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Levels of intelligent grinding system

Introduction

The multi-level structure means that each grinding machine system is made up of units, subunits, elements that are joined together to form elements of the next level etc. from molecules in the comminution sections to population of grinders, mills, crushers. Therefore, each entities is made up of sub-entities, those sub-entities are made up of their sub-entities etc.

The aim of the work is to empirically verify, for already specified principles of the intelligent grinding system and operational parameters with minimum energy and self-regulation of strains-aims of its operation, improvements at various levels of the intelligent grinding system and consequences of the same as regards elements and relations of the grinding space.

Levels of grinding/comminution

Molecular level

Molecules (of biological material and polymer material) of cross-sections, apart from tangential stresses that counter-balance the twisting moment, are subject to normal stresses that counter-balance each other. In the clamping section of the grain, the highest values of stress occur where supporting constrains prevent the complete deformation of the section.

Assuming axis z along the axis of grain/granule and the beginning of a coordinate system at its left end, the following assumed form of the expression for calculation of deformations, the comminution strain of any section at distance z from the clamped section [1–3]:

$$w = \frac{a^2 - b^2}{\pi a^3 b^3 G} M_z xy(1 - e^{-nz}) \tag{1}$$

Function (1) for $z = 0$ gives $w = 0$ (which corresponds to the decay of the clamped section comminution) and changes into the function of free warp (12) [16], only for $z = \infty$. In this sense, function (1) does not formally fulfils the condition stating that for $z = l$ (at a free end) a deformation of the section may be expected as a result of the influence of the tool. Exponential function (1) is of such a kind, that even for a small value of z, it specifies deformation, not much different from the free deformation.

In order to calculate the unknown value of n, the principle of minimum potential energy was used. For the torsion of the elliptical section, the previous assumptions may be applied, that $\sigma_x = \sigma_y = 0$. Then, for axial stresses:

$$\sigma_z = E\varepsilon_z$$

or based on expression (1):

$$\sigma_z = E\frac{\partial w}{\partial z} = n\frac{a^2 - b^2}{\pi a^3 b^3}\frac{E}{G} M_s xye^{-nz},$$

and substituting $G = \dfrac{E}{2(l+\mu)}$ the following is obtained:

$$\sigma_z = n\frac{a^2 - b^2}{\pi a^3 b^3} 2(1+\mu) M_s xye^{-nz} \tag{2}$$

The normal stresses (unevenly distributed throughout the section), in molecules of cross-sections of grains/granules, should change the tangential stresses τ_{xz} and τ_{yz} calculated for free torsion (for $\sigma_z = 0$).

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Obviously, it must also be assumed that tangential stresses τ_{xy} will occur.

For stresses τ_{xy} (this will also be the new assumption) the following form is assumed [1]:

$$\tau_{xy} = k(a^2b^2 - b^2x - a^2y^2)e^{-nz} \tag{3}$$

This expression fulfils the following conditions: for $z = \infty$, τ_{xy} equals zero, i.e. function τ_{xy} is related to function of free deformation (1).

Then, on the profile of the grain section, i.e. for points that fulfil equation $\frac{x^2}{a^2} + \frac{y^2}{b^2} = 1$ the following is obtained $\tau_{xy} = 0$ which for $\sigma_x = \sigma_y = 0$ corresponds to the case when the side surface of the grain is free from stresses. Constant k depends on the twisting moment.

Differential equations for the balance at the molecular level, considering that $\sigma_x = \sigma_y = 0$ takes the following form:

$$\left.\begin{aligned} &\frac{\partial \tau_{xy}}{\partial y} + \frac{\partial \tau_{xz}}{\partial z} = 0, \\ &\frac{\partial \tau_{yz}}{\partial x} + \frac{\partial \tau_{yz}}{\partial z} = 0, \\ &\frac{\partial \tau_{zx}}{\partial x} + \frac{\partial \tau_{zy}}{\partial y} + \frac{\partial \sigma_z}{\partial z} = 0. \end{aligned}\right] \tag{4}$$

Taking into consideration the expression assumed for τ_{xy}, the first two equations (4), when integrated, result in the following:

$$\left.\begin{aligned} \tau_{xz} &= -\frac{1}{n}e^{-nz}4ka^2y(a^2b^2 - b^2x^2 - a^2y^2) + \frac{2M_s}{\pi ab^3}y, \\ \tau_{yz} &= -\frac{1}{n}e^{-nz}4kb^2x(a^2b^2 - b^2x^2 - a^2y^2) + \frac{2M_s}{\pi a^3 b}x. \end{aligned}\right\} \tag{5}$$

The last two terms are any functions, independent of z (they are integration constants) and they have the same form as respective expressions in the theory of free torsion of the ground elliptical section.

Grain level

Functions (5) fulfil the boundary conditions, because on the side surface of the grain, first terms of the formulas for τ_{xz} i τ_{yz} become equal to zero and second terms, taken together, fulfil the boundary condition. Replacing σ_z, τ_{xz} and τ_{yz} in equation (4) with values of expressions (2) and (5) a conclusion may be drawn that it will be fulfilled in terms of identity for:

$$k = n^3 \frac{a^2 - b^2}{8\pi a^5 b^5}(1+\mu)M_s \tag{6}$$

Therefore, stress expressions (2), (3) and (5) fulfil the differential equations of the balance and the static boundary conditions, because both were used above. But unfortunately, due to the fact that expressions for deformation w and for tangential stress τ_{xy} were assumed freely (however, in respect of the grain they correspond to the nature of the problem) above expressions (2), (3) and (5) do not fulfil conditions of inseparability of deformations.

The unit potential energy, for the grain/granule analysed $\sigma_x = \sigma_y = 0$ equals:

$$\varphi = \frac{1}{2G}\left[\frac{1}{2(1+\mu)}\sigma_z^2 + \tau_{xy}^2 + \tau_{yz}^2 + \tau_{zx}^2\right] \tag{7}$$

For the calculation of the potential energy of the whole grain, expression (7) must be integrated in respect of its volume, i.e.:

$$\Phi = \int_0^l \int_F \int \varphi dx dy dz \tag{8}$$

When functions (2), (3) and (5) are placed in expression (8), the following is obtained [3, 8]:

$$\begin{aligned} \Phi = \frac{1}{2G}(1+\mu)^2 M_s^2 \frac{a^2 - b^2}{8\pi a^3 b^3}\left[n^2\frac{a^2b^2}{80} + n^3\frac{a^2+b^2}{24} - \frac{1}{1+\mu}n\right] + \\ + \frac{1}{2G}\frac{M_s^2(a^2+b^2)}{\pi a^3 b^3}l \end{aligned} \tag{9}$$

where l means length of the grain/granule.

When expression (9) is differentiated in respect of n, and the derivative equated to zero, the following is obtained:

$$n^2 = \frac{1}{ab}\left\{-\frac{a^2+b^2}{ab} + \sqrt{\frac{(a^2+b^2)^2}{a^2b^2} + \frac{16}{1+\mu}}\right\}$$

According to the conditions of the grain level, n should be a real and positive number.

Machine level

Efficiency, the degree of comminution and effective work are directly related to strains and stresses. The target mass efficiency $Q_{0.8\div1.6}$ of the grinding process, for a variable number of discs and the method of grain feeding was shown on the diagram (Fig. 1).

Design conditions

W_{kms} of RWT-05:KZ multi-disc grinder were verified on the basis of genetic optimization for three kinds of fed materials (Tab. 1).

Results of the analysis affected the improvements of the genetic procedure, motion parameters (speed, torque, power, acceleration, mass transition etc.) and indicated the preferred applications of technology for a specific material (Fig. 1, Tab. 1).

Integrated levels

Results of the rough theory of torsion and quasi-cutting of the comminution elliptical section may be applied to specific cases. Namely, for $a = b$ (circular section) $n = 1.45\frac{1}{a}$ for such value of n, based on the formula (6): $k = 0$, so all terms of the expressions for stresses that contain n, equal zero.

The potential energy of the ground grain with the circular section is:

$$\Phi = \frac{1}{G}\frac{M_s^2 l}{\pi a^4}$$

Tab. 1. Coefficient of efficiency of the grinding process for selected grain/granule materials

Item	Material	Efficiency criterion kg·h^{-1}	Comminution degree criterion	Load criterion MPa^{-1}	Work criterion* N·m, J	Total k coefficient	Optimum state
I.	Grain	50.18	5.57	0.1149	29.9	960.234	Best (*Optimus*)
II.	PE-LD granules	64.80	3.68	0.0555	20.8	275.283	Good (*Bonus*)
III.	Granules with wood fibre	34.20	3.75	0.0833	27.7	295.927	Better (*Melior*)

*) for the purpose of calculations the direct value of effective work $k_E = L_r$ was used instead of the reverse of the same for a variable number of discs and a variable method of biomaterial feeding (in relation to the general mass efficiency).

In a special case, the model of system efficiency and product quality, considering dependence (1) [14] and (16a) [15] takes on the following form:

$$\lambda = \lambda\left[IS, IW\left(\frac{(0.13 - 0.41l^4)M_s^2}{\mu d_{sr}^5 P_{t-s}}\right)\right] \tag{10}$$

The analysis concerned influences of structural/design features of the grinder population (IS) under variable processing conditions (IW) on the efficiency of the process and the quality of the product; results of the analysis, in relation to the molecule level – deformations of individual grains, polymer and fibre granules complement the essence of integration.

For $a = 10b$ (a heavily flattened ellipsis, the final stage of compression before quasi-cutting of the grain) the greatest, in terms of absolute value, normal stresses occur in the clamped section and these are by 65% greater than the greatest tangential stress for this section. When a may be regarded as infinitively huge as compared to b (granules of

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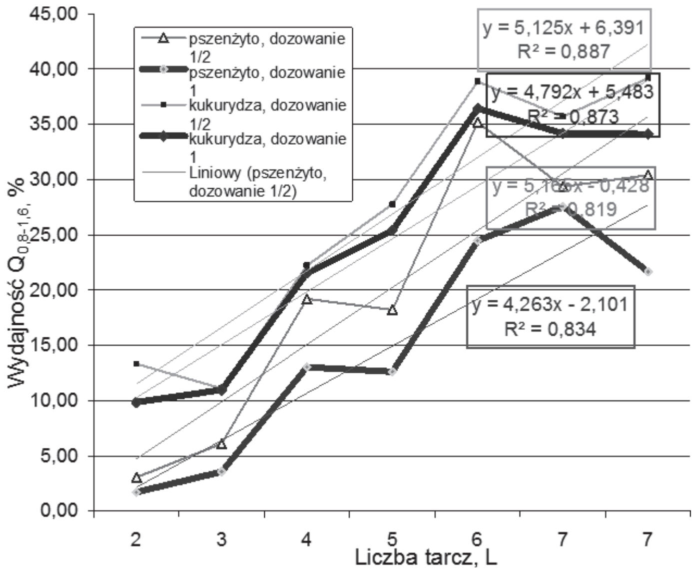

Fig. 1. Percentage values of target mass efficiency $Q_{0.8\div1.6}$ for a variable number of discs and a variable method of biomaterial feeding (in relation to the general mass efficiency)

the same proportion of sides), the greatest normal stress in the clamped section is 1.58 times greater than τ_{max} for the same section if the latter is calculated using the formula for free torsion.

Summary

The empirical verification of the objectives of the intelligent grinding system, described as four aspects of efficiency, confirmed the assumption made that loads generated within the grinding unit are transferred, as strains and stresses, onto elements and relations of the grinding area (machines, grains/granules). This statement relates to a specific design of the grinding system (RWT), molecules of biomaterials and polymer materials and grains of the same. The method of generating load influences the state of comminution strains and stresses. Even elastic stresses may result in comminution strains if the grain is subject to stirring and/or movement loads.

Due to a low speed of moved and stirred grains, the holding of the grain for the duration of quasi-cutting accompanied by torsion and potential acceleration of a particle of the grain as a result of a rebound after the comminution, it may be assumed that the second sate, for the purpose of simplification, is characterized by a continuity of the motion trajectory and that the duration of movement with stirring and grinding equals the time of movement with stirring: $t_{p+m+r} = t_{p+m}$.

RWT multi-disc grinders, with discs mounted coaxially in a vertical arrangement, guarantee an increasing speed of deformation, movement and stirring. Thanks to such properties of the motion, additional loads result in grinding of grains subject to plastic or even elastic stresses, also in clamping places between edges of the tool for quasi-cutting (with torsion).

REFERENCES

[1] *D. Arola, M. Ramulu*: International Journal of Mechanical Sciences. **39**, nr 5, 597 (1997).
[2] *W. Bauer, D. Wustenberg*: Chemical Engineering & Technology, **25**, nr 11, 1047 (2002).
[3] *N. I. Biezuchow*: Teoria sprężystości i plastyczności. PWN, Warszawa 1957
[4] *J. Flizikowski*: Rozdrabnianie tworzyw sztucznych. Wyd. ATR, Bydgoszcz 1998.
[5] *J. Flizikowski*: Rozprawa o konstrukcji. ITEE, Radom 2002.
[6] *J. Flizikowski*: Projekt implementacji inteligentnego systemu wspomagania konstrukcji młynów specjalnych, Min.NiI Warszawa, ATR Bydgoszcz, AGH Kraków 2005.
[7] *J. Flizikowski*: Plastic devices for Energy Engineering. NANOENERGY, Tapis Rouge, Paryż 2008.
[8] *W. Grellmann, S. Seidler*: Deformation and fracture behavior of polymers, Springer Verlag, Berlin 2001
[9] *I. Rokach*: Numeryczno-analityczne modelowanie prób udarowych. Monografie nr 50, Wyd. Pol. Świętokrzyskiej, Kielce 2005.
[10] *J. Sidor*: Badania, modele i metody projektowania młynów wibracyjnych. Rozprawy-Monografie nr 150, Wyd. AGH Kraków 2006.
[11] *G. Szala* i inni: Analiza energochłonności technologicznego ścinania ziaren zbóż. Grant Min. NiI Warszawa, UTP Bydgoszcz 2007.
[12] *J. Yan, J. S. Strenkowski*: Journal of Materials Processing Technology **174**, 102 (2006).
[13] *J. Zawada* i inni: *Wprowadzenie do mechaniki maszynowych procesów kruszenia*. Wyd. ITE, Radom – Warszawa 2005.
[14] *J. Flizikowski*: Inż. Ap. Chem. **50**, nr 3, 22 (2011).
[15] *J. Flizikowski*: Inż. Ap. Chem. **50**, nr 2, 11 (2011).
[16] *J. Flizikowski*: Inż. Ap. Chem. **50**, nr 2, 15 (2011).

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