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Evaluation of gold ore properties and their impact on grinding operations

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Abstract

Purpose. The purpose of this paper is to evaluate the efficiency of grinding operations in terms of how mechanical properties (e.g., strength properties and ore texture) affect the Bond Work Index.

Methods. The specimens have been collected in the Eastern Desert of Egypt, namely Abu Marwat, Hamash and Al Sadd. As a result, strength parameters such as compressive strength, cohesiveness and hardness have been assessed. Ore texture, mineral content and bonds between tiny fabric units have been examined using X-Ray Diffraction (XRD) and thin section.

Findings. This research shows that as the strength properties of the rock increase, the Bond Working Index also increases. Moreover, the results indicate that the level of cohesion of ore minerals with the surrounding tailings, on the one hand, and the variance in the tailing content, on the other hand, play a significant role in the processing operation, given the discrepancy in the Bond Work Index for the six Abu Marawat gold ores of 18.8%.

Originality. This research attempts to develop a methodology for assessing the efficiency of grinding operations as a function of rock strength properties and ore texture in relation to the Bond Work Index.

Practical implications. Ore texture is one of the most important factors influencing the grinding process. Since grinding consumes a considerable amount of energy, the economic evaluation is based on increasing the grinding efficiency. According to previous research, the petrographic, which varies from sample to another, has an impact on the mechanical properties as well as the grinding operations.

Keywords: *grinding operation, ore texture, Bond Work Index, XRD, thin section*

1. Introduction

Size reduction is performed by comminuting either in a dry or wet medium. The primary goal of size reduction is to free valuable minerals from the original rock. The relationship between rock failure and mechanical characteristics has been studied. One of these studies examined the failure of fractured rocks under uniaxial compression, which resulted in the spread of the first micro fractures over a wide shear band, as well as the coalescence of micro fractures into a critical shear failure zone, which resulted in limited testing of this failure. At elevated confining pressures, the Elastic moduli and peak strength values of rock increase, and the deformation passes from fragile to spermatogenesis [1]-[3]. Numerous studies have shown that particle size is crucial, because it is used to identify the mechanical behavior of rock samples of the same composition. The rock composition is important in determining their material characteristics [4]-[6]. The Bond Work Index is used to calculate the resistance and hardness during milling operations. Since milling energy is primarily determined by compressive strength, fracture toughness and tensile strength [6]-[9], the Bond grinding test is widely used to estimate energy requirements in ball and rod mills, as well as to select equipment for comminuting plant scale. To complete the laboratory concentration, three chromite ores from different locations in Turkey have been studied based on their physical and mineralogical properties.

The mineral structure, the degree of recovery of valuable/gangue minerals, grinding properties (Bond Work Index, BWI), and ore sizes are carefully determined. The conclusion is made about the high acceptability of the proposed analytical method for determining the grinding size of primary ore. Thus, the validity of this equation is proposed for testing on other types of ores [10]. Texture is also defined in petrology as the size, shape, and distribution pattern of mineral particles. Furthermore, textures in rocks provide information about the mechanisms of rock formation and control the direct properties of rocks in inhomogeneous circumstances. Various rocks are widely used within regions, such as inner and outer base layer for outfall, highway and asphalt structures, concrete build-ups, and so on. An economically meaningful description of the mechanical characteristics of such materials, commonly referred to as building stone, is given in [6]. The textures are

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studied and analyzed in relation to the mineral composition at the stages of crushing and grinding. Textures have a similar impact on the degree of crushing and grinding of rocks, while the mineral content of the samples does not have significant impact on the dispersion of crystallite size and the degree of grinding [6]. The strength and failure mechanism of composite rock specimens under uniaxial compression are also studied. Their mineralogical composition is determined by the mineral features that comprise rocks and rock fabrics.

The mechanical characteristics of rocks, such as their fabric, texture and weathering, have a significant influence on them [11]. Several papers have examined the relationship between energy consumption and material properties such as mineral composition, mechanical characteristics, and lithological properties for single or mixed materials. The energy in the mixture is calculated using the Charles formula. Thus, the ceramic raw materials, mineral distribution and dimensional modulus are the same whether they are ground separately or in a ternary mixture [12]. A good relationship and equation has been determined to operate with accurate energy conversion for pieces as a result of the impact of the input size distribution and the types of materials. The directional distribution and energy input have been delegated [13]. Sukari ore (gold) is more difficult to mine than that in Kori Kollo. Performance indices of 19.1 kWh/t for mixed and sulphide ores are calculated on the 85^{th} test from various rock types. This performance index of 16.2 kWh/t of material is used as the oxide ore index. Given the vortex product size and P80 (150 microns) after flotation and leaching tests, the stream rate to the grinding system is set at 80% of 112 mm. A pebble crusher is considered necessary in the scheme to crush the more reliable waste from the SAG mill. Setting the SAG mill ball load to 15% and increasing the steel port size to 80 mm provide the required performance [14]. Low energy consumption and cost savings through increased efficiency are studied. Although high-pressure rectification rolls (HPGR) are considered as an energy-efficient alternative, little attention has been paid to their development in modeling and control. Vertical roller mills are used to grind cement raw materials as well as minerals such as phosphorous, manganese oxide, silicate minerals, titanium, and calcareous. Shattering and milling as comminution components are classified as drying processes as a whole and have more advantages than other traditional systems, thereby saving 15%. Chalcopyrite plant ore has a rod and ball factory under these conditions. They have found that they can achieve 18% reductions in energy consumption and fewer internal components [15].

The material composition in networks, such as the cement industry, accounts for approximately 26% of total energy consumption. The focus during grinding is on reducing energy, using a formula to test the performance of ball mills under conditions such as air temperature and input moisture that affect the mill [16]. Liang et al. and Lin et al. conducted uniaxial compression tests on composite samples of varying texture and minerals to study the impact of heterogeneity on failure mode. They have found that since the weaker material (siltstone) fraction influences on the failure mode, this study helps to determine the optimal grinding conditions [15]. Statistical methods were used to study the relationship between rock appearance, milling and pulverizing characteristics. They have found that rock structure has little impact on shape and density factors. However, the density and porosity impacts are strong in this case. Furthermore, the structure influences the level of crushing and grinding of nearby rocks. Meanwhile, it has been revealed that the mineral content does not have an impact on the degree and rate of spalling of the tossed size of particles. The influence of some mechanical characteristics of the geological location and the Bond Index on various types of gold-bearing mines in the Abu Marawat is explored and studied in this study.

2. Methods

Six samples taken from the new site in the Abu Marawat, as well as the energy consumed during the grinding operation, have been studied and examined to determine the relationship between the consumed energy and the mechanical properties of these samples. The authors selected rock samples from various ore types in the studied area. The Abu Marawat is a new gold exploration site in the eastern desert. Ore samples were examined to determine mechanical properties (such as compressive strength, modulus of elasticity, and geological properties). Then their values were compared with the energy consumed to determine the grindability in relation to the Bond Work Index. One of the most important factors influencing the rock characteristics, such as mechanical properties, is geological characteristics.

2.1. Mechanical rock properties

Hardening is assessed after measuring mechanical properties such as compressive strength. To determine the uniaxial compressive strength, five samples are prepared and tested at each location using a compression machine. Samples are prepared in a cylindrical geometry (40 mm diameter and 80 mm length) and dried at 105 + 5°C for hours under standard conditions. To determine the modulus of elasticity, a stress strain curve should be drawn for assessing the modulus of elasticity. The relationship has been revealed between compressive strength and modulus of elasticity.

2.2. Geological characterization of the Abu Marawat gold mine

The Sukari mine has been successful in gold production and all investors considered Sukari a good place to work in gold mining. Many new gold-related websites have emerged recently, including Abu Marwat, Hamash, Al Sadd, and others. The Neoproterozoic surface of northeast Africa is crystallized by the accumulation of transvolcanic islands, the continental nature of the structure, and oceanic plateaus [17].

A 26 km path south of the Safaga-Qena asphalt road, 400 km south-southeast of Cairo, can lead to Abu Marawat. The ore reserve is located at latitude 26°30'30" and longitude 33°39'00". The Abu Marawat region covers 738.8 square kilometers and is located between Egypt and the Nubian Shield. The gold deposits occur with quartz fabric. The region includes sections of the CVZ and FIN veins, which are a couple of subparallel, sloping and east-dipping, gold-copper quartz veins with a north-northwest strike, distributed from 50 to 100 m apart as shown in Figure 1 [18]. Vein, accompanied by distorted felsic metavolcanic rocks and patterned ultramafic unit, is located east of the rhyolite. A 1 km long diorite body, oriented from north to south, is wedged into ultramafic rocks [19]. Pharaohs and Romans mined gold in this area. The structures cover a distance of about 1 km^2 northeast of Wadi Abu Marawat, a Wadi Samna waterway, with the largest workings located along the eastern part of the old mining site [20].

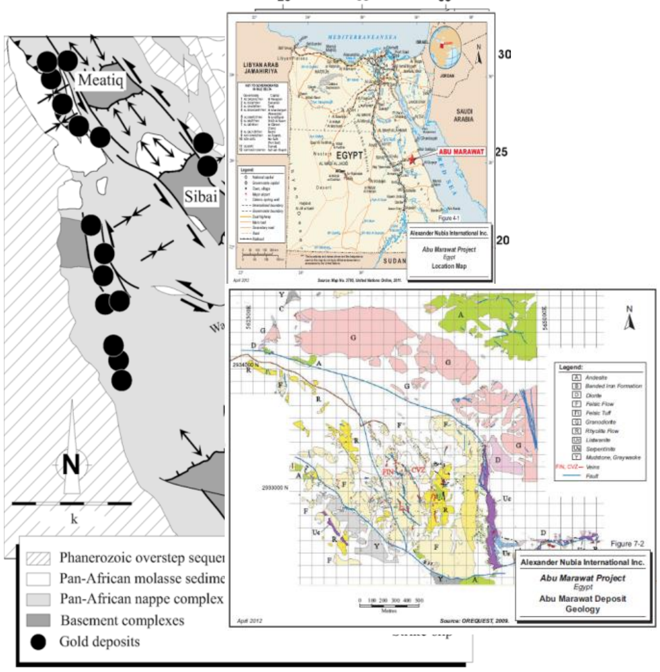

Figure 1. Precambrian rocks of the E.D.E and Sinai as well as the distribution of gold in gold deposits

The study area consists of ANS Precambrian rocks, quite well subjected in raised crustal blocks on the Red Sea flanks. Plate interactions associated with the Pan tectonic event that occurred between 615 and 600 Ma ago formed the lithological structure [21]. The lithosphere is a loosely structured Precambrian series of lava and volcanic rocks that were later transformed into lower schist facies and infringed by a wide range of granites, sho-wing a significant direction of the Proterosic fringes. The Abu Marawat is located between the main east-trending fault and the northwest-trending fault. The latter is part of a network of subparallel faults ranging in length from 10 to 20 km. The Abu Marawat deposit framework prior to the vein creation, the predominately felsic volcanic rocks at Abu Marawat are moderately to severely folded. A region of argillite, a thin layered iron structure, and thin layers of ply felsic tuff, which incorporates multiple pyrites, were inclu-ded in the series and represent a transitional gap in the volcanism. This is most likely geologically comparable to the much larger vicinity of the densely folded, clustered iron structure to the southeast. The felsic igneous rocks are bound by 2 significant faults. A significant, potentially terrestrial fault to the north deflects felsic volcanoes to the south and west from granodiorite, diorite, and andesite to the north and east. It usually runs east-west. A comparable granodiorite was found on the south side of the fault two kilometers west of Abu Marawat, implying just a few kilometers of right-hand displacements. The veins are located in a primary tension area extending from 330° to 350° and plunging from 80° to the west and 80° to the east. It was most likely formed during the same period of deformations as the curvature fold in the northern boundary fault. The Fin vein was divided and slightly displaced by subsequent recent east-west trending of non-mineralized fracture-filling quartz-vein structures and minimal northeast-southwest and north-west-southeast trending faults, implying that the Fin vein would be at the nucleus of a delayed kink fold with linked minimal fault displacement [22]-[25].

2.3. Assessment of grindability of gold samples

Grinding is the second operation in the mining process and is considered one of the most critical determinants of energy consumption. Grindability is an indicator of comminution operations that is independent of many technical specifications. In terms of mill type, the hard grove index is followed by vertical spindle mills, and the Bond Index has been widely introduced with tumbling mills. In this experiment, Bond's standard grindability was used to determine the energy of the comminution operation.

2.4. Standard Bond tests

The energy consumption was measured and classified according to the comminution process. The general concept for energy consumption is how many kilowatts are required to grind one ton of rock with specifications of 80 passes and 100 m in size. When the Bond Work Index is expressed as resistance to grinding, the particle size does not change, indicating that the Bond Work Index has not changed as expected. These particles indicate a variety of indices related to energy consumption. All experiments are carried out at Al-Azhar University's Mining and Petroleum Engineering Department. A general machine specification is shown in Figure 2 (dry, closed-cycle).

Figure 2. Standard Bond Ball Mill

Mill loads of 850 cm^3 and a speed of 100 rpm are used. The samples are then sieved and weighted. The change in seeding, determined from undersize samples, should be 1/3.5 of the total load. The samples are analyzed to determine the mill's grindability as illustrated in Table 1, which can be calculated using Equation 1.

$$W_i = \frac{44.5}{\left(P_i\right)^{0.23} \cdot \left(GbP\right)^{0.82} \cdot \dfrac{1}{\left(P_{80}^{0.5}\right) - \left(\dfrac{10}{F_{80}^{0.5}}\right)}}, \quad (1)$$

where:

F_{80} – denotes 80% of the new stream that enters the ball mill, m;

P_{80} – 80% of generated ground ore, m.

P_i – signifies the screen diameter in millimeters.

3. Results and discussion

Crushing operations are the first step in the mineral processing plant. The present study shows the relationship between some mechanical properties, petrographic properties and energy costs used for gold ore grinding in the Abu Marawat mine area. The characterized gold-bearing ore types have varying mineralogical compositions and fabrics, which are represented by variations in mechanical properties (Compressive Strength, MPa, elastic modulus, GPa, and Bond Work Index, BWI) (kWh ton^{-1}). In the case of G1, the strength properties and modulus of elasticity are 315.85 MPa and 82.5 GPa, respectively, and the Bond Work Index is 21.5 kWh/ton. The geological interpretation is that the sample composition, which includes sulphide, occurs within an acidic volcanic pile. This indicates a very high hardness value and a very high cohesion bond between their matrices, reflecting high values for compressive strength and modulus of elasticity.

3.1. Macroscopic aspects and textures

Underground mining operations in the Abu Marawat gold mine has shown the existence of various ore types in terms of texture, mineral composition and fabrics. Five major ore categories have been identified and core samples from each have been tested. The host rock of gold-bearing sulphide minerals is composed of basic to transitional volcaniclastics, such as tuffaceous mudstones and agglomerates. Among the ore-bearing minerals are pyrite, chalcopyrite, sphalerite, and galena. Such minerals are closely related to tailings minerals such as quartz, devitrified and undevitrified tuffaceous mudstone, chlorite, and clay minerals.

3.2. Petrological investigation

Abu Marawat deposit type. Often these vein-type mineral deposits in mesothermal Late Precambrian calc-alkaline volcanic rocks are found in metavolcanic and associated metasedimentary rocks. Mineralization in the Abu Marawat is typically found in base-metal-bearing brecciated quartz veins. SGM defined the mineralization in the Abu Marawat as cut massive sulphide beds within an acidic volcanic pile, whilst Minex interpreted it as reef-type or breccia-vein type. This is a polymetallic, multi-phase and mesothermal vein system with three stages of mineralization. Pyrite, chalcopyrite, sphalerite, stannite and galena are examples of early high temperature minerals. Low temperature produces low-sulphidation (low fS2 reactionary metamorphism) pyrrhotite, whereas high temperature produces pyrite and derivatives. The Abu Marawat is a mesothermal heavy mineral quartz-sulphide vein connected by a strong geothermal modifying system in slightly altered and thermal decomposed felsic volcanic rocks, as shown in Figures 3 and 4. This indicates a considerable high-temperature and hydrothermal origin of solutions at depth [26].

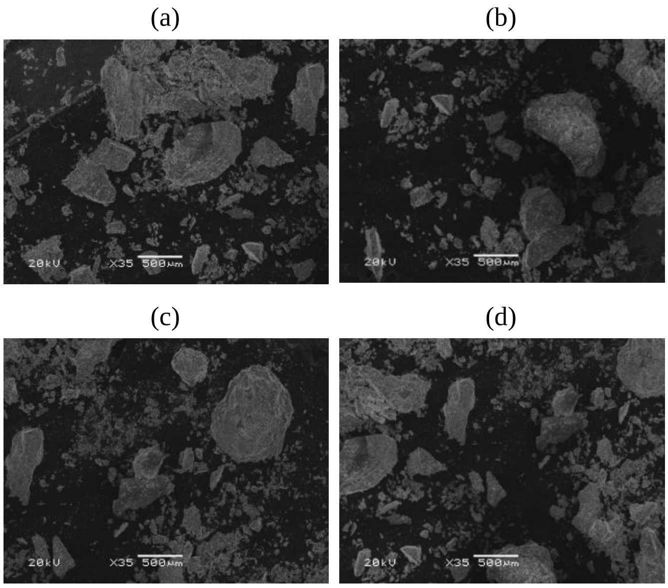

Figure 3. Microscpic pic for different six samples

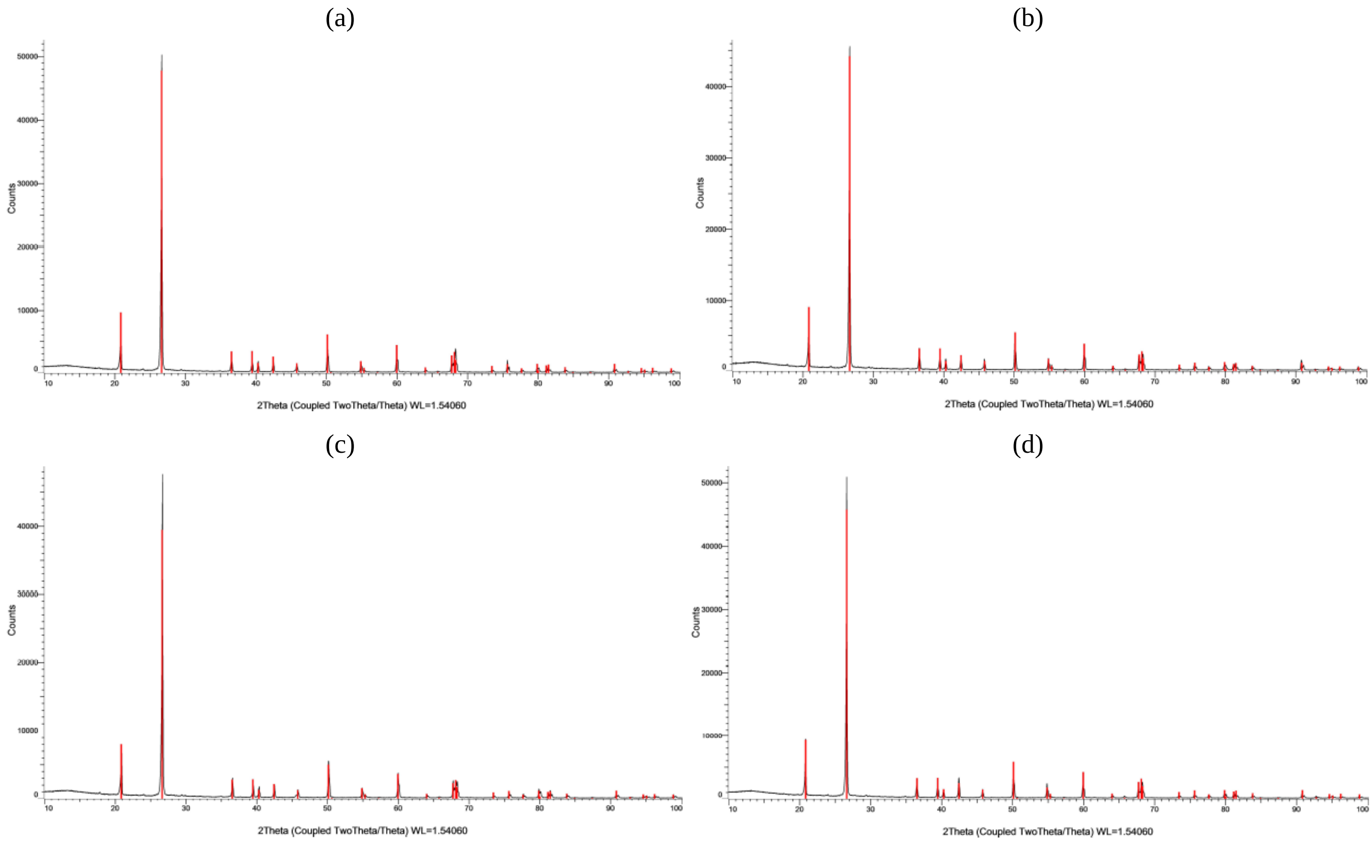

Figure 4. XRD for six samples mainly contains SiO_2 over 90%

Table 1 summarizes the final results for mechanical properties, geotechnical attributes and Bond Work Index for various gold ore types.

Table 1. Summary of geomechanical, geological properties and Bond Work Index

Gold-bearing ore types	Mechanical properties		Geological characteristics	Bond Work Index, (kwh ton^{-1})
	Compressive strength, (MPa)	Elasticity modulus (GPa)		
G1	315.85	82.50	sulphide beds within an acidic volcanic pile	21.5
G2	304.55	79.65	pyrite, chalcopyrite, sphalerite, stannite and galena	20.55
G3	298.45	75.25	low-sulphidation (low fS2 retrograde metamorphism) pyrrhotite	18.99
G4	288.35	71.53	high sulphidation (high fS2) pyrite and tellurides	17.88
G5	259.55	65.32	mesothermal auriferous quartz-sulphide veins	17.55
G6	258.55	64.36	pyrite, chalcopyrite, and galena	17.48

Referring to Table 1 for the mechanical properties of G2, the compressive strength is 304.55 MPa, the modulus of elasticity is 79.65 GPa, and the equivalent of Bond Work Index is 2055 kWh/ton. It has been revealed that for pyrite, chalcopyrite, sphalerite, stannite, and galena, both hardness and cohesion have high values. It then forms a bond between their matrices. According to the study and explanation that it takes more energy to grind the sample, the result so close to sample 1 is referred to that mine site, convergent in composition. The compressive strength and modulus of elasticity for G3 are 298.45 MPa and 75.25 GPa, respectively, while the Bond Work Index is 18.99 kWh/ton, which refers to low-sulphidation (low fS2 retrograde metamorphism) pyrrhotite. Both hardness and cohesion are high in value, indicating a strong bond between the matrixes. Grinding of rocks requires more energy consumption. The date tabulated for G4, the compressive strength and modulus of elasticity values are 288.35 MPa and 71.53 GPa, respectively, resulting in a Bond Work Index of 17.88 kWh/ton. The interpretation for these property values is based on the mineralogical composition (high sulphidation (high fS2) pyrite and tellurides) that requires less energy for G5 than G1.

According to our data, the compressive strength and modulus of elasticity are 259.55 MPa and 65.32 GPa, respectively, with a Bond Work Index of 17.55 kWh/ton. It can be concluded that it is composed of mesothermal auriferous quartz-sulphide veins. Depending on the mineral content and matrix bonding, the G5 has a low hardness and cohesion, which requires low energy consumption for grinding operation. The compressive strength and modulus of elasticity for G6 are 258.55 MPa and 64.36 GPa, respectively, while the Bond Work Index is 17.55 kWh/ton. It is also noted that G6 has low hardness and cohesion, which requires low energy consumption for grinding operations. The detailed petrographic and mineralogical investigations reveal that the calculated values of the Bond Work Index for the five samples differ slightly. The greatest difference between these values is 18.8%. Furthermore, the impact of slight variation in geomechanical properties and petrographic properties has an insignificance impact on energy consumption during milling operation.

This research provides an important study on how the properties of the ore influence on how much energy is used during grinding. Such an operation will inevitably be neglected, so it is necessary to estimate the work index. Consequently, this study is of critical importance for the mining industry. 40% of all mining energy is used only for the grinding process.

The scope of this research can be extended to study the impacts of various ores and their heterogeneity on the cost of energy used in relation to grinding media (e.g., ball size, wear rate, loading, number of balls).

4. Conclusions

Bond grindability is assessed by determining the Bond Work Index and examining the geological characteristics of the gold sample. Mechanical and petrographic tests have been performed in the Abu Marawat gold mine. It has been concluded that there is a slight relationship between the Bond Work Index and various ore groups of the Abu Marawat gold mine. Below are the final results, obtained from this work:

1. The variation in mineral content in different ore types of the Abu Marawat gold ore mine has a limited measurable influence on the Bond Work Index, with a noticeable reduction in Bond Work Index from ore type 1 to ore type 5. This is due to changes in the proportion of various sulphide minerals in different gold-bearing rock types, as well as to the limited variability in the hardenability of these minerals. Because pyrite and chalcopyrite are tougher than sphalerite and galena, the Bond Working Index varies very little. Furthermore, the degree of cohesion of ore deposits bounded by tailings, on the one hand, and the variability of the constituents of tailings, on the other hand, play an important role in the processing processes.

2. The maximum difference in the Bond Work Index for six samples of the Abu Marawat gold ores is 18.8%.

3. The milling operation are influenced by several factors. Nevertheless, due to their various heterogeneous structures, it seems impossible to describe their effectiveness.

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References

[1] Poirier, J.-P. (1979). Experimental rock deformation. The brittle field, by MS Paterson. *Bulletin de Minéralogie*, *102*(2), 301-301. https://doi.org/10.3406/bulmi.1979.7256

[2] Kwaśniewski, M. (2013). Comments on the ISRM suggested method "A failure criterion for rocks based on true triaxial testing". *Rock Mechanics and Rock Engineering*, *46*(4), 917-919. https://doi.org/10.1007/s00603-013-0407-6

[3] Abdelhaffez, G. (2020). Studying the effect of ore texture on the Bond Work Index at the Mahd Ad Dahab Gold Mine: A case study. *Rudarsko-Geološko-Naftni Zbornik*, *35*(1), 111-121. https://doi.org/10.17794/rgn.2020.1.9

[4] Haffez, G.S.A. (2012). Correlation between work index and mechanical properties of some Saudi ores. *Materials Testing*, *54*(2), 108-112. https://doi.org/10.3139/120.110302

[5] Ersoy, A., & Waller, M.D. (1995). Textural characterization of rocks. *Engineering Geology*, *39*(3-4), 123-136. https://doi.org/10.1016/0013-7952(95)00005-Z

[6] Kekec, B., Unal, M., & Sensogut, C. (2006). Effect of the textural properties of rocks on their crushing and grinding features. *Journal of University of Science and Technology Beijing, Mineral, Metallurgy, Material*, *13*(5), 385-392. https://doi.org/10.1016/S1005-8850(06)60079-0

[7] Badr, S., & Abdelhaffez, G. (2012). Numerical modeling of macro-scale brittle rock crushing during impacts. *Journal of Engineering Sciences*, *40*(6), 1781-1792. https://doi.org/10.21608/jesaun.2012.114619

[8] Yuce, A.E. (2017). Grinding size estimation and beneficiation studies based on simple properties of ore components. *Physicochemical Problems of Mineral Processing*, *53*(1), 541-552. https://doi.org/10.5277/ppmp170142

[9] Korman, T., Bedekovic, G., Kujundzic, T., & Kuhinek, D. (2015). Impact of physical and mechanical properties of rocks on energy consumption of jaw crusher. *Physicochemical Problems of Mineral Processing*, *51*(2), 461-475. https://doi.org/10.5277/ppmp150208

[10] Park, B., & Min, K.B. (2015). Bonded-particle discrete element modeling of mechanical behavior of transversely isotropic rock. *International Journal of Rock Mechanics and a Sciences*, (76), 243-255. https://doi.org/10.1016/j.ijrmms.2015.03.014

[11] Ipek, H.A.L.İ.L., Ucbas, Y.A.Ş.A.R., & Hosten, C. (2005). Ternary-mixture grinding of ceramic raw materials. *Minerals Engineering*, *18*(1), 45-49. https://doi.org/10.1016/j.mineng.2004.05.0063

[12] Petrakis, E., Stamboliadis, E., & Komnitsas, K. (2017). Evaluation of the relationship between energy input and particle size distribution in comminution with the use of piecewise regression analysis. *Particulate Science and Technology*, *35*(4), 479-489. https://doi.org/10.1080/02726351.2016.1168894

[13] Vyhmeister, E., Reyes-Bozo, L., Rodriguez-Maecker, R., Fúnez-Guerra, C., Cepeda-Vaca, F., & Valdés-González, H. (2019). Modeling and energy-based model predictive control of high pressure grinding roll. *Minerals Engineering*, (134), 7-15. https://doi.org/10.1016/j.mineng.2019.01.016

[14] Atmaca, A., & Kanoglu, M. (2012). Reducing energy consumption of a raw mill in cement industry. *Energy*, *42*(1), 261-269. https://doi.org/10.1016/j.energy.2012.03.060

[15] Liang, W.G., Yang, C.H., Zhao, Y.S., Dusseault, M.B., & Liu, J. (2007). Experimental investigation of mechanical properties of bedded salt rock. *International Journal of Rock Mechanics and Mining Sciences*, *44*(3), 400-411. https://doi.org/10.1016/j.ijrmms.2006.09.007

[16] Ocak, I. (2008). Estimating the modulus of elasticity of the rock material from compressive strength and unit weight. *Journal of the Southern African Institute of Mining and Metallurgy*, *108*(10), 621-626.

[17] Helmy, H.M., Kaindl, R., Fritz, H., & Loizenbauer, J. (2004). The Sukari Gold Mine, Eastern Desert-Egypt: Structural setting, mineralogy and fluid inclusion study. *Mineralium Deposita*, *39*(4), 495-511. https://doi.org/10.1007/s00126-004-0426-z

[18] Klemm, R., & Klemm, D. (2012). *Gold and gold mining in ancient Egypt and Nubia: Geoarchaeology of the ancient gold mining sites in the Egyptian and Sudanese eastern deserts*. Heidelberg, Germany: Springer Berlin, 649 p. https://doi.org/10.1007/978-3-642-22508-6

[19] Valliant, W.W., & Salmon, B. (2012). *Technical report on the Abu Marawat concession, Egypt*. NI43-101 Report for Alexander Nubia International Inc. by Roscoe Postle Associates Inc. SEDAR published report.

[20] Gabr, S., Ghulam, A., & Kusky, T. (2010). Detecting areas of high-potential gold mineralization using ASTER data. *Ore Geology Reviews*, *38*(1-2), 59-69. https://doi.org/10.1016/j.oregeorev.2010.05.007

[21] Botros, N.S. (2004). A new classification of the gold deposits of Egypt. *Ore Geology Reviews*, *25*(1-2), 1-37. https://doi.org/10.1016/j.oregeorev.2003.07.002

[22] Botros, N.S. (2015). Gold in Egypt: Does the future get worse or better? *Ore Geology Reviews*, (67), 189-207. https://doi.org/10.1016/j.oregeorev.2014.11.018

[23] Bampton, M. (2017). *Hamama West Deposit, Abu Marawat concession, Arab Republic of Egypt*. NI 43-101 Independent Technical Report. Perth, Western Australia: Cube Consulting Pty. Ltd., 121 p.

[24] Işman, A. (2013). *Proceedings Book of the International Science and Technology Conference*. St. Petersburg, Russian Federation: ISTEC, 1041 p.

[25] Zoheir, B.A., & Akawy, A. (2010). Genesis of the Abu Marawat gold deposit, Central Eastern Desert of Egypt. *Journal of African Earth Sciences*, *57*(4), 306-320. https://doi.org/10.1016/j.jafrearsci.2009.10.002

[26] Ahmed, A.H. (2022). *Mineral deposits and occurrences in the Arabian-Nubian shield*. Jeddah, Saudi Arabia: Springer Nature, 521 p. https://doi.org/10.1007/978-3-030-96443-6

Оцінка властивостей золоторудної сировини та їх вплив на процеси подрібнення

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Мета. Оцінка ефективності процесів подрібнення з точки зору того як механічні властивості (властивості міцності та текстура руди) впливають на індекс подрібнюваності в кульовому млині Бонда.

Методика. Зразки були зібрані в східній пустелі Єгипту, а саме Абу-Марват, Хамаш і Аль-Садд. У результаті були оцінені такі параметри міцності як міцність на стиск, когезійність і твердість. Текстуру руди, вміст мінеральних речовин і зв'язки між крихітними елементами петроструктури досліджували за допомогою методу рентгенівської дифракції (XRD) і тонкого шліфу.

Результати. Експериментально встановлено, що зі збільшенням міцності гірської породи індекс подрібнюваності в кульовому млині Бонда також збільшується. Визначено, що рівень когезії рудних мінералів із оточуючими хвостами, з одного боку, та дисперсія у вмісті хвостів, з іншого боку, відіграють значну роль у процесі переробки, враховуючи розбіжність у індексі подрібнюваності в кульовому млині Бонда для шести золотих руд родовища Абу-Марват 18.8%.

Наукова новизна. Удосконалено методологічні підходи для оцінки ефективності процесів подрібнення, зокрема функції властивостей міцності гірських порід і текстури руди по відношенню до індексу подрібнюваності в кульовому млині Бонда.

Практична значимість. Текстура руди є одним з найважливіших факторів, що впливає на процес подрібнення. Оскільки подрібнення споживає значну кількість енергії, економічна оцінка базується на підвищенні ефективності подрібнення. Згідно з попередніми дослідженнями, петрографія, яка змінюється від зразка до зразка, впливає на механічні властивості, а також на процеси подрібнення.

Ключові слова: *процеси подрібнення, текстура руди, індекс подрібнюваності в кульовому млині Бонда, метод рентгенівської дифракції, тонкий шліф*