UDC 622.724: 622.76 DOI: https://doi.org/10.1051/e3sconf/201910900058

EFFECT OF WATER MEDIUM UPON THE PROCESS OF ORE DISINTEGRATION IN WET SELF-GRINDING MILLS

[1]Monastyrskyi V.F., [1]Monastyrskyi S.V., [1]Mostovyi B.I.

[1]*Institute of Geotechnical Mechanics named by N. Poljakov of National Academy of Sciences of Ukraine*

ВПЛИВ ВОДНОГО СЕРЕДОВИЩА НА ПРОЦЕС РУЙНУВАННЯ РУДИ В МЛИНАХ МОКРОГО САМОПОДРІБНЕННЯ

[1]Монастирський В.Ф., [1]Монастирський С.В., [1]Мостовий Б.І.

[1]*Інститут геотехнічної механіки ім. М.С. Полякова НАН України*

ВЛИЯНИЕ ВОДНОЙ СРЕДЫ НА ПРОЦЕСС РАЗРУШЕНИЯ РУДЫ В МЕЛЬНИЦАХ МОКРОГО САМОИЗМЕЛЬЧЕНИЯ

[1]Монастырский В.Ф., [1]Монастырский С.В., [1]Мостовой Б.И.

[1]*Институт геотехнической механики им. Н.С. Полякова НАН Украины*

Annotation. This article presents the results of theoretical and experimental studies on the processes of destruction ore in wet self-grinding mills (WSGM). Depending on *pH* (hydrogen parameter) and *Eh* (oxidizing-restoration parameter) values, water medium is capable of penetrating into the lumps through cracks formed in the mother rock (germinal ones). Argillaceous and ochreous minerals being practically always available in mineralogical composition of the deposits of diamond-bearing raw material, form specific films on the mineral surfaces. When the lump and obstacles interact, surfaces are destructed, microcracks are closed at the expense of material elasticity, and a lump may be represented as a sphere inside of which there are minor cavities filled with the incompressible liquid. The equivalent circuit for determining the stress-strain state of a piece exposed to the load at an angle of repose of the material in motion are justified. In this case, a uniformly distributed pressure acts on the body of arbitrary shape, depending on the hydrostatic pressure of the pulp inside the drum and the force of hydrodynamic resistance). It is assumed that a piece has the shape of a sphere with a uniform structure, but in some of its parts there are cavities filled with an incompressible fluid. Under the action of forces inside the cavity wedging effects of water occur, the effect of which on the strength ores depends on the expansion force and the angle of the micro crack. The experimental researches are done under laboratory and industrial conditions. Effect of a wedging force upon the ore strength was determined experimentally under laboratory conditions using a plant for one-axial compression of samples from different ores and rocks; the plant was equipped with hydraulic press with 60 kN and computer for simultaneous recording of compression force and deformation. The research methodology stipulated that tests were carried out involving following samples: dry, previously wetted, solid, glued two-layer, and with a cavity. It was established that the disintegration of kimberlitic ore in WSGM is significantly influenced by the characteristics of the aquatic environment *pH* and *Eh*, the values of which vary from 3.2 to 7.0 and from -500 to +1020 mV.

Keywords: liquid, experiment, durability, equivalent circuit, hydrogen parameter, oxidizing-restoration parameter.

Dressing plants, which process diamond-bearing raw material, use wet self-grinding mills (WSGM) to crush and grind bulk commodity with the coarseness of 300–900 mm; the plants help liberate diamonds, remove films on their surface, and grind initial ore up to the required processing depth. Currently, ore-mining enterprises often use WSGM of the diameter from 5 up to 10.5 m produced by Syzran plant and such foreign companies as *Svedala* and *Rockcyle*. According to the studies by *Yakutniproalmaz* [1] the mills operate at n_o=0.75n_{cr} rotation frequency (n_{cr} is the critical frequency of drum rotation), coefficient of drum charge being from 0.3 to 0.45, H:L > 1:0.8 ratio, and temperature of process water being 4° or equal to the environmental one at the ore surface taking into consideration permafrost conditions.

In the process of drum rotation, water medium is heated and the obtained heat energy is used for the material thawing along with its dissipation in the environment. In terms of long-term thawing, diamond-bearing ore loses its iciness, strength, and durability which results in the fact that the lumps are broken even in terms of insignificant dynamic loading. However, papers [1, 2] determine that in the context of near-lifter and waterfall operating modes of WSGM, lumps are raised by height H during the drum rotation and interact with the load core (totality of lumps) or components of the drum liner at β angle under the gravity force. In this case, dynamic loads remain to be significant and water medium has not time to effect considerably the strength and durability of lumps.

Paper [3] represents computational scheme and analytical expressions to determine energy losses of a falling lump at the moment of its interaction with the water plane depending upon the lump mass, its falling height, and interaction angle. It has been determined that water layer reduces the velocity of lump falling by 25–30 %; that results in the increased dynamic loads on separate lumps in the center of WSGM and improves diamond integrity.

Depending on *pH* (hydrogen parameter) and *Eh* (oxidizing-restoration parameter) values, water medium is capable of penetrating into the lumps through cracks formed in the mother rock (germinal ones) or due to the effect of a blast wave. Argillaceous and ochreous minerals being practically always available in mineralogical composition of the deposits of diamond-bearing raw material, form specific films on the mineral surfaces which contact with them at the molecular level. According to [4], such films are capable of widening (wedging) the microcracks though which water penetrates into a lump filling the available cavities. When the lump and obstacles interact, films are destructed, microcracks are closed at the expense of material elasticity, and a lump may be represented as a sphere inside of which there are minor cavities filled with the incompressible liquid. Effect of the water medium characteristics upon the process of rock and ore breaking inside the WSGM drum was studied both theoretically and experimentally.

A problem of determining stress and strain state of a lump in the process of its effecting by water medium and dynamic loads was solved theoretically while a problem of selecting basic characteristics of water medium in terms of which ore and rock breaking would be optimal was solved experimentally.

Figure 1,a,b demonstrates computational schemes to determine stress and strain state of a lump (sphere) located on a lifter plane and being effected by the loads at the angle of natural slope of the material in motion (ε). In this case, an arbitrary shaped body is effected by equally distributed pressure (P_k) which value is defined depending upon hydrostatic pressure of the pulp (P_p) inside a drum and force of hydrodynamic resistance (P_r) in terms of lump movement along with the lifter at velocity

$$V_k = \omega_0 \frac{D_d}{2},$$

where $\omega_0 = \pi n_d/30$ is frequency of drum rotation; n_d is quantity of turns of drum; D_d is drum diameter.

To formalize the computational scheme, following factors were assumed:

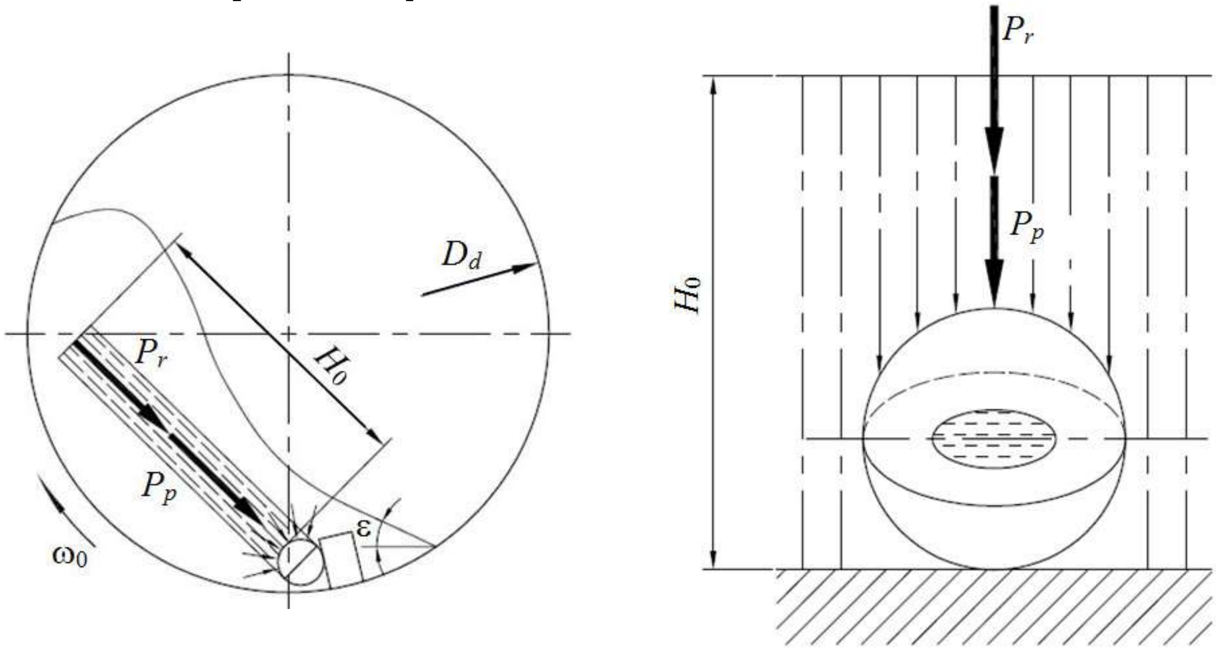
– lump shape is taken as a sphere which projection to the plane perpendicular to the force effect is determined from expression $S = \pi D^2/4$, where D is sphere diameter;

– we should study three-axial compression of a lump under the effect of uniform pressure (P_k);

– stress and strain state of the sphere is considered at the moment when forces of resistance and hydrostatic pressure have their maximum values (Fig. 1);

– lifter elasticity is neglected, a lump is considered to be lying on a rigid base; and

– sphere is of homogeneous structure, however, its certain parts have cavities filled with incompressible liquid.



a b

Figure 1 – Computational scheme to determine stress and strain state of a lump (sphere)

According to [5], pressure effecting the lump is determined from expression

$$P_k = g\gamma_p H_0 + K_{hd}\,\gamma_h V^2 S,$$

where γ_h, γ_p are densities of hard and pulp masses respectively; H_0 is hydrostatic (maximum) pressure on the lump in the center of its mass; g is free fall acceleration; V is velocity of lump motion in the liquid; K_{hd} is hydrodynamic coefficient of liquid resistance; and S is area of the sphere projection on the interaction plane.

In terms of three-axial compression by (P_k) pressure, any area inside the sphere experiences stresses equal to P_k [6]; depending upon the cross-section area of a cavity filled with water, force $F = P_k F_c$ (where F_c is cross-section area of cavity inside the sphere) will occur at any direction.

Figure 2 represents computational scheme to determine wedging effect of water inside the sphere. In this context, we consider that pressure from force F is transmitted to a microcrack with 2α angle by means of *R* forces which value is defined by projecting all the forces on axes X and У: $R = F/2\sin\alpha$.

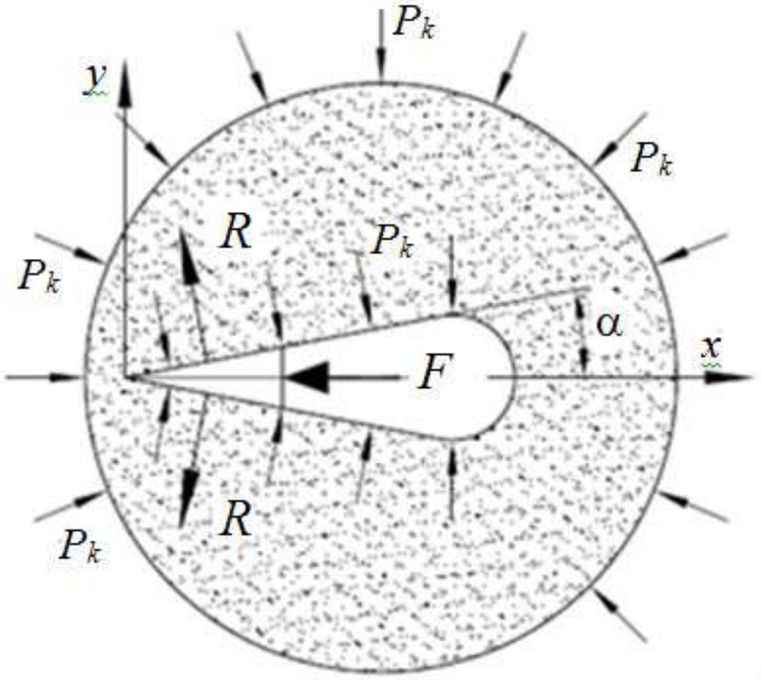


Figure 2 – Computational scheme to determine wedging effect of water

Effect of a wedging force upon the ore strength was determined experimentally under laboratory conditions using a plant for one-axial compression of samples from different ores and rocks; the plant was equipped with hydraulic press with 60 kN and computer for simultaneous recording of compression force and deformation. The research methodology stipulated that tests were carried out involving following samples: dry, previously wetted, solid (Fig. 3,a), glued two-layer (Fig. 3,b), and with a cavity (Fig. 3,c). Table 1 represents the results of tests for samples compression up to their breaking; Figures 4–6 demonstrate diagrams of sample compression and their photos after breaking.

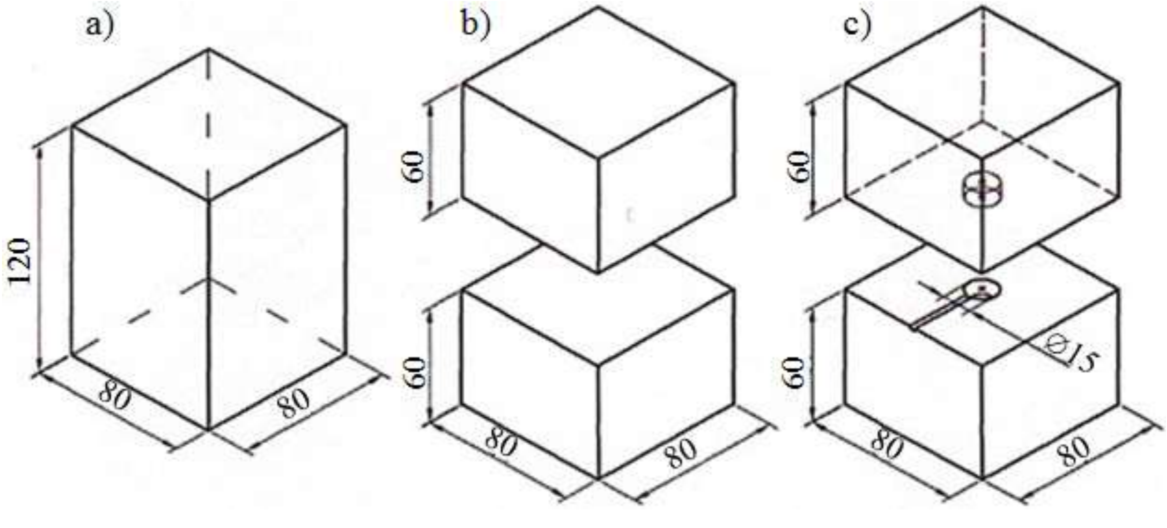
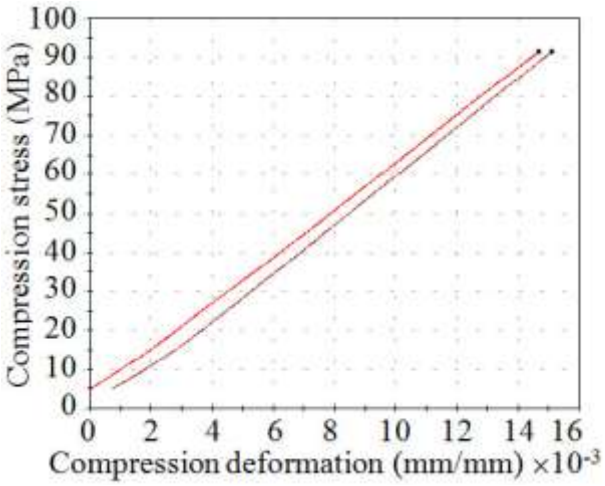


Figure 3 – Test samples: a) solid sample; b) cut sample; c) sample with a cavity

Table 1 – Results of sample testing for breaking compression.

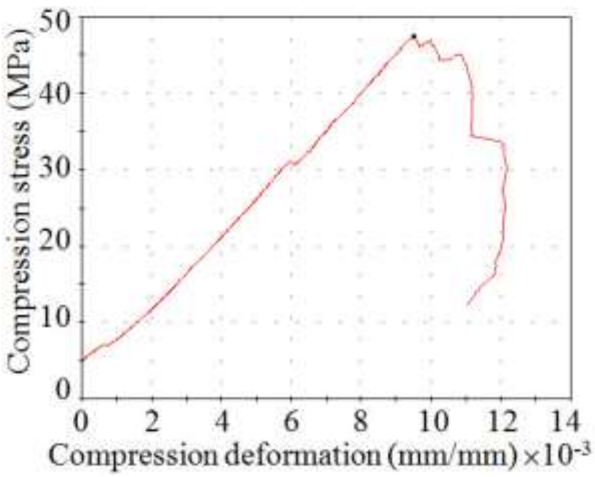
Sample	Sample characteristics	Ultimate compression strength (MPa)	Ultimate loading deformation, mm/mm	Ultimate compression loading, kN	Modulus of elasticity, MPa	Young modulus in terms of compression stress 6–20 MPa
1	80x80x120, dry	91.47	0.01437	630.01	6281.54	5850.81
2	80x80x120, dry	91.46	0.01452	630.01	6209.54	5907.68
3	80x80x120 wet	82.82	0.01439	570.43	6077.81	5093.89
4	80x80x120, wet	57.76	0.00998	465.02	5163.72	5012.77
5	80×80×120, dry	71.58	0.01363	493.01	5488.86	5106.93
6	80×80×120, wet	51.25	0.00965	432.23	5098.72	5006.11
7	80×80×120, dry	55.28	0.00974	443.11	5122.61	5010.18
8	80×80×120, wet	47.38	0.00949	326.34	5083.19	4821.06



a

b

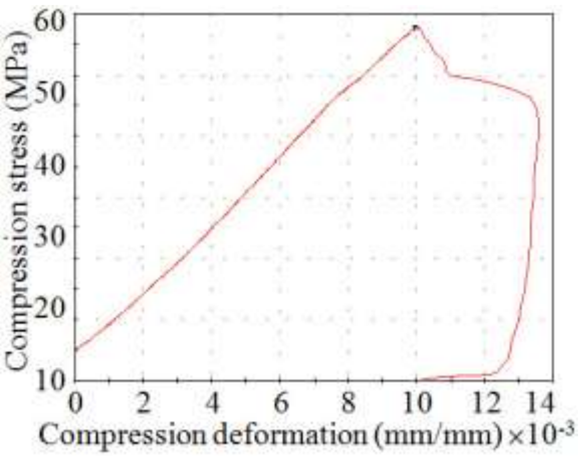
Figure 4 – Diagram of samples №1 and №2 compression (a) (Table 1)
and their photos in broken condition (b)



a

b

Figure 5 – Diagram of sample №5 compression (a) (Table 1) and its photo in broken condition (b)



a

b

Figure 6 – Diagram of sample №6 compression (a) (Table 1) and its photo in broken condition (b)

Basing upon the performed studies, following conclusions may be drawn:

– while compressing dry and wet samples, stress is subject to a linear law depending upon their relative deformation: in terms of dry solid sample (Fig.4,a) up to 0.015; in terms of wet solid sample (Fig. 5,a) up to 0.010; and in terms of wet sample with a cavity (Fig. 6,a) up to 0.009;

– if sample condition is changed (dry, wet, with a cavity), ultimate breaking stresses are as follows (Table 1): 91 MPa for solid dry (samples №1 and №2); 83 MPa for solid wet (sample №3); 71 MPa for dry two-layer (glued) without a cavity (sample №5); 57 MPa for wet two-layer (glued) without a cavity (sample №4); 55 MPa for dry with a cavity (sample №7); and 48 MPa for dry with a cavity (sample №8).

Thus, water medium reduces strength of solid ore samples by 8–10%; in case of wet samples with a cavity the reduction is by 40 % comparing to the solid ones.

Paper [7] determines experimentally the effect of water characteristics *Eh* and *pH* upon the process of ore disintegration. The experiments were carried out in the apparatus of membraneless type in continuous-flow mode with process water parameters. It is defined that if return water is treated by different electrodes, then *pH* and *Eh* characteristics vary within the ranges from 3.2 up to 7.0 and from -500 up to +1020 mV; in this context, *Eh* shifts towards the range of negative values making it possible to apply widely physical and chemical pulp characteristics. While changing physical and chemical properties of the return water in wide range, the obtained results allow developing such a water composition in terms of which disintegration process and water penetration into the rocks will increase by several time. In particular, if water system composition is turned to be acid, then disintegration process and water penetration into the ore samples will grow by 2–3 times [6, 7]. Results of the laboratory studies are confirmed by industrial tests performed under conditions of factory №3 [8]. It is identified that ore and rock breaking inside WSGM is more intense in terms of process water treatment in electrolysis units before its supply into WSGM; that indicates considerable effect of water properties upon ore softening.

Conclusions. Thus, ore disintegration in WSGM is effected considerably by water medium characteristics *pH* and *Eh* which values vary within the ranges from 3.2 up to 7.0 and from -500 up to +1020 mV. In this context, *Eh* shifts towards the range of negative values making it possible to vary significantly physical and chemical pulp characteristics and changing its composition so that disintegration process and water penetration into the ore will increase by several times.

REFERENCES

1. Monastyrsky, V. F. and Soloviev, S. V. (2004), "Optimization of the modes of self-grinding mills during the enrichment of diamond-containing raw materials", *Gornyi Zhurnal: Izvestiya VUZov*, no. 6, pp. 45–49.

2. Firm Kluff starts to carry out the project of processing of diamonds in Copeton (1990), *Mining Mag.*, no. 1, pp. 62–68.

3. Monastyrsky, V. F. and Vorontsov, V. S. (2012), "Models of diamond-bearing ore disintegration in the aquatic environment of wet self-grinding mills", *Geo-Technical Mechanics*, no. 104, pp. 146–159.

4. Goryachev, B. E. (2010), *Tekhnologiya almazosoderzhashchikh rud* [Diamond Ore Technology], MISIS, Moscow, Russia.

5. Langelier, W. F. (1946), "Chemical Equilibria in Water Treatment", *Journal of the American Water Works Association*, no. 38, pp. 169–181.

6. Feodosev, V. I. (1999), *Soprotivlenie materialov* [Resistance of materials], MSTU, Moscow, Russia.

7. Chanturia, V. A. and Vigdergauz, V. E. (2008), "Innovative technologies for processing technogenic mineral raw materials", *Gornyi Zhurnal*, no. 6, pp. 71–74.

8. Dvoichenkova, G. P., Chernysheva, E. N., Savitsky, L. V. and Vorontsov, V. S. (2009), "Intensification of the processes of ore preparation and heavy-medium separation of diamond-containing raw materials of the Nyurbinskaya tube", *Gornyi Zhurnal*, no. 6, pp. 72–7.

СПИСОК ЛІТЕРАТУРИ

1. Монастырский В. Ф., Соловьев С.В. Оптимизация режимов мельниц самоизмельчения при обогащении алмазосодержащего сырья // Горный журнал: Известия ВУЗов. – 2004. – №6. – С. 45–49.

2. Firm Kluff starts to carry out the project of processing of diamonds in Copeton. *Mining Mag.*, 1990, no. 1, pp. 62–68.

3. Монастырский В. Ф., воронцов В.С. Модели дезинтеграции алмазоносной руды в водной среде мельниц мокрого самоизмельчения // Геотехническая механика: Межвед. сб. научн. тр./ИГТМ НАН Украины. Днепропетровск, 2012. Вып. 104. С. 146–159.

4. Горячев Б. Е. Технология алмазосодержащих руд. М: МИСИС, 2010. 326 с.

5. Langelier W. F. Chemical Equilibria in Water Treatment // Journal of American Water Works Association. 1946. 38. Pp. 169–181.

6. Феодосьев В. И. Сопротивление материалов. М.: МГТУ, 1999. 592 с.

7. Чантурия В. А., Вигдергауз В.Е. Инновационные технологии переработки техногенного минерального сырья // Горный журнал. 2008. №6. С. 71–74.

8. Двойченкова Г. П., Чернышева Е.Н., Савицкий Л.В., Воронцов В.С. Интенсификация процессов рудоподготовки и тяжелосредной сепарации алмазосодержащего сырья трубки «Нюрбинская» // Горный журнал. 2009. №6. С. 72–75.

About the authors

Monastyrskyi Vitalii Fedorovych, Doctor of Technical Sciences (D. Sc), Senior Researcher, Senior Researcher in the Department of Geomechanics of Mineral Opencast Mining Technology, Institute of Geotechnical Mechanics named by N. Poljakov of National Academy of Sciences of Ukraine (IGTM, NASU), Dnipro, Ukraine, vfmon@mail.ru

Monastyrskyi Serhii Vitaliiovych, Candidate of Technical Sciences (Ph. D), Junior Researcher in the Department of Geomechanics of Mineral Opencast Mining Technology, Institute of Geotechnical Mechanics named by N. Poljakov of National Academy of Sciences of Ukraine (IGTM, NASU), Dnipro, Ukraine, vfmon@mail.ru

Mostovyi Borys Ivanovych, Master of Science, Principal Specialist in the Department of Geomechanics of Mineral Opencast Mining Technology, Institute of Geotechnical Mechanics named by N. Poljakov of National Academy of Sciences of Ukraine (IGTM, NASU), Dnepr, Ukraine, sly3@i.ua

Про авторів

Монастирський Віталій Федорович, доктор технічних наук, старший науковий співробітник, старший науковий співробітник відділу геомеханічних основ технології відкритої розрабки родовищ, Інститут геотехнічної механіки ім. М. С. Полякова Національної академії наук України (ІГТМ НАН України), Дніпро, Україна, vfmon@mail.ru

Монастирський Сергій Віталійович, кандидат технічних наук, молодший науковий співробітник відділу геомеханічних основ технології відкритої розробки родовищ, Інститут геотехнічної механіки ім. М. С. Полякова НАН України (ІГТМ НАН України), Дніпро, Україна, vfmon@mail.ru

Мостовий Борис Іванович, магістр, провідний інженер відділу геомеханічних основ технології відкритої розробки родовищ, Інститут геотехнічної механіки ім. М. С. Полякова Національної академії наук України (ІГТМ НАН України), Дніпро, Україна, sly3@i.ua

Анотація. У даній статті представлено результати теоретичних nf експериментальних досліджень процесів руйнування руди в млині мокрого самоподрібнення (ММС). Водне середовище залежно від значень *pH* (водневий показник) і *Eh* (окислювально-відновний показник) здатне проникати всередину крупних шматків через тріщини, які утворюються в материнській породі (зародкові). Глиністоохристі мінерали, які практично завжди присутні в мінералогічному складі родовища сировини, до складу якого входять алмази, утворюють на поверхні мінералів плівки, які при взаємодії шматка з перешкодами руйнуються, мікротріщини закриваються за рахунок пружності матеріалу і крупний шматок можна представити у вигляді кулі, усередині якої є невеликі порожнини, заповнені нестислива рідиною. Обґрунтовано еквівалентну схему для визначення напружено-деформованого стану шматка, що піддається дії навантаження під кутом природного укосу матеріалу в русі. В цьому випадку на тіло довільної форми діє рівномірно розподілений тиск, залежний від гідростатичного тиску пульпи усередині барабана і сили гідродинамічного опору. Прийнято, що шматок має форму кулі з однорідною структурою і порожнинами, заповненими нестисливою рідиною. Під дією сил усередині порожнини виникають розклинювальні дії води, вплив яких на міцність руд залежить від зусилля розпору і кута мікротріщини. Експериментальні дослідження виконувалися в лабораторних і промислових умовах. Вплив розклинювального зусилля на міцність руди визначався експериментально в лабораторних умовах на установці для одноосного стиснення зразків з різних порід і руд, обладнаній гідравлічним пресом 60 кН і комп'ютером для одночасної фіксації сили стиснення і деформації. Методикою досліджень передбачалися випробування зразків сухих і заздалегідь зволожених, монолітних, склеєних двошарових і з порожниною. Встановлено, що на дезінтеграцію руди в ММС істотний вплив чинять характеристики водного середовища *pH* і *Eh*, значення яких змінюються в межах від 3,2 до 7,0 і від -500 до +1020 мВ.

Ключові слова: рідина, експеримент, міцність, еквівалентна схема, водневий показник, окислювально-відновний показник.

Аннотация. В настоящей статье представлены результаты теоретических и экспериментальных исследований процессов разрушения руды в мельнице мокрого самоизмельчения (ММС). Водная среда в зависимости от значений *pH* (водородный показатель) и *Eh* (окислительно-восстановительный показатель) способна проникать внутрь крупных кусков через трещины, которые образуются в материнской породе (зародышевые). Глинистоохристые минералы, которые практически всегда присутствуют в минералогическом составе месторождения алмазосодержащего сырья, образуют на поверхности минералов пленки, которые при взаимодействии куска с препятствиями разрушаются, микротрещины закрываются за счет упругости материала и крупный кусок можно представить в виде шара, внутри которого имеются небольшие полости, заполненные несжимаемой жидкостью. Обоснована эквивалентная схема для определения напряженно-деформированного состояния куска, подвергающегося воздействию нагрузки под углом естественного откоса материала в движении. В этом случае на тело произвольной формы действует равномерно распределенное давление, зависящее от гидростатического давления пульпы внутри барабана и силы гидродинамического сопротивления. Принято, что кусок имеет форму шара с однородной структурой и полостями, заполненными несжимаемой жидкостью. Под действием сил внутри полости возникают расклинивающие воздействия воды, влияние которых на прочность руд зависит от усилия распора и угла микротрещины. Экспериментальные исследования выполнялись в лабораторных и промышленных условиях. Влияние расклинивающего усилия на прочность руды определялось экспериментально в лабораторных условиях на установке для одноосного сжатия образцов из различных пород и руд, оборудованной гидравлическим прессом 60 кН и компьютером для одновременной фиксации силы сжатия и деформации. Методикой исследований предусматривались испытания образцов сухих и предварительно увлажненных, монолитных, склеенных двухслойных и с полостью. Установлено, что на дезинтеграцию руды в ММС существенное влияние оказывают характеристики водной среды *pH* и *Eh*, значения которых изменяются в пределах от 3,2 до 7,0 и от -500 до +1020 мВ.

Ключевые слова: жидкость, эксперимент, прочность, эквивалентная схема, водородный показатель, окислительно-восстановительный показатель

Стаття надійшла до редакції 29.06. 2019.
Рекомендовано до друку д-ром техн. наук В.П. Надутим