



PROPERTIES OF SOLID POLYURETHANE RECYCLAT OBTAINED IN THE COMPACT MULTISTAGE SYSTEM OF CUTTING MILLS

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Abstract

Due to specific elastomers properties, fine grinding of them (for example cured rubber, polyurethane elastomers) into powder of the average particles size below 1mm is realized usually in energy-consuming facilities. These lines consist of machines that are connected with transportation system and segregating system of grinded product. Because of this, powder production of elastomers is expensive and, simultaneously lack of full quality control of the received product is a usual case. Compact multistage system of cutting mills cooperation was proposed. The aim of investigations was to determine conditions for PUR grinding for further usage of received powder in composite together with other polymers, for example with new PUR. Obtained results of investigations indicate the purposefulness of multistage rotational cutting system application to polyurethane grinding. The require number of milling stages is dependent on final degree of fineness (needed size of grain). Polyurethane powder of high fineness degree and of different particles shape was received by the multistage system of cutting mills. The average grain size of polyurethane powder reached the range from 0.22 to 0.90 mm. Grain-size distribution was similar to normal distribution for all multistage grinding versions. Recycled powder obtained as a result of fine grinding can be re-used as filler to the PUR manufacturing. In this aspect geometrical features and the grain surface state were determined. The characteristics of particles geometrical features were made based on the particles project images received with the use of CCD camera and SEM.

Keywords: elastomer, recycling, fine grinding, cutting, sieve analysis

1. Introduction

In the area of the material recycling of cast polyurethane waste, PUR crumb plays the important role. The increase of interest in using grinded PUR for filling urethane components during their synthesis (for example cast polyurethane elastomers) is observed [1, 2]. It may be anticipated that introduction of polyurethane particles into new PUR material causes the decrease of PUR manufacturing costs [2]. Based on this, it is important to study the influence of the particle's geometry (especially a shape and a size) and a nature of this modifier (method of disintegration) as well as others factors on the composite properties (using ground cast polyurethane). For elaboration the basis of manufacturing technology of PUR composites with optimal properties at minimal cost is needed.

Due to specific elastomers properties, fine grinding of them (for example cured rubber, polyurethane elastomers) into powder of the average particles size below 1mm can be complicated and is conducted usually in energy-consuming facilities. These lines consist of machines that are

connected with transportation system and segregating system of grinded product. Therefore powder production of elastomers is expensive and, simultaneously lack of full quality control of the received product is a usual case. The received PUR powder however can be used only as a filler. In this aspect (applying the obtained ground PUR for filling others polymers) determination of geometrical features and the grain surface state plays most important role. In case of crosslinked polymers, fineness of grinded powder determinates their further usability [1-3]. In this area the reverse relation can be observed, reuse of recycled materials requires particular grain size distribution of crumbs. It was acknowledged that for cast polyurethanes the main cause of their division in a grinding chamber should be the cutting knives. Pure shear is the most profitable for elastomers [1, 3]. Cutting at the narrow slit between cutting edges of the knives assures the conditions of pure shear.

To recapitulate the above consolidations, the thesis may be formulated, that the most important condition of polyurethane fine grinding processes is making the biggest possible number of PUR cuts at a narrow slit between cutting edges of the stationary and the rotary knives of the mill. Completing this condition requires alternative solutions of single-stage construction cutting mills. In case of verification the presented thesis two original constructional solutions of further, hypothetic still grinding machine for polyurethanes are presented. First solution bases on the idea of multistage, gravity feed mill (potentially the number of material cut increases). Second constructional solution assumes for every stage (every stage is a working chamber of single-mill) a suitable geometry of cutting knives. Because of this, the aim of presented work was to determine conditions for PUR grinding for further usage of received powder in composite together with other polymers, for example with raw PUR. In case of polymer fine grinding, there is an advantageous number of grinding levels for each material of a different structure and input form of waste.

2. Concept of multistage grinding

During machine construction the correct collaboration between the individual stages must be taken into consideration. In the effect a product with specific fineness (needed fineness by reason for its further usage) should be received. Because of parallel arrangement of the knives edges, cutting of PUR is difficult and a number of cuts is limited in particular for fine grains. The latter are eliminated in the hyperboloidal-rotary cutting mill developed recently and evaluated in laboratory (Fig. 1).

After cursory analysis this solution seems to be simple in practical use, but PUR properties (particularly about low hardness) needs a qualification of suitable processing conditions and their fulfilment assures efficient working of this specific facility (cascade machine) for grinding by the hiperboloidal cutting method.

The most important requirements of proper work of mill should be obtainment "permeability effect" of whole grinding line as well as fulfillment "thermal safety" throughout of grinding. In practice it shows, that material division processes (share) on individual stages have to be held with approximate efficiency (efficiency of each following stage of cascade should be slightly higher than the previous level), however increase of temperature of grinded material on the next stage cannot be higher than temperature causing a material degradation and loss of a potency in cascade (higher than melting point of material).

Due to high number of processing factors, and also to various forms of PUR waste and their structure, investigation was conducted with the support of the model of investigations object, which was worked out for technology of grinding rubber by multistage hiperboloidal cutting (MHC). This model was described earlier [3, 4, 7]. Concept of hiperboloidal cutting is based on an analysis that the single-envelope hyperboloid comprises of two families of the generating straight lines [5]. Moreover, it is possible to generate a rotating, single-envelope hyperboloid, also comprising of two families of generatrices of the same single-envelope hyperboloid. Cutting at the

hiperboloidal interaction of straight cutting edges is evidently advantageous in comparison to parallel cutting, because width of the slit is permanently set at very low level of $0,05 \times 10^{-3}$ m. It is very important for elastomers fine grinding. To minimize influence of sizes dispersion on composite properties we disintegrated PUR in specially designed mill. Based on the aim of the investigation the test stand was provided additionally with the set of sieves and the suitable cutting knives.

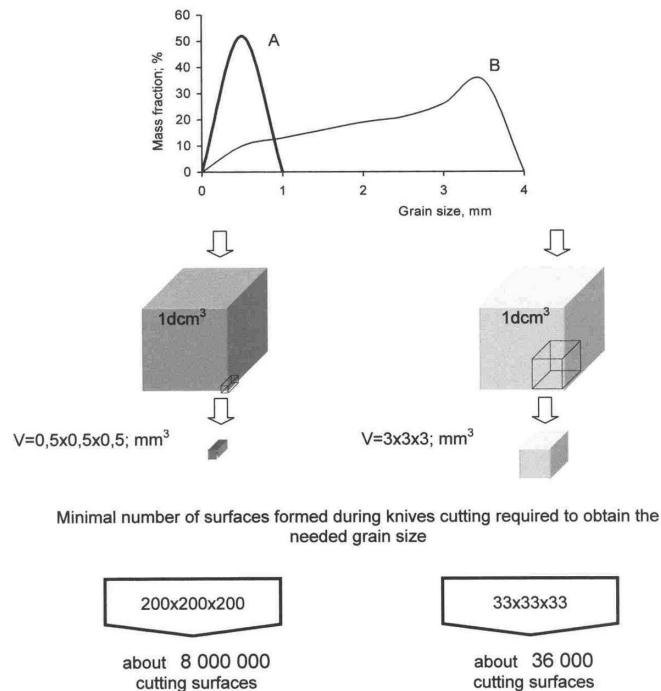


Fig. 1. Difference between fine grinding (A) and typical grinding (B) in the cutting mill

Examinations of PUR cutting and grinding were conducted at the test stand with the cutting mill as the most important element. The construction of the mill enables an application different methods of knife rotational cutting, while the knives are in different positions towards each other (for example: hiperboloidal cutting). The stand gives a possibility of simultaneous measurement of seven physical parameters (among others: shearing force, net torque).

3. Quantity and quality assessment of fine grinded product

Essential estimation criteria of grinding effectiveness is the determination of obtained product properties. The grain-size distribution of powder and geometrical features depend on material volume reduction method. This is important estimation criterion of product usability to apply it as a filler. Grain size distributions of received ground PUR were determined based on dry sieve analysis. Sieving was carried out in the vibratory and gyratory shakers. During this process particles are strongly accelerated due to the high oscillation rate and to relatively high vibration intensity of the column. For every samples of grinded material total sieving times at a level of 45 minutes was determined. Sieve analysis were conducted with the usage of 12 woven metal sieves with the mesh widths from 0.05 to 1.5mm. The results of measurement were represented as cumulative curves. Moreover obtained powders were characterized by determination of the particle's equivalent diameter, adequately to maximal value of the fraction range.

The characteristics of particles geometrical features were made based on the particles project images received with the use of CCD camera FS-5612P (Bischke, Germany) [6]. Thanks to additionally installed optical system, the pictures of 40 times magnification were obtained. With

the help of MultiScan version 4.01 software (Computer Scanning System, Warsaw, Poland), the linear dimensions l_{max} and l_{min} , projected outline P and projected surface area S of particles were described. Direct measurement of these values was performed during particles projected image observation for their stable orientation. Based on the received results, the dimensionless shape factors were determined, which were the ratios of the characteristic dimensions of the particles project image:

- elongation factor W_e , described as the ratio of maximum and minimum linear dimension of the projected particle, and
- surface development factor W_{sd} calculated from the formula:

$$W_{sd} = \frac{P^2}{S} \quad (1)$$

where:

P- projected outline of particles,

S - projected surface area of particles

In addition, the asymmetry factor W_a was employed, which describes the ratio of the particle maximum linear dimension to the hypothetical diameter of the perfect spherical particle having the same surface area as that for the particle [8]. The estimation of surface topography was made by observation of particles images received with the use of CCD camera and scanning electron microscope JSM-5600 (Jeol, Tokyo, Japan). To investigations cast polyurethanes were used about hardness's 40-70 ShD.

4. Results summary

Results of investigations show, that use of multistage cutting system to PUR grinding enables receiving the fine product. The number of used stages depends on final degree of grinded material. Several versions of PUR multistage grinding were examined. In all grinding versions homogeneous fine polyurethane powders of the average particles size below 1mm were obtained. Average size of grains, resulted from applied cascade, varied from 0.22 mm to 0.9 mm (powders about average sizes of grains 0.31mm, 0.44mm, 0.66mm were also received). The most grinded grains were received by the use of 6-stage grinding system. Grain size distributions of obtained products are similar to normal distribution, regardless the number of grinding stages (Fig. 3).

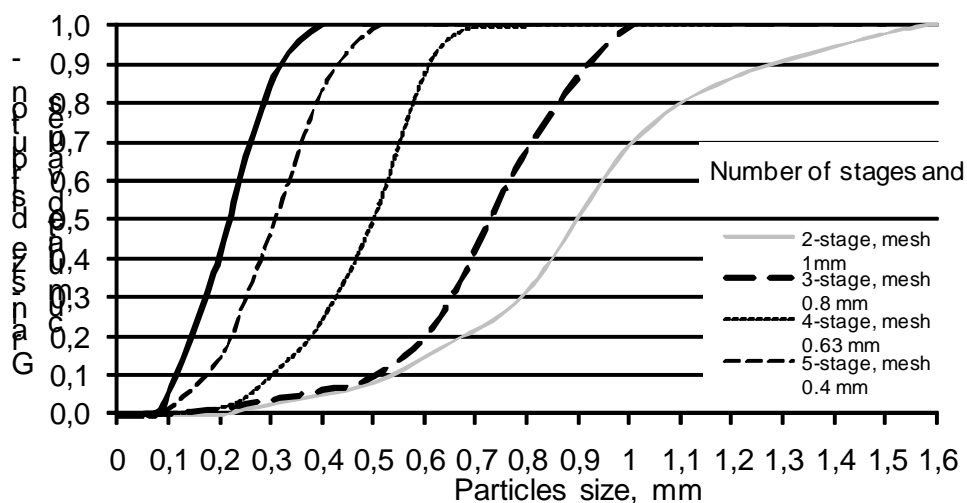


Fig. 3. Cumulated curve of ground PUR according to number of grinding stages used in the mill by hiperboloidal rotational cutting

Similar character of the grain-size distributions curves indicate the very similar manner of grains division in the milling chamber. Determined average diameters of grains are significantly lower than a sieves mesh at the finally grinding stage (the exception is smallest powder, $d_p=0.22$ mesh of sieve 0.2mm).

The largest particles received by multistage rotational cutting have the shape close to rectangular prism and a cube, regardless of their size (Fig. 4). There are scratched planes and straight cutting edges visible on the polyhedral surfaces of the particles. Small differences in minimal and maximal sizes as well as a value of asymmetry ratio show that their shapes are similar to rectangular prism, cubes and spherical bodies (Tab. 1).

Qualitative analysis shows that application of the multi-stage grinding system (using very fine mesh sieves, for example 0.2mm, 0.4 mm) caused further essential disintegration of grains and visible changes of both: their shape and the state of surface image (Fig. 4).

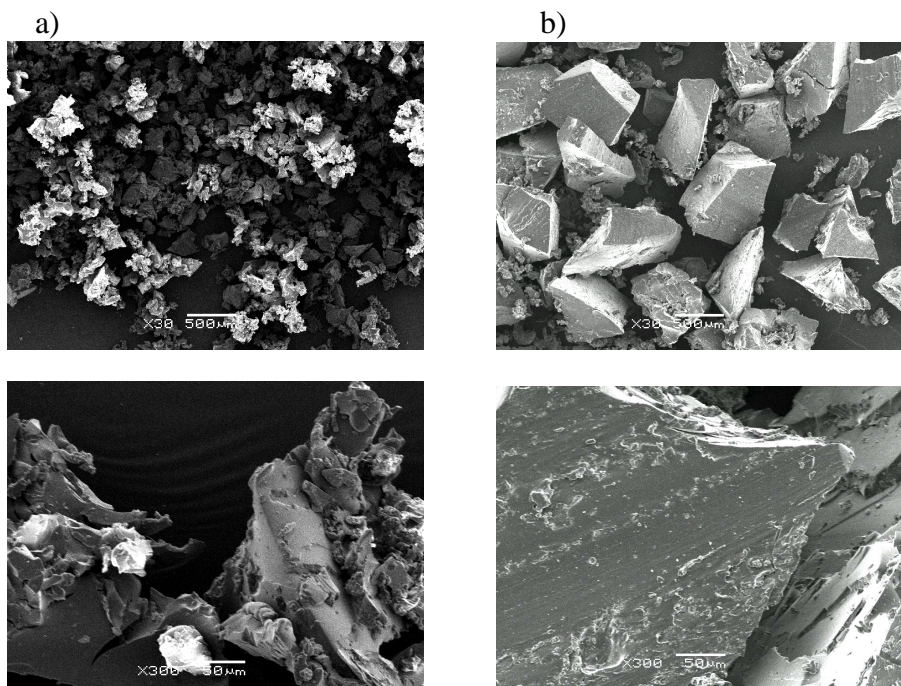


Fig. 4. Exemplary projection images of polyurethane grains obtained with use: (a) 6-stage grinding system (final sieve mesh width – 0.2mm) and (b) 3-stage grinding system (final sieve mesh width –0.8mm). Images were made by SEM, magnification 30 and 300x

As a result, it is possible to observe simultaneous appearance of the grains with the shape similar to large particles (obtained in the single- or two-stage grinding system) and also the irregular shapes particles, which are similar to the PUR grain obtained with the usage of the other grinding method, for example by disintegration on disk mill. In this case a grinding time grows, what creates additional possibilities of further material division (not necessarily through cut). Reduction on particles size was caused mainly by variable stresses applied to the PUR at the higher (in comparison to grinding with use the sieves of the large mesh width) temperature during milling. It is evidence among others by changes in a shape of cutting surface (higher development) and large number curvilinear cutting edges. The level of these changes depends on the number of grinding stages and is most evident for the use in our investigation maximal stages number (6-stage grinding system). Such experiment was necessary for further discussion on changes in geometrical characteristics of PUR particles subjected to shear forces and to their eventual thermomechanical degradation during milling. It is necessary to mention that during continuous milling the temperature in the mill chamber did not exceed 100°C , although the grinding was conducted without cooling (for all grinding systems).

Tab. 1. Geometrical characteristics of PUR particles obtained in the multistage grinding system

Final mesh sieve width used mm	Elongation factor W_e	Surface development factor W_{sd}	Asymmetry factor W_a
1	1.394	17.03	1.308
0.8	1.429	25.44	1.331
0.63	1.463	25.6	1.333
0.40	1.458	28.1	1.286
0.20	1.526	27.13	1.315

5. Conclusions

Recapitulating the model investigations of cast polyurethane grinding as well as earlier works [3, 4, 7], it can be observed, that for characteristic types of cast polyurethane waste it is possible to affirm, that the advantageous set of a processing conditions exists (suitable knives geometry, number of grinding stages, suitable inclination angle, etc.). Study of these conditions based on experimental examination resulted in obtaining fine grinded polyurethane products of the average particles size below 1mm. It can be also stated that grain surface image is a reflection of load state, which caused the polyurethane disintegration. By indirect means, the state of this particles surface images the value of energy consumption during grinding process.

Prior to the presentation of the detail investigation results it can be affirmed, that after fulfilment of supplementary investigations, it is possible to design and to make an original, prototype technological line, for the fine grinding PUR waste, both: cast and porous structure. It should be underscored that the hiperboloidal cutting was successfully used in fine grinding polyurethanes down to 0.5 mm grain size.

It is possible to design prototyping grinding line to conduct milling by hiperboloidal cutting for cast polyurethane waste as well as for foam systems.

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