Proven Excellence.

Selection of the Comminution Technology according to the Material Properties of the Product

Business Unit
GRINDING & DISPERSING

Selection of the Comminution Technology according to the Material Properties c

Dr. Stefan Mende | NETZSCH-Feinmahltechnik GmbH, Selb | Germany
Christian Höfels | NETZSCH Trockenmahltechnik GmbH, Hanau | Germany

1. Introduction

In addition to agglomeration, separation and mixing, comminution is one of the four basic operations in mechanical process engineering. Based on the possible material properties and the desired quality criteria, this article will discuss the criteria according to which a comminution technology should be selected in order to facilitate the most efficient and, at the same time, most powerful process.

2. Basics of Comminution

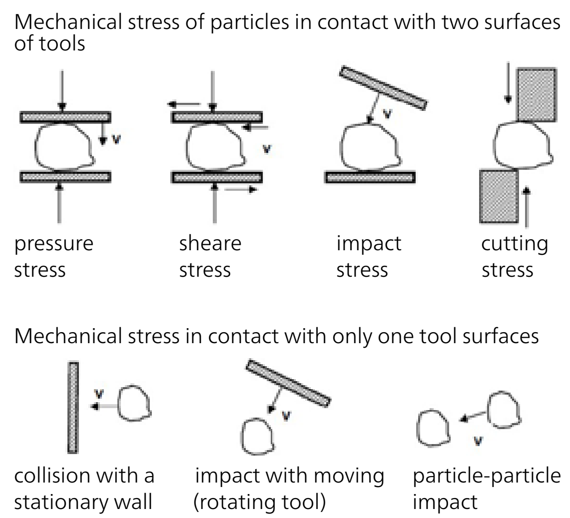
According to our general understanding, comminution usually means the breaking up of a solid structure under the action of mechanical energy. Such comminution processes can be divided into real comminution, deagglomeration or disaggregation. However, emulsification, i.e., the breaking up of liquid droplets or gas bubbles in another liquid, or even processes in which cell disruption is the goal, can also be understood as comminution processes.

The mechanical energy acts as pressure, impact or shear stress or cutting stress on the regrind (see Fig. 1). The mechanical energy can be transferred to the product to be ground by two tools, just one tool or, in the special case, by mutual particle collision.

The ratio of the work theoretically required for surface generation and the actual technical energy input can be understood as the efficiency of comminution machines and represents an astonishing aspect for most users in grinding technology. Only about 5 to 10 % of the energy expended is effectively used to generate new surfaces in ultra-fine grinding processes. The bulk of the energy used in technical comminution processes is converted into heat or is „lost" for the actual comminution process through ineffective collisions and stresses. Fuerstenau [1] assumes an even worse efficiency for the area of ultra-fine grinding. Therefore, in the development of new comminution machines, in addition to a high realizable energy density and the most efficient possible transfer of energy to the regrind, particular attention is also given to maximizing the cooling surfaces.

Fig.

Stresses that can lead to mechanical comminution



Due to the high specific energy requirement, especially for fine and ultra-fine grinding, possibilities for increasing the effectiveness have been examined repeatedly in the past.

Starting points for increasing energy utilization are:

- further development of grinding machines through improvements to known or utilization of new mechanical or non-mechanical principles and improving their adaptation to the respective grinding task
- more favorable design of the overall system - grinding machine - classifying machine, particularly for rapid separation of the sufficiently fine material (primarily in dry grinding)
- optimization of the comminution behavior through the addition of additives (so-called grinding aids) to reduce agglomerate formation during fine grinding.

Frequently, however, the selection of the most suitable comminution technology as a function of:

- the mechanical properties of the regrind
- the size and shape of the particle
- the rheological behavior of a regrind suspension
- the morphology and the actual comminution task

along with the optimization of the process control, the operating parameters and the formulation are already essential steps to significantly increase the effectiveness and thus the production output and efficiency, i.e., the efficiency of the comminution process.

Important prerequisites for this are a basic understanding of elementary processes and the mechanical behavior of materials, but also of the reproducible characterization of quality criteria of a wide variety of products such as:

- particle size and particle size distribution
- particle shape
- material morphology
- color intensity, transparency and shine
- suspension stability
- taste, and much more.

2.1. Elementary Process of Particle Fracture

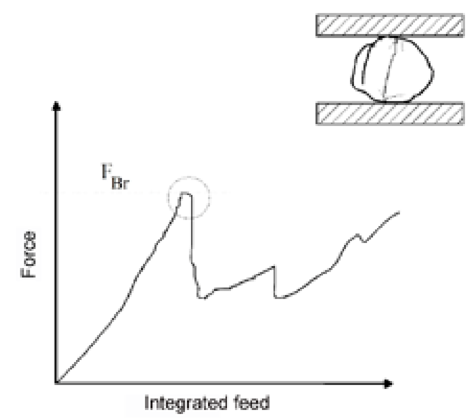
If a particle is deformed by stress, a three-dimensional field of tension is created with compressive, tensile and shear stresses. If the tension is sufficiently high, fractures are triggered. The first fracture that traverses the particles leads to the particle fracture. This can be seen in the stress diagram as a sudden drop in tension (see Fig. 2).

#The stress state governs what happens. It determines whether inelastic deformations or fractures occur [2].

The stress state depends on the one hand on the stress conditions such as number, direction and strength of the forces, properties of the tool (hardness, shape, roughness), stress speed and temperature, and on the other hand on the particle properties, which include the mechanical and thermal

Fig. 2

Stress diagram of a pressure test



material properties as well as the size, shape and internal structure of the particles. A schematic of the relationships is shown in Fig. 3.

Just as the number, direction and strength of the forces, the properties of the tools, the stress speed and the temperature as well as particle properties have an effect on the three-dimensional state of tension. There is an influence on the nature and shape of the fracture lines and fracture surfaces as well as on the shape and size the resulting fragments or the fines (see Fig. 4).

Experiments with glass beads have shown that a fine material cone or a central fine material area develops below or above the contact area during compressive stress. This phenomenon cannot be explained from the original stress field, because according to that, no tensile stresses exist there. It turns out that the fines form only when this area is released by the shell fractures and relaxes almost instantly. The material expands beyond the relaxed state, creating tensile stresses equal to the compressive stresses previously present. These are high enough to trigger a large number of fractures. Fine material cones and spontaneous particle fracture are typical of brittle spheres.

The above representations apply analogously to the impact stress, in which, however, the shell fractures do not converge, leaving an unbroken residual cone [2].

Fig. 3
Structural schematic of particle fracture [2]

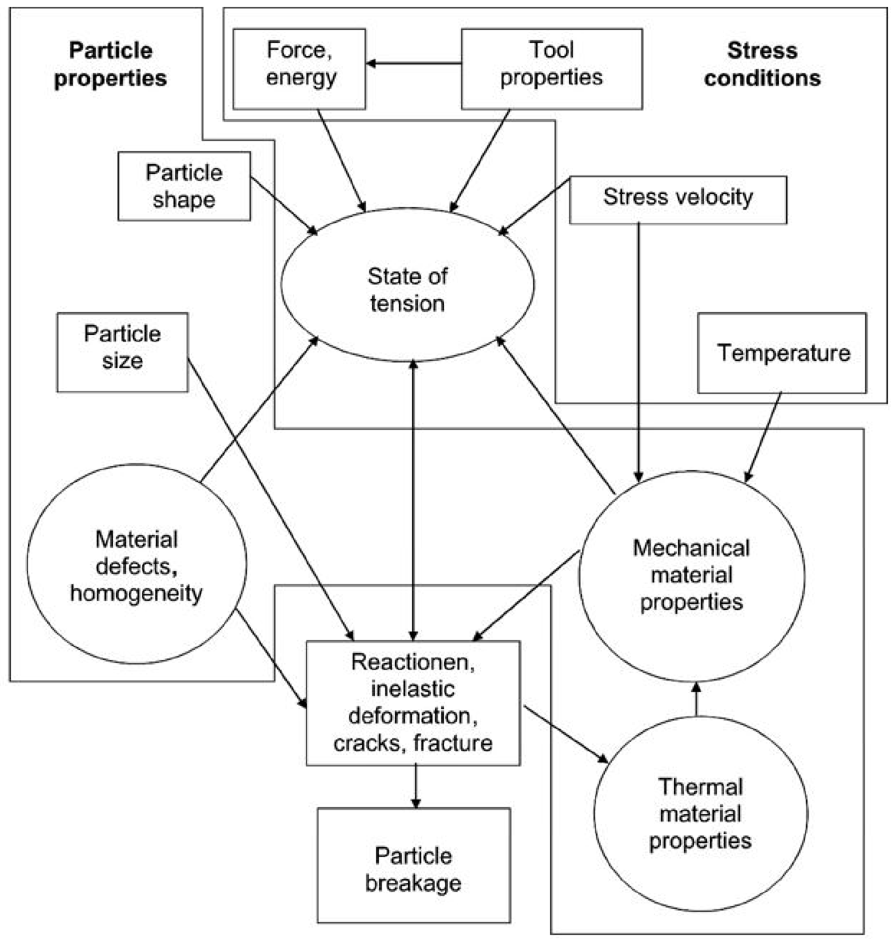
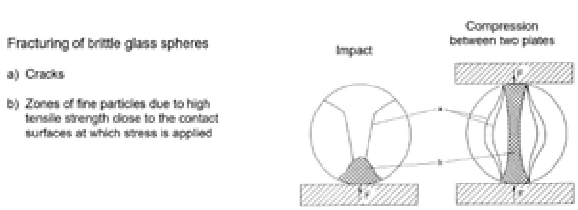


Fig. 4
Effects of subjecting particles to different types of stress



2.2. Deformation Behavior of Solids

Usually, regrind is divided into hard, medium-hard and soft or brittle and plastic or ductile materials. According to Schönert [2] , however, the consideration of elastic, plastic and viscous material properties makes more sense. Then the three borderline cases elastic, elastic-plastic and elastic-viscous deformation behavior can be distinguished.

2.2.1. Elastic deformation behavior

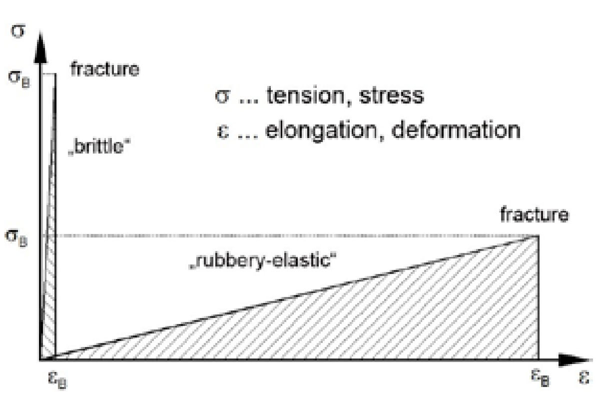
Elastic deformation behavior means that no change in shape remains after the load is removed, i.e., with ideal elastic deformation behavior, the energy supplied is completely recovered. The deformation process is therefore reversible. Theoretically, the elasticity is independent of the rate of expansion. The stress rate and temperature have no or negligible influence on the deformation behavior of elastic particles

Elastic deformation behavior means that no change in shape remains after the load is removed, i.e., with ideal elastic deformation behavior, the energy supplied is completely recovered. The deformation process is therefore reversible. Theoretically, the elasticity is independent of the rate of expansion. The stress rate and temperature have no or negligible influence on the deformation behavior of elastic particles

A material is described as brittle if its deformation is mainly elastic for a small maximum elongation until it breaks (see Fig. 5).

Fig. 5

Brittle-elastic deformation behavior of a solid

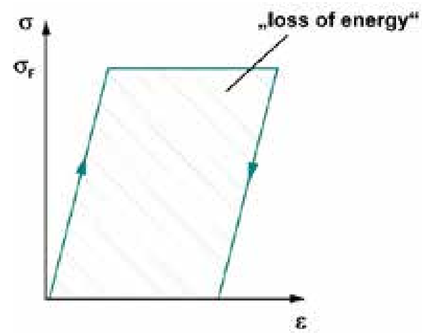


2.2.2. Elastic-plastic deformation behavior

Essentially, the initial deformation of elastic-plastic materials is linear elastic. After reaching a yield criterion, they deform only plastically without further increase of stresses (see Fig. 6). The yield criterion is a function of temperature but is independent of the stress rate. As the temperature increases, yielding starts earlier. Below a certain temperature, a further reduction in temperature leads to embrittlement of the material, i.e., the yield criterion is suppressed. Elastic-plastic materials can also become brittle after extended flow processes (e.g., multiple stresses as can be realized in agitator bead mills). This effect is referred to as cold embrittlement.

Fig. 6

Elastic-plastic deformation behavior of a solid



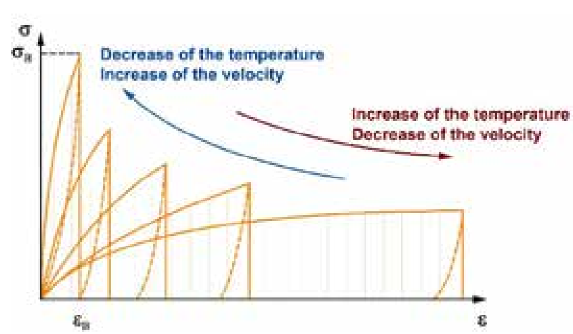
Typical representatives of this group of materials are metals. Their comminution can be improved by lowering the temperature. More practical, however, is multiple stressing, which also leads to cold embrittlement; this can be realized, for example, in bead mills or, in the very fine particle range, in agitator bead mills.

2.2.3. Elastic-viscous deformation behavior

In the case of elastic-viscous material behavior, the viscous deformation component is largely dependent on the rate of expansion and temperature. Viscous solids can be recognized by the fact that the tension decreases with a fixed deformation or that the material deforms plastically even under constant load. Typical representatives of this class of materials are plastics.

Fig. 7

Elastic-viscous deformation behavior of a solid



2.3. Particle Strength

In terms of strength theory, a fracture represents a failure of the particles. The particle strength, σ_P , can be defined as the quotient of the effective breaking force, F_{Br}, and the particle cross-section. Assuming spherical particles, the following applies:

$$\sigma_P = \frac{4 F_{Br}}{\pi x^2}$$

Here, x is the particle diameter. The particle strength is a function of the particle size. This can be explained by the lower number of material defects.

2.4. Brittle-plastic Transition

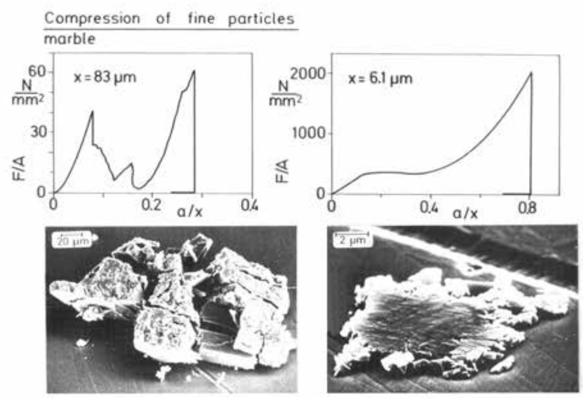
During the investigation of the particle strength of various materials, it was no longer possible to trigger particle breakage through single-grain stress in the range between 20 µm and a few micrometers, depending on the material. Fig. 8 shows results for single-grain stress tests [2] on marble particles. The compressive force with respect to the particle cross-section is plotted against the feed rate (a/x) of the compression plate with respect to the particle size.

For the 83 µm particle, the particle fracture appears at (a/x) of about 0.08. Then the force initially drops further, then rises again to a second peak, which belongs to the fracture of a larger primary fragment. Subsequently, there is a significant increase in force due to the resistance of the fragment cluster to the further advance of the plate. The picture below shows an SEM image of the fragments. The load diagram for the 6.1 µm particle is completely different; it is a smooth curve with a pronounced intermediate plateau and a subsequent steep rise. The stress was applied up to a relative feed of 0.8, i.e., at the end the gap between the compression plates was only about one micron. The SEM image (see Fig. 8) shows a flattened particle whose outer region is broken up by vertical fractures. Clearly, the deformation of this smaller marble particle was primarily inelastic. This transition from somewhat brittle to extremely plastic behavior was found in all investigated materials [3].

The particle strength as a function of particle size and the transition from brittle-elastic to plastic

Fig. 8

Stress diagram of an 83 µm and 6.1 µm marble particle, respectively, and SEM images of both particles after the test.

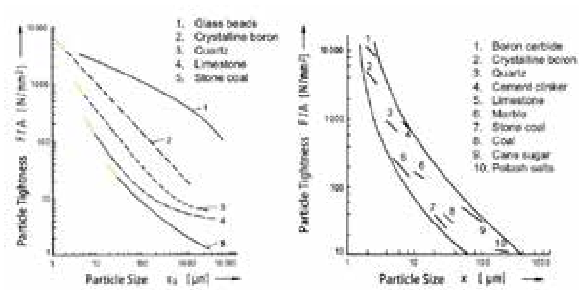


material behavior were plotted for different materials as a function of the particle size (see Fig. 9).

This transition from somewhat brittle to extremely plastic behavior was found by Hess [3] for all materials investigated. Fig. 9 shows a compilation of the results, with the just detectable particle strengths plotted over the corresponding particle size range. Even though these pronounced planar fragments are not found in grinding, the results indicate that below the material-specific transition range comminution becomes more difficult.

Fig. 9

Particle strength as a function of particle size - transition from brittle to plastic material behavior



3. Classification and Selection of Comminution Machines

3.1. Classification according to the Properties of the Regrind

An almost infinite number of the most varied of products is ground within one production process. The type of comminution and thus the selection of the suitable machine depends primarily on the required grain size, shape and grain-size or particle-size distribution. Another factor is the subsequent processing of the product or the required production output. The deformation behavior of the material to be ground, which can vary from brittle-elastic to inelastic and elastic-plastic to elastic-viscous, is the most important criterion for the applicability of a comminution technology (see Table 1).

If the selection of the comminution machine is initially based on the deformation behavior of the regrind, a rough selection of the most suitable technology can first be made as shown in Fig. 10. Further, the choice of technology is decisively influenced by the initial particle size and the target fineness of the process (see Fig. 11).

The technologies offered by the Grinding & Dispersing Business Unit of NETZSCH are framed in orange in Fig. 10 and Fig. 11. This overview shows that in the field of grinding, from agglomerate regrind to nanoparticulate systems, a suitable comminution technology is available in the NETZSCH portfolio for regrind with every conceivable deformation behavior.

Table 1
Distinguishing features for comminution technologies

Material	Fineness	Throughput	Medium	Medium	Tool
single grain	agglomerate	production	gaseous	gaseous	pressure surface
collective	coarse	pilot plant	liquid	liquid	friction surface
	fine	lab		Schnitt	cutter
hard	submicron			Prall	impact surface
soft	nano	t/h			air jet
brittle		kg/h			roller
viscous		g/h			grinding media
					medium

Fig. 10

Selection of a comminution machines based on the deformation behavior of the regrind

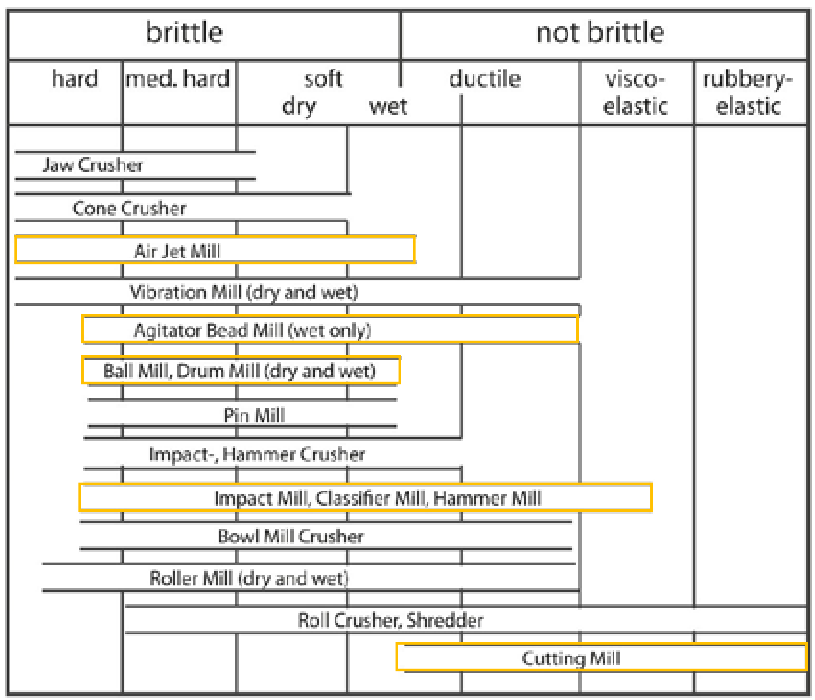
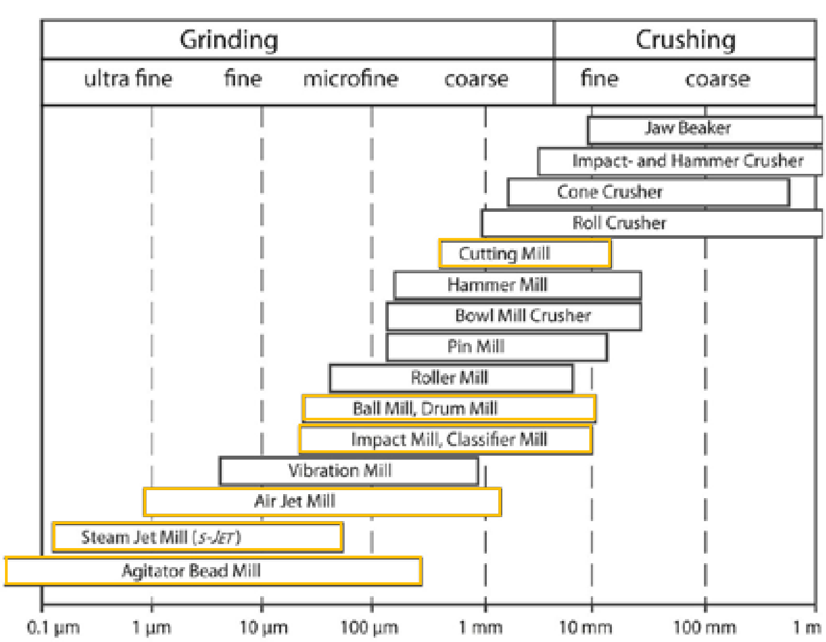


Fig. 11

Selection of comminution machine based on the particle size



3.2. Dry Grinding or Wet Grinding

The question of whether the regrind should be ground dry or wet is also elementary for process design. Wet grinding processes offer several advantages over dry grinding processes. Therefore, in most cases, the decision will be made in favor of wet grinding, if:

- the material to be processed is already available as a suspension
- the product material is to be further processed as a suspension
- the particle size of the ground material is to be smaller than 1 µm - limit of dry grinding (exception s-JET ®)
- material losses are always to be avoided
- toxic materials are being ground
- regrinds have a tendency to dust explosions.

In addition, the decision may be in favor of wet processing because the investment costs for a complete dry comminution plant including a compressor or steam generator and dedusting technology are usually much higher than for a wet comminution plant with comparable production capacity.

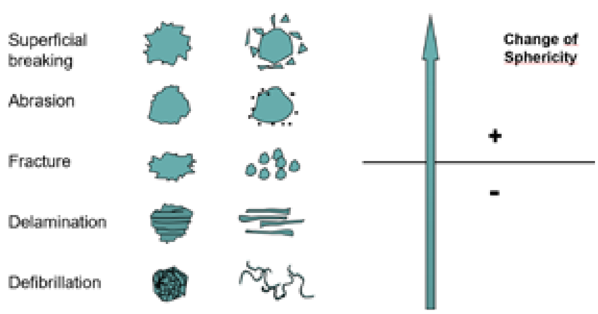
Due to the physically „catastrophic" efficiency of comminution processes, a large part of the energy input into comminution machines is converted into heat. Dispersion media such as water or solvents have a higher specific heat capacity compared to air. This aspect leads to the fact that in wet comminution processes, efficient cooling of the machine and thus control of the product temperature is much easier.

3.3. Objective of the Comminution Process

The objective of a comminution process can be very different. In some cases, even particle fracture should be completely avoided so that the product properties are not negatively affected. The focus of this consideration is the particle shape or the sphericity (see Fig. 12).

Fig. 12

Classification of comminution processes according to particle shape



For example, the aim of the process can be defibrillation, i.e., untangling and separating fibers without shortening their original length. Typical examples here are CNTs (Carbon Nano Tubes) or cellulose fibers.

Delamination is when platelet-shaped particles are separated without changing their aspect ratio. The largest possible aspect ratio, i.e., the largest possible surface area with a simultaneously minimal particle thickness, can be of great importance for, among other things, fillers that are intended to achieve a barrier effect or for conductive coatings.

In special cases, however, the goal of a comminution process is a targeted rounding, i.e., increase in the sphericity of the particles by breaking off or rubbing off surface outgrowths or roughness.

If such a process is then additionally combined with a classification process, for example, not only is a targeted change in the particle shape possible, but a "dedusting" as well, and thus a change in the particle size distribution, towards a monomodal product system.

3.4. Emulsification or Cell Disruption

Production of an emulsion, i.e., the fine distribution of liquid droplets in another liquid, can also be understood as a type of comminution process. A very stable emulsion is produced primarily when the liquid droplets are as monodisperse as possible, i.e., of uniform size in the dispersion medium.

Processes in which the objective is the disruption of biological cells are also comminution processes. However, true comminution of the cells is usually undesirable, since a separation of cell contents and other cell components can then become problematic. Thus, the aim here is only to break through the cell wall or to preserve it in the largest possible sections.

High-pressure homogenizers can be used for both emulsification and cell disruption processes. With Omega technology, NETZSCH also has highly developed equipment in this area.

4. The NETZSCH Grinding and Dispersing Business Unit

The Grinding & Dispersing Business Unit is a network of highly-specialized companies and has a very broad product portfolio for all tasks in the processing stages of dispersing, mixing, deaerating, wet and dry grinding, and classifying.

4.1. Dry Grinding and Classifying

NETZSCH Trockenmahltechnik GmbH is one of the world's leading companies in the area of dry product processing. The product range includes machines and systems for comminution and fine grinding, as well as classification of the finest powder. The company is based in Hanau am Main. In addition to assembly and administration, a large laboratory and technical center are also located here in order to carry out comprehensive and customer-specific tests with the machines and systems from NETZSCH Trockenmahltechnik GmbH. An overview of the variety of machines is shown in Fig. 13.

4.2. Suspending, Mixing, Homogenizing, Wet Grinding and Deaeration

NETZSCH-Feinmahltechnik GmbH in Selb, Upper Franconia is the world market leader in the processing of liquid and pasty dispersions. The comprehensive portfolio offers machines and systems for mixing, suspending, emulsifying, dispersing, deaerating and wet grinding. Fig. 14 provides an impression of the variety of machines in this area.

All available technologies from NETZSCH are offered with machine sizes ranging from laboratory scale to real production-scale systems. Further information can be found in brochures, on the company website (www.netzsch.com) or in the NETZSCH Compendium [4].

With direct contact to the product specialist at NETZSCH, we will be happy to provide you with comprehensive advice. In addition, the global network guarantees the greatest possible proximity to customers with various production facilities and application laboratories in Germany, Brazil, Russia, India, South Korea, China, Spain and the USA, as well as numerous sales and service offices.

But the Grinding & Dispersing Business Unit of NETZSCH does more than just build special machines. NETZSCH designs, builds and supplies customers from a wide variety of sectors with individual machines specially tailored to the product requirements, or takes on the engineering, delivery, installation, commissioning and training of operators for complete production systems. NETZSCH has product specialists for various fields of application and business, such as pharmaceuticals and cosmetics, food, minerals and ores or the chemical industry.

In addition, NETZSCH offers comprehensive after-sales service, which includes reliable delivery of spare parts, service and maintenance contracts and extensive practice-oriented training programs. In this way, NETZSCH guarantees a high level of production reliability at all times.

REFERENCES

[1] D. W. Fuerstenau
Grinding Aids, KONA No. 13, 1995, pp. 5-14

[2] K. Schönert
Kapitel 2: Hochschulkurs Zerkleinern und Dispergieren mit Rührwerkskugelmühlen Umdruck zum Hochschulkurs vom Institut für Mechanische Verfahrenstechnik und Kwade + Schwedes Zerkleinerungstechnik, Braunschweig, 2008

[3] W. Hess
Einfluss der Schubbeanspruchung und des Verformungsverhaltens bei der Druckzerkleinerung von Kugeln und Partikeln, Dissertation TU Karlsruhe, 1980

[4] S. Mende, et all.
NETZSCH Compendium, Grinding & Charakterization of Particles. September 2016

Fig. 13

Overview of the comminution technologies of NETZSCH Trockenmahltechnik GmbH

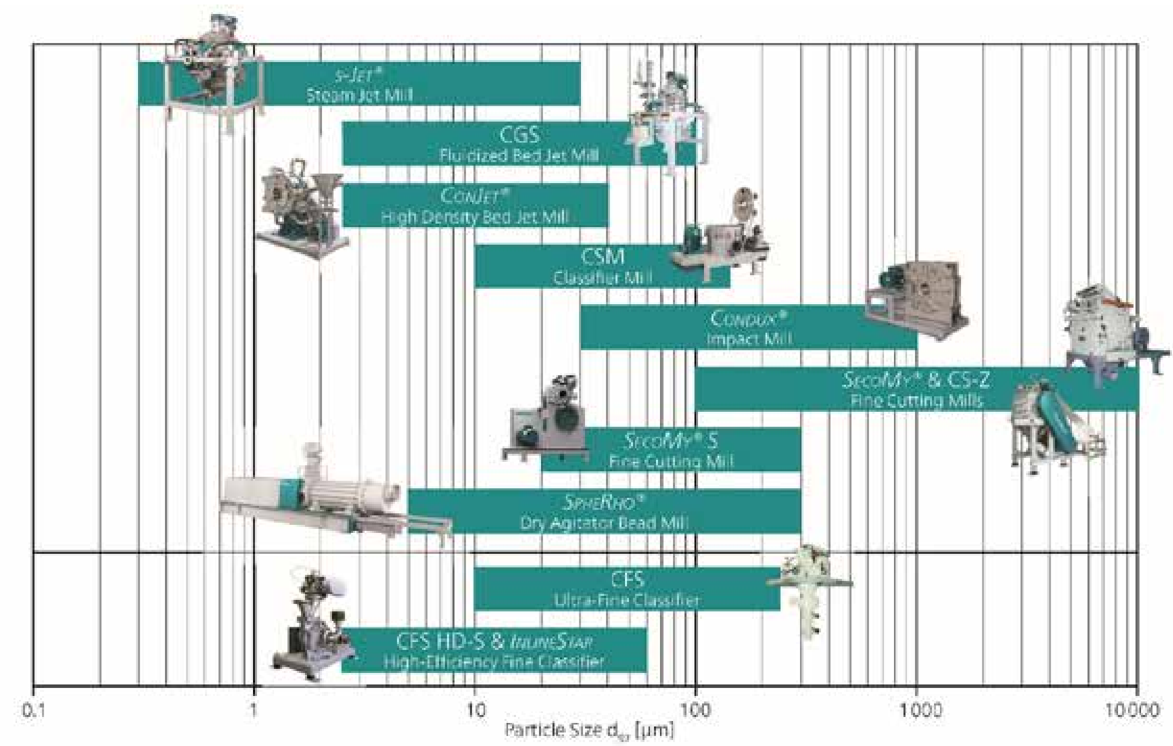
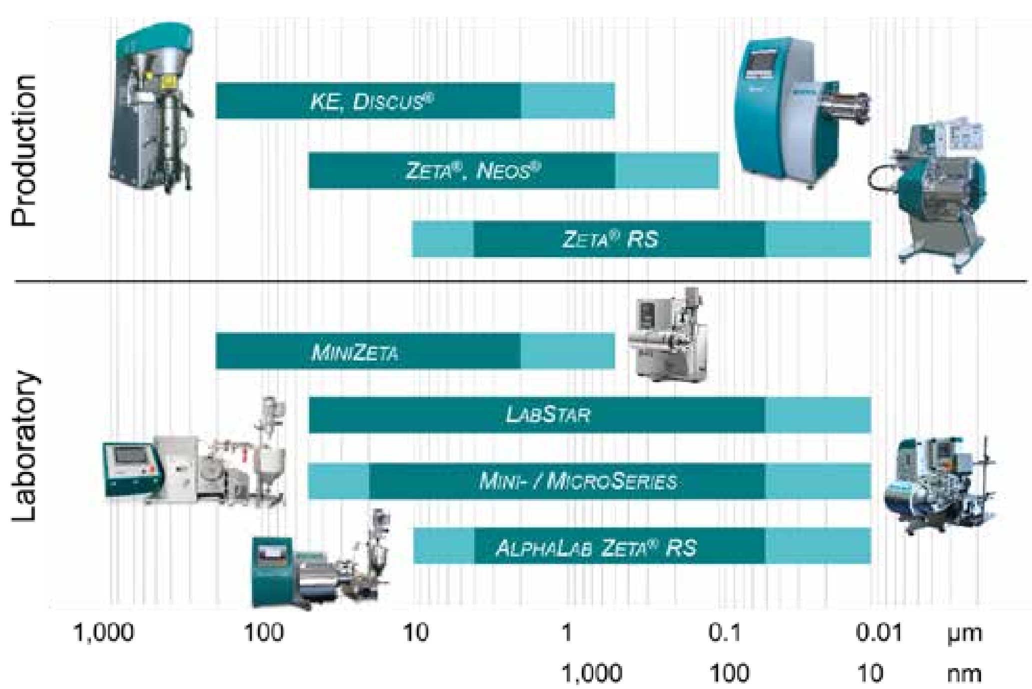


Fig. 14

Overview of the comminution technologies of NETZSCH-Feinmahltechnik GmbH



The NETZSCH Group is an owner-managed, international technology company with headquarters in Germany. The Business Units Analyzing & Testing, Grinding & Dispersing and Pumps & Systems represent customized solutions at the highest level. More than 4 000 employees in 36 countries and a worldwide sales and service network ensure customer proximity and competent service.

Our performance standards are high. We promise our customers Proven Excellence – exceptional performance in everything we do, proven time and again since 1873.

Proven Excellence.

Business Unit Grinding & Dispersing – The World's Leading Grinding Technology

NETZSCH-Feinmahltechnik | Germany
NETZSCH Trockenmahltechnik | Germany
NETZSCH Vakumix | Germany
NETZSCH Lohnmahltechnik | Germany
NETZSCH Mastermix | Great Britain
NETZSCH FRÈRES | France
NETZSCH España | Spain
ECUTEC | Spain

NETZSCH Machinery and Instruments | China
NETZSCH India Grinding & Dispersing | India
NETZSCH Tula | Russia
NETZSCH Makine Sanayi ve Ticaret | Turkey
NETZSCH Korea | Korea
NETZSCH Premier Technologies | USA
NETZSCH Equipamentos de Moagem | Brazil

NETZSCH-Feinmahltechnik GmbH
Sedanstraße 70
95100 Selb
Germany
Tel.: +49 9287 797 0
Fax: +49 9287 797 149
info.nft@netzsch.com

www.netzsch.com

G&D · WhitePaper Selection of the Comminution Technology · EN · 06/23 · Technical specifications are subject to change.