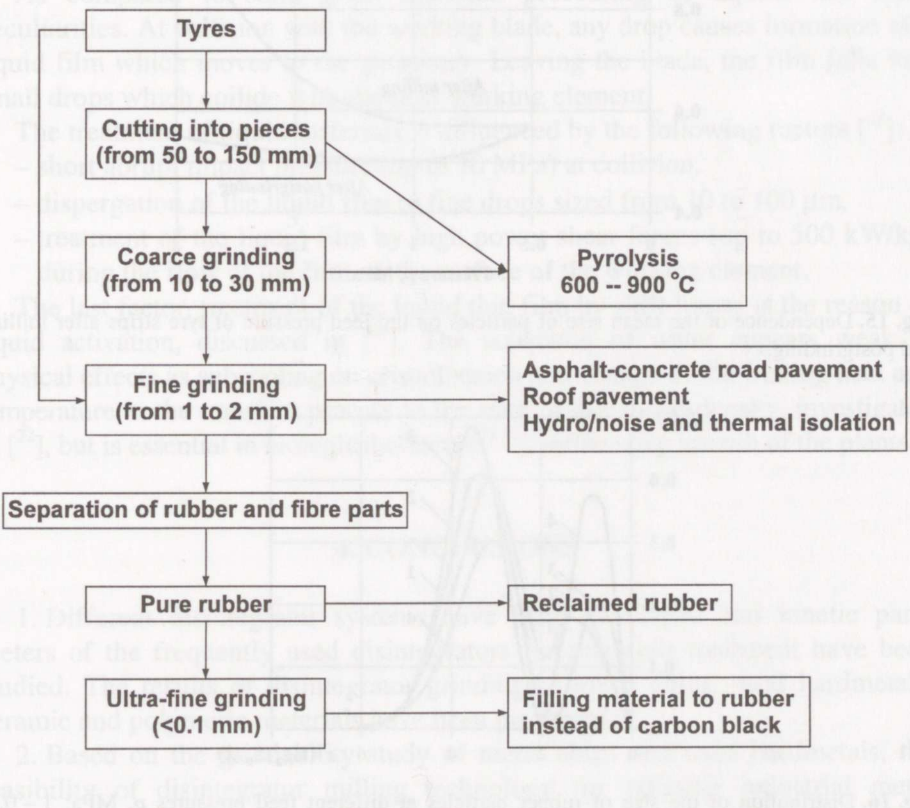


**Fig. 14.** Principal scheme of utilization of tyres at normal temperature.

Direct grinding of whole tyres to the powder of 1–3 mm is more effective. In this case, the disintegration system consists of two units, for milling and postgrinding. The granulometry of the product depends on the pressure of the tyres against the milling tool. The mean size of the product after milling is shown in Fig. 15. The dependence of the mean size of the particles on the pressure is strong. Postgrinding evens the size of the particles. The granulometry of the final product is shown in Fig. 16. It can be seen that the distribution function is two-modal.

Comparative grinding of pure rubber at normal and low temperatures was also conducted. The results are shown in Fig. 17. As can be seen, the relative mean size $X_m/X_{m0}$ and the relative increase in the specific surface area $\Delta S/S_0$ of rubber particles, depend on the specific treatment energy $E_s$. Figure 17 shows that cryogenic grinding is more effective, particularly because of the increase in the surface area of rubber particles.

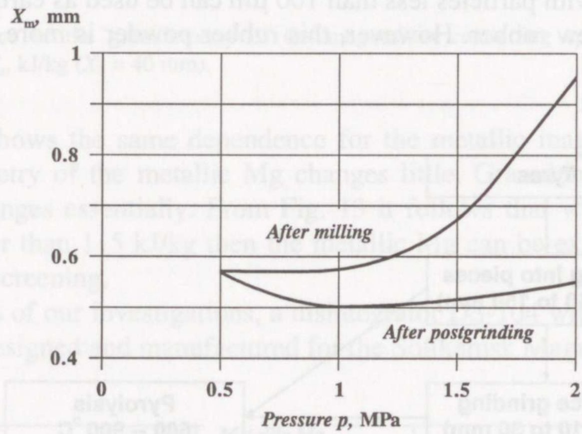


**Fig. 15.** Dependence of the mean size of particles on the feed pressure of tyre strips after milling and postgrinding.

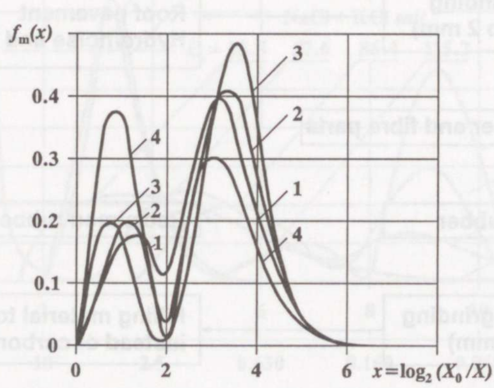


**Fig. 16.** Distribution of the size of rubber particles at different feed pressures $p$, MPa: 1 – 0.5; 2 – 1.0; 3 – 1.5; 4 – 2.0 ($X_0 = 5$ mm).

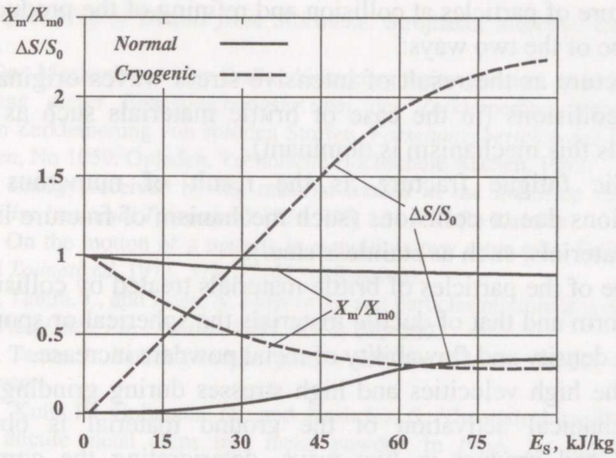


**Fig. 17.** Dependence of the granulometry and specific surface area of ground rubber on specific treatment energy by normal and cryogenic treatment.

## 3.5. Treatment of liquid materials

As compared to solid grain material, processing of liquids has some peculiarities. At collision with the working blade, any drop causes formation of a liquid film which moves to the periphery. Leaving the blade, the film falls into small drops which collide with the next working element.

The treatment of liquid materials is influenced by the following factors [21]:

– short abrupt impact pressure (up to 10 MPa) at collision,

– dispergation of the liquid film to fine drops sized from 10 to 100 μm,

– treatment of the liquid film by high power shear forces (up to 500 kW/kg) during the flow of the film on the surface of the working element.

The last factor, treatment of the liquid thin film by shift forces is the reason of liquid activation, discussed in [21]. The activation of water appears weak in physical effects as subcooling on cristallization and change of the wetting heat and temperature in the transient process to the state of maximum density, investigated in [22], but is essential in biological effects [23,24], influencing growth of the plants.

# 4. CONCLUSIONS

1. Different disintegrator systems have been developed and kinetic parameters of the frequently used disintegrators for materials treatment have been studied. The results of disintegrator grinding of metal chips, used hardmetals, ceramic and polymeric materials have been presented.

2. Based on the grindability study of metal chips and used hardmetals, the feasibility of disintegrator milling technology for utilizing industrial metal wastes has been shown.

3. The fracture of particles at collision and refining of the product to be ground can occur in one of the two ways:

– direct fracture as the result of intensive stress waves originated from high velocity collisions (in the case of brittle materials such as cast iron and hardmetals this mechanism is dominant),

– low cyclic fatigue fracture as the result of numerous local plastic deformations due to collisions (such mechanism of fracture is dominant for ductile materials, such as stainless steel).

4. The shape of the particles of brittle materials treated by collision approaches the isometric form and that of ductile materials the spherical or sponge form. As a result, the bulk density and flowability of metal powders increase.

5. Due to the high velocities and high stresses during grinding, an additional effect of mechanical activation of the ground material is observed, which influences the end product in two ways, deteriorating the compactedness of powders and activating the diffusion in the technological processes.

6. The produced powders (cast iron and steel powders for powder metallurgy, zinc alloy powders for mechanical coatings, and hardmetal powders for thermal spray coatings) can be used as raw material in powder technology.

7. Based on the study of grindability of brittle ceramic materials, their direct fracture is a result of the intensive stress waves originated by high velocity collisions, where low specific energy of grinding is needed. High selectivity of the grinding of multicomponent materials has been obtained.

8. The possibility of utilizing tyres with disintegrator milling at normal temperature has been demostrated and principal design of a disintegrator system for the treatment of rubber has been proposed.

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## MATERJALIDE TÖÖTLEMINE DESINTEGRAATORSEADMEIS

Aleksei TÜMANOK ja Priit KULU

On antud ülevaade desintegraatori tööpõhimõttest, töödeldavale materjalile mõjuvatest jõududest, materjalide desintegraatorjahvatussüsteemide loomisest ja nende arendamise suundadest. Põhitähelepanu on pühendatud mõnede materjali-gruppide (metalsete, polümeersete ja keraamiliste materjalide) desintegraator-

jahvatamisele erinevate jahvatussüsteemide (otse-, separatsioon- ja selektsioonjahvatuse) abil. On toodud andmed metallilaastu, kasutatud kõvasulami, kvartsliiva, magneesiumiräbu ja kummi jahvatatavuse kohta ning esitatud jahvatusprodukti (metalli- ja kõvasulampulbrite, jahvatatud liiva, kummipuru ja muu) granulomeetriat ning morfoloogiat iseloomustavad näitajad.