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Numerical simulation of brittle rock loosening during mining process

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Abstract

In this paper, the results of the finite elements method simulations of loosening of rock by special design ripping head [F. Eichbaum, Schneidend- brechende Gewinnung mit der Schneidscheibe. Experimentell und theoretische Untersuchungen. Gluckauf- Betriebsbucher, Band 22, Verlag Gluckauf GMBH Essen, 1980] have been presented. The influence of friction factor rock and ripping tool on trajectory of loosing of rock has been investigated. It is important to obtain wide range loosing of rock in mining technology. This makes getting a thick excavated material possible and guarantees more energy-saving excavating process.

The results show that increase of friction angle results in growth of crack propagation range, so loosing rock pieces are bigger. Numerical studies were carried out for an angle varying from 0° to 24°. Calculations done using finite elements method determine mechanical conditions necessary for optimization and improvement of experimental head for future research. In crack propagation analysis, loosing element method and Podgórski's plasticity condition were utilized [J. Podgórski, Journal of Mining Science 38 (4) (2002) 374–380, July; J. Podgórski, Journal of Engineering Mechanics 111 (2) (1985) 188–201] .

Keywords: Rock mining process; Mechanism of chip formation; Model of rock falling-off

1. Introduction

Searching for methods of finding large coal sizes is always of relevance in mining technology, because on the one hand there is the limitation of process energy consumption, limiting the smallest particles (hazardous in a mine atmosphere) and on the other hand, the high price of large coal sizes achieved.

One of the technical methods of fulfilling such requirements is using a milling–chipping head (described in detail in [4–7]), which is a modification of the heads designed in Germany [1]. The idea behind the operation of this head is to separate large coal sizes using an appropriately shaped chipping head, the operation diagram of which is shown in Fig. 1.

In publications [4–7], analytical model of rock cutting by a new generation head, which uses lower tensile and shear strength in relation to the pressing strength, was developed. Analytical model describing the process of loosing continuity of material in the modeled rock by an action of experimental cutting-and breaking head, was presented. Numerical testing, carried out on the base of chip formation mechanism as well as distribution and dislocation of stresses in area of cutting head action, were presented to verify results obtained from analytical calculations. Also verifying stand tests, which determined qualitative relationships between design parameters and technological parameters and shape of broken rock were presented. Based on the results obtained from testing, an analysis of optimal technological parameters, which enable to develop an algorithm for calculation of head's geometrical parameters, was made. Finally, a proposal for a model of the cutting-and breaking head, which could be used for industrial testing, was given.

The purpose of the presented analysis stage is to investigate the influence of the coefficient value of rock friction against the head side surface on the separation trajectory range, related to the chip sizes.

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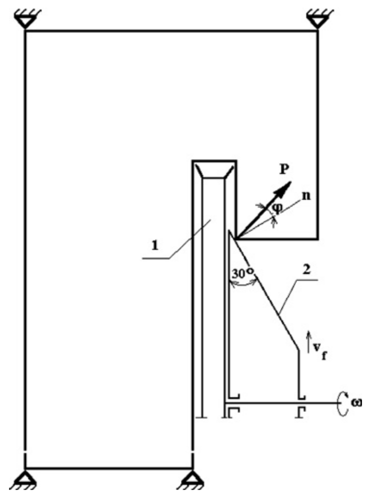

Fig. 1. Influence of the chipping head on the rock protrusion: (P–separation force, n – chipping head normal to generator, φ – angle of rock friction against chipping disc side surface,1 – undercutting disc, 2 – chipping head, v_f – head travel speed, ω – angular velocity of undercutting disc drive shaft) [4,5].

Therefore, an assumption has been made that the numerical tests using the MES, should lead to specifying the mechanical conditions for creating large rock chips, which can be a basis for optimization and upgrading the design form of the described milling–chipping head, in possible further tests.

The gap propagation analysis uses the loosing element method and the Podgórski yield criteria PJ, described in detail in [2,3].

In the analysis of this issue, the loosing element method and the PJ failure criterion was applied [2,3]. Its practical application in the problems related to material cracking. This condition was proposed in a form expressing dependence of three alternative invariants of the stress tensor:

$$\sigma_0 - C_0 + C_1 P(J)\tau_0 + C_2\tau_0 + C_2\tau_0^2 = 0,$$

Where $P(J) = \cos(\frac{1}{3}\arccos(\alpha J) - \beta)$ is a function defining the shape of the cross section of a limit (or failure) surface,

$$\sigma_0 = \frac{1}{3}I_1, \qquad \tau_0 = \sqrt{\frac{2}{3}J_2}, \quad J = \frac{3\sqrt{3}J_3}{2J_2^{3/2}},$$

where I_1 is the first invariant of the stress tensor; J_2, J_3, are the invariants of the stress deviator; α, β, C_0, C_1 and C_2 are constants depending on material properties.

2. Analysis assumptions

The analysis has been conducted in the head axial section plane, running parallel to the floor. It has been assumed that the chipping disc affects the created rock base with the force P, deflected from the normal plane of this disc by the angle of rock friction against the disc φ ($\mathrm{tg}\varphi = \mu$, μ-coefficient of rock friction against the chipping head). It has also been assumed that the chipping head rotation axis is parallel to the head traveling direction. Head convergence angles β is assumed at 30° (Fig. 2).

For MES analysis purposes the head influence model has been digitized with a grid of finite elements, as shown in Fig. 3 [4]. Please note that in order to increase the accuracy of the analyses in comparison with the initial tests [5], the model digitization method has been changed.

In order to analyze the influence of the value of the angle of rock friction against the disc side surface friction on the run of gap propagation, calculations for different values of angle φ have been conducted (deflection of pressure force P of the disc from disc normal to generating), in the range 0°–24° (every 6°), which corresponds to the change of friction coefficient μ in the range 0–0.45.

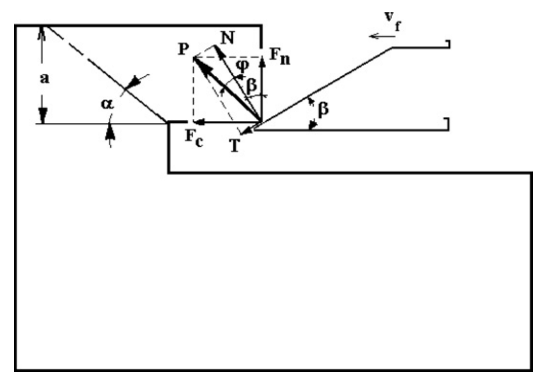

Fig. 2. Model of loading of the rock base with chipping head: (a – rock base thickness, P – chipping head force affecting the rock base, α – rock separation angle, β - chipping head angle, φ – angle of rock friction against chipping disc side surface, N – chipping head normal to generator, T – force of rock friction against the head, F_c – separation force component compliant with the head travel direction, F_n – separation force component, normal to the head travel direction) [4,5].

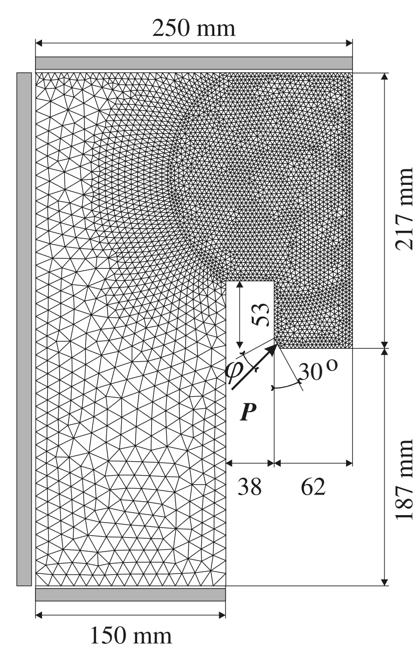

Fig. 3. Digitization of the mechanical model of chipping head influence with a grid of finite elements.

3. Numerical analysis results

The obtained results of numerical simulation are shown in Fig. 4. As the figure shows, the increase of the angle of friction of the rock against the chipping disc significantly increases the gap propagation range, thus significantly increasing the linear dimensions of separated rock elements. At the same time the resultants of displacement of

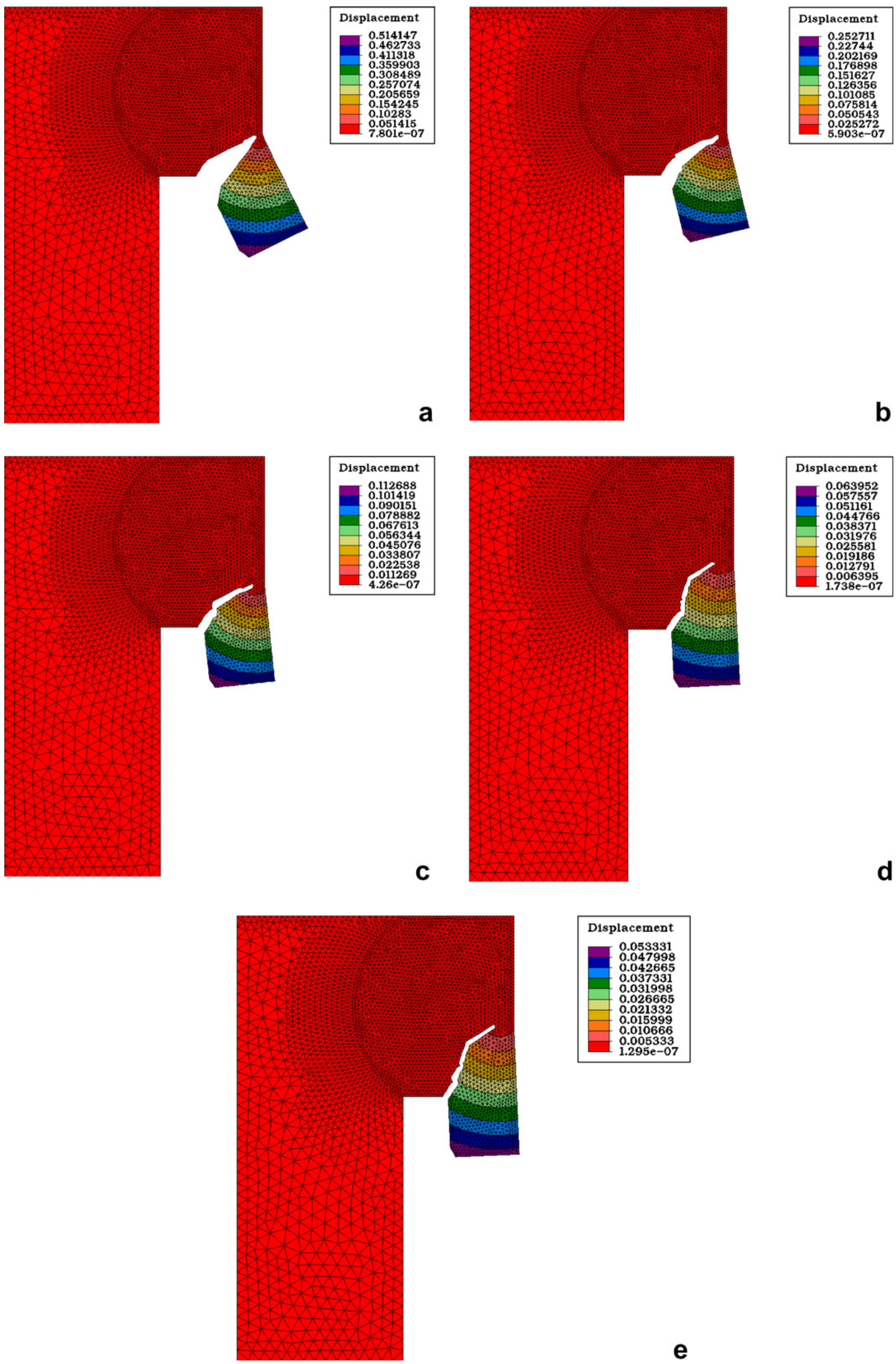

Fig. 4. Influence of friction angle to crack propagation: (a) $\varphi = 0°$, (b) $\varphi = 6°$, (c) $\varphi = 12°$, (d) $\varphi = 18°$, (e) $\varphi = 24°$ ($\mu = 0.45$). Rock Young's modulus $E = 2 \times 10^4$ MPa, Poisson ratio $\nu = 0.2$, $f_c = 20$ MPa, $f_t = 2$ MPa.

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the rock material adjacent to the chipping disc are reduced. The rock material flow down the disc is hindered somewhat, so the movement of the end of the rock shelf parallel to the head travel decreases, which could facilitate breaking of the rock shelf. The results of initial analyses have therefore been confirmed [5]. The local, violent changes of gap propagation direction obtained from the MES model using the loosing element method, can testify to the imperfection of the used calculation algorithm; this however, has no impact on the curvilinear, end shape of the separation trajectory.

4. Summary

Numerical analysis has confirmed that the range of separation of rock with a chipping head largely depends on the coefficient of friction of the rock against the head. The greater the coefficient, the larger the range. As a result, we should expect increased sizes of coal chunks separated with the head.

As might be expected, the number of factors influencing the range of separations is larger. The influence of some of them has been described, for example in study [5]. However, in order to precisely explain the numerous impacts of the chipping head on the rock, further numeric and site tests must be performed.

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