Mining of Mineral Deposits
ISSN 2415-3443 (Online) | ISSN 2415-3435 (Print)
Journal homepage http://mining.in.ua
Volume 10 (2016), Issue 2, pp. 72-77

UDC 622.831.3:531.36 http://dx.doi.org/10.15407/mining10.02.072

STUDYING A CRACK INITIATION IN TERMS OF ELASTIC OSCILLATIONS IN STRESS STRAIN ROCK MASS

O. Sdvyzhkova[1*], Yu. Golovko[1], M. Dubytska[1], D. Klymenko[1]
[1]*Higher Mathematics Department, National Mining University, Dnipropetrovsk, Ukraine*
**Corresponding author: e-mail sdvyzhkova_e@nmu.org.ua, tel. +380676301048*

ВИЗНАЧЕННЯ УМОВИ СТАРТУ ТРІЩИН, ЩО ІНІЦІЙОВАНИЙ КОЛИВАННЯМИ В ПОРОДНОМУ НАПРУЖЕНО-ДЕФОРМОВАНОМУ СЕРЕДОВИЩІ

О. Сдвижкова[1*], Ю. Головко[1], М. Дубицька[1], Д. Клименко[1]
[1]*Кафедра вищої математики, Національний гірничий університет, Дніпропетровськ, Україна*
**Відповідальний автор: e-mail sdvyzhkova_e@nmu.org.ua, тел. +380676301048*

ABSTRACT

Purpose. Deriving the criterion of a crack (joint) initiating under simultaneous effect of the rock stress state and elastic oscillations generated by an external source is the research purpose. Determining the quantitative relations to estimate the contribution of oscillations to crack initiation and creating a theoretical basis for the improvement of rock burst forecasting technique is a goal as well.

Methods. The brittle failure theory and a time-space approach are applied to determine a critical length of initiating cracks depending on stress level and amplitude-frequency characteristics of acoustic oscillations. Analysis of experimental data and comparison with the numerical results are carried out.

Findings. Quantitative ratios between the critical length of the crack, the stress intensity factor, oscillation amplitude and frequency are determined. It is shown that there are such values of the oscillation frequencies at which the critical crack length is especially sensitive to the amplitude alteration. The increase in the oscillation amplitude initiates starting the crack with small length. Numerical estimation is made for close-grained sandstone using such characteristics as crack resistance factor and Rayleigh' wave velocity and tensile strength. Increasing the amplitude twice at the frequency of 1145 Hz causes the triple reduction of the starting crack length. Numerical results correlate with in situ data related to acoustic predicting the dynamic phenomena in the rock mass.

Originality. The crack initiation criterion has been identified.

Practical implications. Quantitative relations between stress components and amplitude-frequency characteristics should be used to improve the outburst forecasting technique and increase the reliability of dynamic effect prediction.

Keywords: *crack initiating, dynamic phenomena, stress, oscillations, failure*

1. INTRODUCTION

Predicting the dynamic phenomena (rock burst, outburst) in coal mining is a great challenge when ensuring the safety of workers. Some forecast techniques are based on the registration and analysis of oscillations in rock mass (Standart SOU…, 2005). However the criteria of dangerous states emergence are not justified enough.

The forecast of dynamic effects can be defined as prediction of the rock failure. That is why studying the oscillations influence on crack propagation in previously stress-strained rock mass is appropriate. It should be noted that sources of oscillations can be different and often not properly identified. Acoustic impulses are generated in a solid body during such violations of its integrity as dislocations and cracks. A large number of scientific works is devoted to generation of elastic impulses at crack initiation in a solid body.

It is supposed that cracks are the centers of the acoustic activity in rocks because the rock mass can be considered a kind of a solid body as well. Internal contacts in the rock structure are broken by cracks and the energy of the rock stress strain state in the crack vicinity is a source of the crack initiating. The crack propagates if the stresses exceed a certain level and releases the excess of elastic energy into the coal seam. At the same time the crack is a stress concentrator itself. The abrupt stress change around the crack generates an impulse affecting other cracks (Prykhodchenko, Sdvyzhkova, Khomenko & Kovrov, 2008).

Elastic waves can stop or speed up the process of crack propagation under loading resulting in the material fracturing (Morozov & Petrov, 1997). They can contribute to appearance of new surfaces of weakening. Various rock-destroying mechanisms are the sources of oscillations as well. In this case the generated oscillations are "enriched" with oscillations caused by the destruction processes in the working tools zone.

Joints (cracks) initially present in the rock mass are influenced both by slowly-changing stress strain state and by much faster-changing oscillations. These are generated by an external source which is individual for each crack and can provoke increase in the crack dimensions.

Determining the conditions under which such crack growth becomes possible (i.e. the conditions of the crack initiation) is an important theoretical constituent in developing reliable methods of forecasting the rock bursts and outbursts and other dynamic effects on the basis of acoustic signals registered in the rock mass.

2. THE MAIN PART OF THE ARTICLE

2.1. Experimental data analysis

Results of studying the potentially dangerous areas of the rock mass in situ are presented by the authors. The coal seam has been sounded with acoustic signal generated by mining mechanisms. Registration of the acoustic signal that is extending into the rock mass was implemented using the acoustic equipment AK-1 (Shashenko, Zhuravlev, Sdvizhkova & Dubytska, 2015).

The operation principle of the outburst monitoring system AK-1M is based on the registration and analysis of acoustic oscillations. Oscillations are generated both by the rock mass itself at the stress state changing around the excavations and by the mechanisms used for coal mining. The acoustic signal produced by drifting tools is picked up by an underground block of the equipment with a build-in sensor (geophone *1* in Figure 1).

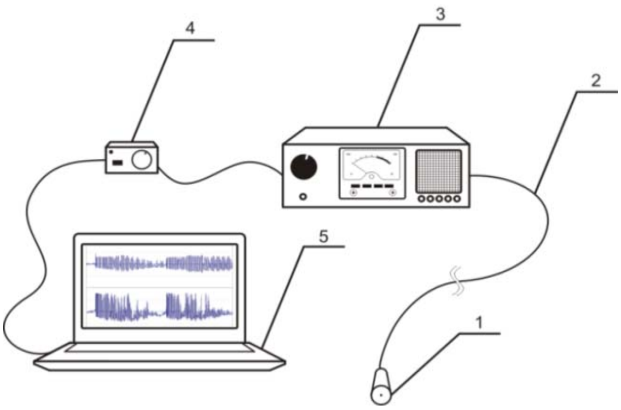

Figure 1. Functional scheme of equipment AK-1M: 1 – geophone; 2 – link; 3 – surface part of the equipment with intrinsically safe output circuit; 4 – attenuator; 5 – analysis complex

The sensor activity is based on using a piezoelectric effect. It has high dynamic characteristics and ability to perceive oscillations within a wide range of frequency (from several Hz to dozens of MHz). An electric charge appears under the influence of acoustic and seismic waves pressure on external and internal sides of piezoelectric couple plates. A total electromotive force between an output wire and a case changes proportionally to the pressure. Then the signal is transmitted to the surface part of the equipment *3* (Fig. 1) over the intrinsically safe communication line *2*. The surface part of the equipment is located in a seismic service department of the mine. The communication line can be nearly 10 km length. Then the signal is redirected to an attenuator *4*. It is intended for the smooth, stepped or fixed drop in voltage, current strength, power of electric and electromagnetic oscillations. After that the signal comes to an analytical complex *5*. The analysis, recording and preservation of the sound signals are actualized in this complex.

The rock mass area investigated by the acoustic signals has to be located between a source of oscillations and the sensor. Actually this condition is difficult to implement with existing technologies of coal mining. Reception of the acoustic signal in conditions of coal deposit is possible due to the layered structure of the rock mass and divergence in physical and mechanical properties of coal seam and rocks in the roof and floor.

In particular, sandstone layers have high acoustic conductivity and other rocks in the roof are characterized by significantly bigger acoustic hardness in comparison with the coal seam. It gives a possibility to register the signals far from the studied area.

The most important technical requirement is absence of additional sound intervention when acoustic observations take place. For example, borehole drilling or drift heading should be absent to register oscillations generated by shear equipment. That is why the sensor should be placed out of working zone (Fig. 2).

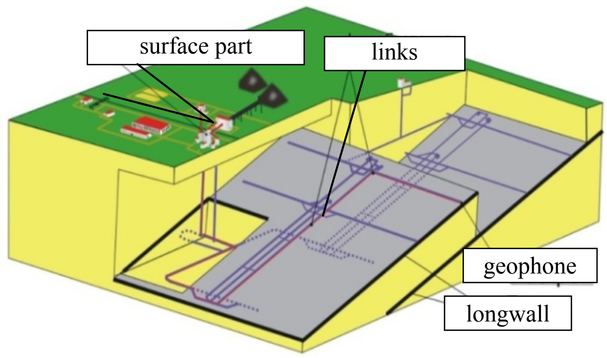

Figure 2. Arrangement of sensors

Studying acoustic signals during a longwall retreating is carried out by setting geophones into the walls of two parallel roadways. One of them is installed in the main gate and the other is placed in the tailgate. The geophones are located at a distance of 10 to 40 m in front of the coal face if a panel method of coal field preparation is adopted (Fig. 2). The sensor should be tightly installed in the borehole to ensure sufficient contact with the rock mass. There is a risk of moisture seeping into the electric circuit of the sensor due to the coal seam inclination. Therefore the sensor should be placed into the borehole which is drilled under some positive angle regarding to the horizon.

When the longwall advances at a distance of 10 – 40 m, the space between the sound source and geophone is reduced. Then the next borehole is prepared and other geophone is installed. The surface unit switches over to the next geophone respectively. The sensor installed at the previous station is extracted and used to prepare the further station.

Processing the acoustic signal results in an amplitude-frequency spectrum. Analysis of the amplitude-frequency components is conducted within a range of 0 – 300 Hz and 1250 – 4000 Hz. The statistical data processing allowed to establish a correlation between the amplitude-frequency characteristics (AFC) of elastic oscillations and probability of the rock outburst. Numerous experiments have been carried out in situ at various coal mines of Central and Western Donbass for this purpose. A real zone of potential danger in a coal seam is characterized by the variability of AFC including migration of the main frequency in a wide range. Appearance of high-amplitude and high-frequency harmonics is the main feature noted in all registered cases of rock outburst. Therefore doubling or tripling of the amplitude of the registered oscillation at frequencies of 1000 – 1300 Hz is considered an empirical warning of the possible dynamic effect of rock pressure. However this criterion has not been proved theoretically.

It can be assumed hypothetically that the change in amplitude and frequency of acoustic oscillations at the moment of outburst is connected with formation of new free surfaces (cracks). We consider the crack initiation in terms of elastic oscillation impact.

2.2. Crack initiation criterion

Let us consider a single crack at infinite space under the action of time-dependent stress field. We determine the loading conditions under which the increase of the crack dimensions is probable, i.e. the crack initiates.

The following assumptions are adopted. The rocks are represented as an elastic body and the crack is a disk one. The rock destruction is considered as a brittle failure and the stress is supposed to be normal to the crack plane. The effects of fatigue failure are not considered. Rock stresses are represented as a sum of the harmonic and the quasi-static components.

It is known that any crack is a discontinuity in a continuum body. It creates stress concentration in the surrounding area, so the stress value at the top of the crack can exceed the yield strength. In terms of fracture mechanics, this means exceeding the limit value of the stress intensity factor, which causes the crack growth and creates the condition under which the new cracks appear and a certain amount of the rock fails.

There are different approaches to define a criterion of rock failure under the impact of stress changing in time and space. Morozov & Petrov (1997) proposed a general kind of the criterion:

$$\frac{1}{\tau \cdot d} \int_{x_0-d}^{x_0} \int_{t_0-\tau}^{t_0} \sigma_1(x,t) dt dx \geq \sigma_{1c}, \tag{1}$$

where:

$\sigma_1(x,t)$ – principal stress;

σ_{1c} – tensile strength; τ is a time parameter characterizing the response delay of the failed material on the considered structural level;

d – length parameter; x is an axial coordinate (axis X is perpendicular to the principal stress);

t – current time value;

x_0 – X-coordinate of a point in the rock mass;

t_0 – time of failure.

The stress field is determined by the stress intensity factor $K_1(t)$ defined by the formula:

$$\sigma_1(x,t) = \frac{K_1(t)}{\sqrt{2\pi \cdot x}}. \tag{2}$$

Morozov & Petrov (1997) obtained the condition of the destruction as $d = \dfrac{2K_{1c}}{\pi\sigma_{1c}^2}$:

$$\frac{1}{\tau} \int_{t_0-\tau}^{t_0} K_1(t) \geq K_{1c}, \tag{3}$$

where K_{1c} is the critical value of K_1 which is the crack resistance factor determining the ability of a solid to resist loading without crack initiation. The validity criterion is illustrated by experimental results (Atroshenko, Krivosheev & Petrov, 2002).

2.3. Criterion of crack initiation under harmonic stress component

Let us express the stress intensity factor in terms of regular principal stress σ_1 for a disk crack. Let the radius of the crack be l. Using (3) we obtain a condition of the crack initiation at the given stress level:

$$\frac{1}{\tau} \int_{t_0-\tau}^{t_0} \sigma_1(t) dt = \frac{\sqrt{\pi}}{2} \frac{K_{1c}}{\sqrt{l}}. \tag{4}$$

Not only quasi-static stresses are acting in rocks in the general case. The sign-variable and quick-changing stresses occur in elastic waves due to the action of impulsive load in the rock mass. The elastic oscillations are generated by an internal source during the rock brittle destruction.

Under the simultaneous action of quasi-static stress and elastic vibration, a stress tensor $T_{\sigma(t)}$ can be represented as a sum of a quasi-static component $T_{kc(t)}$ and an oscillation one $T_{в(t)} : T_{\sigma(t)} = T_{kc(t)} + T_{в(t)}$.

The stress acting normally to the plane of the crack should be considered in the vicinity of the initiation time t. We can represent this stress in the form:

$$\sigma_1(t) = \sigma_0 + k \cdot (t - t_0) + a \cdot \cos\left[2\pi\nu \cdot (t - t_0) + \varphi_0\right], \tag{5}$$

where:

$\sigma(t) = \sigma_0 + k \cdot (t - t_0)$ – a component not related to oscillations;

σ_0 – actual tensile stress;

$k = \left(\frac{d\sigma}{dt}\right)_{t=t_0}$ – a component associated with the stress change in time during the development of mining operations;

a, ν, φ_0 – amplitude, frequency and phase of elastic oscillations respectively.

Substituting (5) into (4) and carrying out the mathematical transformation, we obtain the inequality:

$$a \cdot \sin c(\pi \nu \tau) - \frac{\tau \cdot k}{2} + \sigma_0 > \frac{\sqrt{\pi}}{2 \cdot \sqrt{l}} K_{1c}. \quad (6)$$

This expression defines the moment of the crack initiation considering the impact of elastic oscillations in the rock mass. Inequality (6) can be used at high and low frequencies of oscillations (including the value $\nu = 0$).

Incubation time τ is not a uniquely specific parameter and its value can be chosen and interpreted differently (Parton & Borisov, 1988). In any case, τ should be considered (as it was mentioned above) as a parameter characterizing the response delay of failed material to the considered structural level at unsteady loading. If a failure criterion is expressed through the full stress, the parameter τ is determined as the transfer of energy between neighboring elementary structures of failure with the characteristic size d. In case of using only a regular stress component (as it has been done in (4)), the response time can be estimated in terms of a consecutive expansive wave falling upon the crack of the finite length. The numerical solution of this problem and its analysis showed that the stress intensity factor at the crack tip increases monotonically (Alekseev & Nedodaev, 1982). The stress intensity factor reaches maximum at the time of a Rayleigh wave coming from the opposite top. On this basis we get $\tau = \frac{l}{c_R}$, where c_R is a rate of the Rayleigh wave.

Hence, we transform the inequality (6) to the form:

$$\bar{a} \cdot \sin c(\pi \bar{l}) \geq \frac{K_{c\nu}}{\sqrt{\bar{l}}} + \frac{\alpha \cdot \bar{l}}{2} - 1, \quad (7)$$

where: $\bar{l} = \frac{l\nu}{c_R}$, $\bar{a} = \frac{a}{\sigma_0}$, $\alpha = \frac{k}{\sigma_0 \cdot \nu}$, $K_{c\nu} = \frac{K_{1c}}{2\sigma_0} \cdot \sqrt{\frac{\pi\nu}{c_R}}$.

These values are dimensionless by assumption.

Equation (7) determines the criterion of the crack initiation. If values $K_c, c_R, \sigma_0, k, \nu$ are constants, then the parameters $K_{c\nu}$ and α are invariants as well. Then only parameters $\bar{l}$ and $\bar{a}$ are variables in the criterion (7), i.e. the initiation of the crack of length l is determined only by the amplitude of oscillation $\bar{a}$. The functional link between these values can be obtained as a solution of the transcendental equation (7).

It should be noted that if we consider the crack initiation caused by elastic oscillations, then both sides of (7) must be positive. If the right-hand side is negative then the crack initiation is caused only by quasi-stationary stress. If $K_{c\nu} < \sqrt{\bar{l}}$, the failure is provided by the constant stress component.

2.4. Numerical analysis of the criterion

Let the crack resistance factor K_c, the velocity of Rayleigh' waves spreading c_R and parameters of stress state σ_0, k be constant. Then the equation (7) gives a relationship between the relative amplitude of the elastic oscillation $\bar{a}$ and the relative crack length $\bar{l}$ (Fig. 3). The crack initiation occurs for the given level of amplitude.

The results of the numerical solution of the equation (7) are presented in Table 1. The calculations are carried out for close-grained sandstone. The crack resistance factor is assumed to be $K_{1c} = 1.47$ MPa$\sqrt{\text{m}}$, the Rayleigh' waves spreading velocity $c_R = 2400$ m/s and the tensile strength $\sigma_0 = 0.9$ MPa. We also assume that the stress component does not change in time. This means the parameter α is equal to zero ($\alpha = 0$).

Table 1. The dimensionless and real length of the initiating crack at different values of the oscillation amplitude and frequency

Frequency, ν	Crack resistance factor, $K_{c\nu}$	Amplitude, $\bar{a}$	Dimensionless length, $2\bar{l}$	Real length, $2\bar{l}$
733	0.8	0.0	1.2	4.2
		0.2	1.0	3.4
		0.4	0.8	2.4
		0.6	0.6	1.8
		0.8	0.4	1.4
		1.0	0.4	1.2
		1.5	0.2	0.6
		2.0	0.14	0.4
928	0.9	0.0	1.6	4.2
		0.2	1.4	3.6
		0.4	1.0	2.8
		0.6	0.8	2.0
		0.8	0.6	1.4
		1.0	0.4	1.2
		1.5	0.2	0.6
		2.0	0.18	0.4
1145	1.0	0.0	1.996	4.2
		0.2	1.994	4.18
		0.4	1.980	4.16
		0.6	1.12	2.4
		0.8	0.76	1.6
		1.0	0.6	1.2
		1.5	0.4	0.8
		2.0	0.2	0.4
1386	1.1	0.0	2.4	4.2
		0.2	2.4	4.2
		0.4	2.4	4.2
		0.6	2.4	4.2
		0.8	2.4	4.2
		1.0	0.8	1.4
		1.5	0.4	0.7
		2.0	0.28	0.48

The changes of an initiating crack length depending on the amplitude of the oscillations are presented in the graphs in Figure 3.

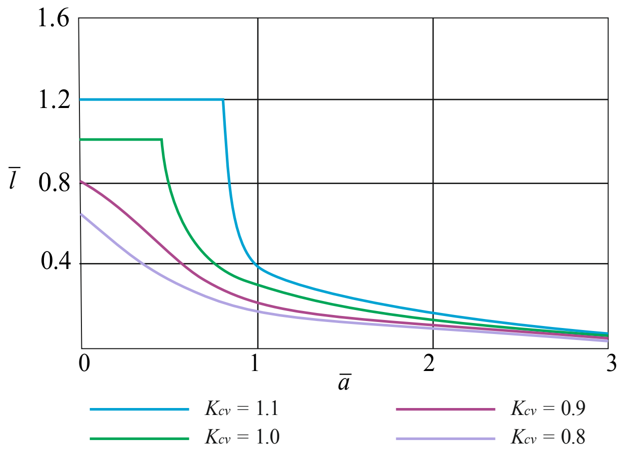

Figure 3. The critical crack length as a function of the relative oscillation amplitudes (α = 0)

We consider the curves with a sharp drop in the critical crack length $\bar{l}$ ($K_{cv} = 1.0$ and $K_{cv} = 1.1$).This fact is observed after sections that are parallel to the X-axis. Note that the horizontal portions of the curves correspond to the criterion:

$$\frac{K_{cv}}{\sqrt{\bar{l}}} + \frac{\alpha \cdot \bar{l}}{2} - 1 \le 0. \qquad (8)$$

This means that crack initiation occurs only because of the quasi-stationary stress component. There is no connection with the oscillations. At small values of complex parameter K_{cv} the critical crack length decreases smoothly enough depending on the increase in the oscillation amplitude. But at large values of parameter K_{cv} the horizontal sections increase and significant reduction in the critical crack length reaches unrealizable values of $\bar{a} > 1$. Therefore, we consider the value $K_{cv} \approx 1.0$ as a critical one when a small change in amplitude causes a sharp decrease in the length of those cracks which are ready to initiate. We can see on the plot that at $K_{cv} = 1.1$ the doubling the dimensionless amplitude leads to approximately triple reduction of the initiated crack length.

In particular, this effect can be seen clearly in case of sandstone. When the oscillation frequency is 1145 Hz, the value of complex parameter is approximately $K_{cv} \approx 1.0$, and we can observe from the table that insignificant increase in oscillation amplitude (from 0.4 to 0.8) provokes initiation of the short cracks. The length of initiated cracks decreases very sharply (from 4 to 1.6 m). This fact can be interpreted as a significant risk of catastrophic rock failure.

The results of theoretical research coincide with the empirical data described above. Doubling and tripling the amplitude of registered oscillation at frequencies of 1000 – 1300 Hz lead to the “short” crack initiation in the rock mass. As a result, new free surfaces are created and possibility of sudden release of potential energy occurs. This means a high probability of dynamic effects in the rock mass (rock bursts and outbursts).

Quantitative assessment shows that the amplitude alteration within the high frequency range is extremely important for predicting dynamic effects in hard rocks. Therefore, forecasting technique should be improved by analyzing the high-frequency part of the acoustic signal spectrum. Several prognostic indicators (maximum amplitude in the high-frequency part of the spectrum, the spectrum area, the ratio of amplitude and spectrum area) can be identified to improve the accuracy of dynamic effect prediction (Maslennikov, 1999).

3. CONCLUSIONS

The criterion of a crack initiation under unsteady loading has been developed on the basis of the general space-time approach to the description of a solid fracture. The stress component acting normally to the plane of the crack is supposed to be a sum of quasi-stationary and harmonic components. The quantitative relation has been obtained to determine the critical value of the crack length at which the crack initiates depending on the quasi-static stress and oscillation amplitude and frequency.

In particular case of a sandstone layer the increase of elastic oscillation amplitude in 2 times at frequency 1145 Hz reduces the critical length of initiating crack in 2 – 3 times.

Numerical results correlate with experimental data regarding the acoustic prediction of dynamic effect in the rock mass. In situ data indicates that increasing the amplitude of the recorded oscillations in the rock mass in 2 – 3 times at frequencies 1000 – 1300 Hz is a sign of possible dynamic effects (rock bursts and outbursts).

The analysis of oscillation amplitude alteration is extremely important within the high frequency part of the acoustic signal spectrum. Several prognostic indicators (maximum amplitude in the high-frequency part of the spectrum, the spectrum area, the ratio of amplitude and spectrum area) can be identified to improve technique of acoustic sounding and increase the accuracy of dynamic effect prediction.

ACKNOWLEDGEMENT

We are very grateful to the staff of the mine “Krasnolymanska” PSSC for providing statistical data.

REFERENCES

Alekseev, A.D., & Nedodaev, N.B. (1982). *Predel’noe sostoyanie gornykh porod*. Kiev: Naukova dumka.

Atroshenko, S., Krivosheev, S., & Petrov, A. (2002). Rasprostranenie treshchiny pri dynamicheskom razrushenyy polymertilmetacrylata. *Zhurnal tekhnicheskoy fiziki*, *72*(2), 52-58.

Maslennikov, E.V. (1999). Otsenka vozmozhnostey sposobov prognoza dinamicheskikh yavleniy na ugol’nykh plastakh, opasnykh po vnezapnym vybrosam uglya i gaza. *Scientific journal NMA Ukraine*, (5), 60-61.

Morozov, N.F., & Petrov, Yu.V. (1997). *Problemy dinamiki razrusheniya tverdykh tel*. Sankt-Peterburg: SPbGU.

Parton, V.Z., & Borisov, V.G. (1988). *Dinamika khrupkogo razrusheniya*. Moskva: Mashinostroenie.

Prykhodchenko, V., Sdvyzhkova, O., Khomenko, N., & Tykhonenko, V. (2016). Effect of time-transgressive faults upon methane distribution within coal seams. *Visnyk Natsional-noho Hirnychoho Universytetu*, (1), 31-35.

Shashenko, A.N., Zhuravlev, V.N., Sdvizhkova, Ye.A., & Dubytska, M.S. (2015). Forecast of disjunctives based on mathematical interpretation of acoustic signal phase characteristics. *Naukovyi Visnyk Natsionalnoho Hirnychoho Universytety*, (2), 61-65.

Standart SOU 10.1.00174088.011-2005. (2005). *Pravyla vedennia hirnychykh robit na plastakh, skhylnykh do hazodynamichnykh yavyshch*. Standart Minvuhlepromu Ukrainy.

ABSTRACT (IN UKRAINIAN)

Мета. Визначити критерій зрушування тріщини у породному середовищі при одночасному впливі внутрішніх напружень у породному масиві й акустичних коливань, що генеруються зовнішнім джерелом, а також отримати кількісні співвідношення для оцінки впливу коливань на процес страгування тріщини та створити теоретичну основу для вдосконалення методу акустичного прогнозу.

Методика. Застосування теорії крихкого руйнування у просторово-часовій постановці для отримання кількісних співвідношень між критичною довжиною тріщини, що стартує, та амплітудно-частотними характеристиками коливань. Порівняння чисельних результатів з даними експериментального прогнозу динамічних явищ.

Результати. Надані кількісні співвідношення між критичною довжиною тріщини, квазістатичним напруженням, амплітудою і частотою пружних коливань у породному масиві. Показано, що існують частоти коливань, на яких критична довжина тріщин особливо чутлива до зміни амплітуди. Так, наприклад, для пісковику збільшення амплітуди коливань у 2 рази на частоті 1145 Гц призводить до зменшення довжини тріщин, що стартують, у 3 рази. Чисельні результати корелюють з експериментальними даними акустичного прогнозу динамічних явищ у породному масиві.

Наукова новизна. Визначено умову старту тріщини.

Практична значимість. Кількісні співвідношення між компонентами напружень і амплітудно-частотними характеристиками коливань є основою для вдосконалення методики прогнозу й підвищення його достовірності.

Ключові слова: *тріщина, напруга, амплітуда, руйнування, коливання*

ABSTRACT (IN RUSSIAN)

Цель. Определить критерий страгивания трещины в породной среде при одновременном воздействии внутренних напряжений в породном массиве и акустических колебаний, генерируемых внешним источником, а также получить количественные соотношения для оценки влияния колебаний на процесс страгивания трещины и создать теоретическую основу для совершенствования метода акустического прогноза.

Методика. Применение теории хрупкого разрушения в пространственно-временной постановке для получения количественных соотношений между критической длиной страгиваемой трещины и амплитудно-частотными характеристиками колебаний. Сравнение численных результатов с данными экспериментального прогноза динамических явлений.

Результаты. Даны количественные соотношения между критической длиной трещины, квазистатическим напряжением, амплитудой, и частотой упругих колебаний в породном массиве. Показано, что существуют частоты колебаний, на которых критическая длина трещин особо чувствительна к изменению амплитуды. Так, например, для песчаника увеличение амплитуды колебаний в 2 раза на частоте 1145 Гц приводит к уменьшению длины страгиваемых трещин в 3 раза. Численные результаты коррелируют с экспериментальными данными акустического прогноза динамических явлений в породном массиве.

Научная новизна. Определено условие страгивания трещины.

Практическая значимость. Количественные соотношения между компонентами напряжений и амплитудно-частотными характеристиками колебаний являются основой для совершенствования методики прогноза и повышения его достоверности.

Ключевые слова: *трещина, напряжение, амплитуда, разрушение, колебания*

ARTICLE INFO

Received: 5 April 2016
Accepted: 26 May 2016
Available online: 30 June 2016

ABOUT AUTHORS

Olena Sdvyzhkova, Doctor of Technical Sciences, Head of the Higher Mathematics Department, National Mining University, 19 Yavornytskoho Ave., 5/33, 49005, Dnipropetrovsk, Ukraine. E-mail: sdvyzhkova_e@nmu.org.ua

Yurii Golovko, Candidate of Physics and Mathematics Sciences, Associate Professor of the Higher Mathematics Department, National Mining University, 19 Yavornytskoho Ave., 5/26, 49005, Dnipropetrovsk, Ukraine. E-mail: y_golovko@mail.ru

Mariia Dubytska, Candidate of Technical Sciences, Assistant Professor of the Higher Mathematics Department, National Mining University, 19 Yavornytskoho Ave., 5/33, 49005, Dnipropetrovsk, Ukraine. E-mail: dubitskayam@gmail.com

Dina Klymenko, Senior Lecturer of the Higher Mathematics Department, National Mining University, 19 Yavornytskoho Ave., 5/26, 49005, Dnipropetrovsk, Ukraine. E-mail: dinklim@mail.ru