Report:

Bond Work Index

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Problem statement

Friability of ores and rocks can be termed by the tests associated with brittleness. An apparatus to test the brittle nature, in order to determine the value related to friability has been created to suit gold ore strength characteristics for the commercial purposes. The term friability values of gold ores have been compared and determined with corresponding bond work index (BWI) and grind-ability index of the mentioned gold ores (Aras, Özşen&Dursun, 2019). The physico-mechanical properties of tested materials have been determined to understand their effect on grinding and friability. Before concentrates, metal ores are powdered and ground for the metal bearing elements to be released. Sufficient reduction in size is not suitable enough for downstream physical separation.

However, the process associated with mineral processing is in high demand for extracting gold in its pure form, making it extremely important to ensure that the right method is followed for extracting the metals (Menéndez, Gent, Torno& Crespo, 2017). Reliable behavior pertaining to ore's comminuting behavior helps in providing a clear idea to select proper types of unit operations size and equipment. The importance of studying metallurgical interventions is to create a spatially based predictive model for mineral processing. Testing of the ores is important in geometallurgical programs being applied industrially for particular ore body. The metallurgical intervention for gained immense importance due to the following reasons, in few Asian and even the Middle Eastern countries the commercial value of gold tends to be on the higher side. As stated by Shad, Sereshki, Ataei&Karamoozian (2018), gold is often termed to be an investment that makes it equally important for evaluating the strength and extraction of gold from ores from commercial perspectives.

Geometallergy is seen to combine information of metallurgy and geology for creating a spatially based predictive model for processing mineral plants. Ore testing is often termed as an important part. Previous research done by Williams et al. (2015), discussed about the ways ores gold ores were subjected to indirect testing discussing several systematic intervention. The implementation of comminution testing is based on the quality of the ores. In similar regards the mixed tests and ability to grinding is often tested through several steps. In case the material is too hard, materials must be restricted to reach the targeted size. In addition to that a combination of steps can be used to reach the targeted particle size. In addition to that there exists a combination of processes that can be adjusted to grind the ores. In case of high throughput is maintained to expense related to size particle the consequence would be related to poor mineral liberation, linking to poor recovery due to increased loss by locked particles.

Hence, it is of prime importance to design indirect testing methods helps in selecting the right method of operations unit and the size of equipment for right output. The current study is of prime importance as it provides an expansive idea about the extensive testing undertaken for extracting gold from the ores. The design and control is inclusive of extensive testing. The bond work index can be termed as a blend of hard and soft ores as function of the volume faction of the softer ore used in the process of blending. The dotted margin between two extremities is indicative of the weighted average work index, on the basis of volume fraction. The work index values is inclusive of the magdalinovic method are seen to be on same perspective with bond work index as the method does not stimulate recycling harder metal components into the mill charge. However, the work index obtained using the standard bond tests are shown that weighting of the work index is leveraged towards the harder component due to the resulting circulating load.

On regards with the current practices that is determined by sole fixing of the particle size, it is questionable whether the mentioned intervention would be suitable enough to work or not.

Research study conducted by Mazur (2017), there is an evident variation in grain size of gold therefore using a fixed process to extract metal from the ores may not give fruitful result. Thus, one of the prime challenges in developing efficient metal extraction such as gold, effective comminution methods of testing is considered of liberation properties of how liberation can be carried forward can be used in geometallurgical models. Thus, the thesis in the mentioned case aims to establish a comprehensive method of extracting gold from ores, demonstrating correlation between Bond work indexes for Gold ores through indirect tests. The indirect test method was previously used by Lvov, Sishchuk&Chitalov (2017), measured the breakage rates and distribution of different blends of ores for predicting the work index of blend, through Bond batch grinding tests. Qualitative analysis relating to breakage properties are seen to suggest that there remains a correlation between the components within the blend, ultimately affecting the individual breakage rates. The breakage properties of certain ores is harder and likely to have greater impact on the overall breakage properties and bond work index of the blend than the soft materials such as gold.

Scope

Different methods of mineral processing are available. It starts with communication in mineral processingplants. The methods are an essential part of mineral processing plants. Then gold are extracted from the ore. Gold is in huge demand and it is extracted as a by-product. The demand for gold has made companies to obtain more gold to meet the demand. The grinding method is used for the Bond Work Index. The size is measured by the higher kWh/t size. The Bond Work Index approach is the method to grind the gold ores. Most gold ores occur from an underground mines. The procedure for this index is calculated on how new fines is determined from the test. Various methods and techniques are used to extract the mineral like rock fragmentation, Coals and crushers, etc. In this process, the ore is mainly

washed at the mine. Gold is separated by the method of floatation by using chemicals. To separate the gold, the Cyanidatio method is used. To precipitate the mineral Carbon-in- pulp method is utilized.

Gold extraction process has increased rapidly in recent years among various companies across the world. It has become a global business, and it has noticed a Substantial growth rate in the market.

Objective

The mentioned research makes use of established notion that there may a correlation between bond work index and indirect methods associated with crushing of the ores. Hence, following are the objectives that can be formed:

- To evaluate the relationship between indirect method and resistance to crushing as per the mentioned scenario
- To propose better strategies related to metallurgical intervention and correlation of Bond work index for Gold ores through indirect tests

Literature review

Introduction

The literature review will demonstrate the correlation of Bond work index of gold ore with the indirect test. In simple terms, the Bond Work Index is the measurement of the resistance of ores when they are subjected to grinding or crushing. The Bond Work Index is measured in the Bond Grinding Tests of the ores. The indirect test represents the indirect tensile strength test, which is conducted to examine the tensile strength of the metals. The purpose of the literature study is to disclose the perspective of the different works of pieces of literature regarding the connection between Bond Work Index or gold and the indirect tests to examine the behaviour of gold under circumstances of tensile stress. To explore the various aspects of the research question, the topic has been broken down into the concepts of "Bond work index of gold", "Indirect tests of gold", and "Relation between Bond work index and different mechanical properties of ores".The literature gap is discussed in the final section of the literature review.

Concept of Bond work index

Todorovic, Trumic, Andric, & Milosevic, (2017) depicts that the Bond Work index is a "parameter" that represents the resistance of an ore against grinding. The index is a numeric, that represents the amount of energy in k Wh / sht that is required to reduce material of 1 short ton from an infinite feed size-to-size where 80 per cent of the material is passed a sieve measuring aperture100 micrometres. The following is the formula of Bond Work Index:

$$W_i = 1{,}1\frac{44{,}5}{P_c^{0{,}23}G^{0{,}82}\left(\frac{10}{\sqrt{P_{80}}}-\frac{10}{\sqrt{F_{80}}}\right)}$$

Figure**: Formula of Bond work index**

(Source: Todorovic, Trumic, Andric, & Milosevic, 2017)

In the above formula,

- W_i represents the Bond work index
- Pc represents the mesh size of the res sieve in micrometres
- G represents the weight of the sieve used in sieve measured in g/rev
- P_{80} represents the opening of the sieve size passing 80 per cent of the most recent cycle test sieve undersize product
- And finally, the F_{80} represents the mesh size of the test sieve passing 80% of the feed before grinding

The test is conducted in the bond ball mill. The Bond work index is measured in terms of energy consumed for the grinding of ore in the Bond ball mill (Todorovic, Trumic, Andric, & Milosevic, 2017). The definition and formula of Bond Work Index is same in every study. The measurement is crucial to understand the properties of the different ores and metals.

Indirect Test Methods

As expressed by the Mwanga (2014), communication test methods are used within the mineral processing in which an ore based communication technology gets developed. Besides, this method appears as a designed grinding circuit along with its related required equipment. As opined by the author (Mwanga, 2014) the comprehensive testing of ore communication hence appear as expensive in the context of geometallurgical.

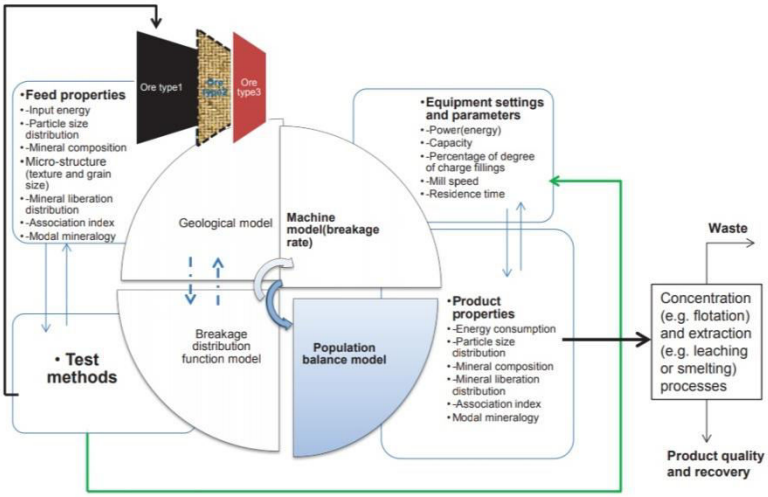

Figure: Conceptual Framework of Communication Test

(Source: Mwanga, 2014)

Concerning the factors mentioned above, the author developed the small scale communication tests in order to find out the correlation between golden ores and bond work index. Furthermore, the author set up a modeling framework in which the mineral liberation information was included (Mwanga, 2014). This study seeks for further research in the areas of mineralogy effects, mineral liberation and the appropriate Geometallurgy communication models.

Argued with the above authors, Todorović, Bartulović, Jovanović, Ivošević (2017), the grinding procedure contains a great significance with the processing of minerals. The required energy appears as Bond work values for obtaining some standard methods. As a result, it is seen that the composite samples get produced from the ores throughout the several weight ratios (Todorović, Bartulović, Jovanović, Ivošević, 2017). However, in the mineral processing, the energy savings are considered as crucial while understanding the way in which the ore mixtures grind from the non-similar deposit parts.

Sample	Test sieve, µm	W_i, kWh/t	W_i calcul., kWh/t	Difference, %
Limestone : andesite 100 : 0	74	13.90	/	/
	105	12.77	/	/
	150	12.63	/	/
Limestone : andesite 75 : 25	74	14.51	14.95	3.02
	105	13.91	13.81	-0.72
	150	13.59	13.48	-0.85
Limestone : andesite 50 : 50	74	15.50	16.00	3.19
	105	14.60	14.85	1.71
	150	14.26	14.32	0.42
Limestone : andesite 25 : 75	74	17.03	17.04	0.07
	105	16.41	15.89	-3.17
	150	15.13	15.17	0.23
Limestone : andesite 0 : 100	74	18.09	/	/
	105	16.93	/	/
	150	16.01	/	/
Mean difference				1.49

Figure: Bond Work Index Values

(Source: Todorović, Bartulović, Jovanović, Ivošević, 2017)

Ore grin disability generally represented by the index valued Bond Work concerning the purposes related to mineral processing. As opined by the authors (Todorović, Bartulović, Jovanović, Ivošević, 2017), the Bond Work experimental index obtains the calculated value as per the mixture components. These components have consisted of the mass portions with a difference of 3%.

The relation between Bond work index and other characteristics of different ores

The measurement of Bond Work Index of ores is crucial, in spite of examining the mechanical properties (such as elasticity, plasticity, tensile strength) of the ores. Through the Bond Work index, the crushing resistance or grind ability of the ores or metals are examined and measured. Through the indirect tensile testing, the tensile property of ores is measured, which is very crucial to develop the understanding of mechanical properties of the ores. As the resistance against grinding or crushing is one of the mechanical properties of an ore, this could be assumed that the Bond work Index is associated to the mechanical properties and indirect tensile testing of the ores. Abdel Haffez, (2012) ponders upon the relationship

between Bond work indexes and the mechanical properties of the metals. The different mechanical properties of the ores like abrasion, hardness, elasticity modulus, compressive strength have been examined. The article has emphasized on the following result:

Material examined	Bond's Work Index	Compressive strength	Hardness,	Abrasion	Modulus of elasticity
Kaolinite	11.6	58.3	13.71	0.795	32.2
Bauxite	10.8	36.1	6.59	1.48	25.6
Quartz	16.6	181.5	56.15	0.023	77.8
Granite	20.4	217.1	47.63	0.016	91.7
Magnetite	14.75	98.4	29.59	0.064	61.3
Feldspar	17.06	112.6	37.75	0.182	86.9

Figure: Relation between the Bond's Work Index and different properties of metals or ores

(Source: Abdel Haffez, 2012)

Abdel Haffez, (2012) have concluded the result that the prevention of the leakage of energy through the voids of metals was possible due to the extremely compact grains of the metals. The metals having a higher rate of hardness have a higher capability of preventing the bond from crushing or grindings. Hence, the metals that possess higher compressive strength, tensile strength, show the higher Bond's Work Index (Abdel Haffez, 2012). For instance, Granite has a higher modulus of elasticity and compressive strength than Quartz. Hence the Bond's Work Index of Granite is also higher than Quartz. Just same as that, Feldspar has higher Compressive strength than Magnetite; hence the Bond's Work Index of Feldspar is also higher than Magnetite (Abdel Haffez, 2012).

Thus, the study made the conclusion that there exists a correlation between Bond's Work Index and the results of the indirect tensile strengths of the ores or metals, and the Bond's Work Index is directly proportional to the results received from the indirect test of metals (Abdel Haffez, 2012). Thereby, the literature review renders that gold ore's Bond's Work Index is also direct proportionality correlated to the indirect tests.

Mwanga, (2014) ponders upon the indirect tests and Bond work index of the metals. In the article, the indirect tests render the indirect test of measurement of tensile strength and the other comminutionbehaviour of the ores. Both the Crushing test and grinding tests have been conducted to examine the Bond work index of the rocks. Point load test have been conducted as an indirect test of measuring the tensile strength. The various properties of the ores were characterized as comminutionbehaviour (Mwanga, 2014). The Bond Work Index is directly correlated with the SAG grinding (Mwanga, 2014).

The Bond's Work Index is dependents on the chemical composition of the ores and the bonds. The tensile strength, hardness and other the comminutionbehaviours are also dependent on the chemical composition and bond structure of the samples. From the perspective, eventually, both the communiationbehaviour and the Bond's Work Index are depended on the same factors. Thus, both the aspects are directly proportional to each other (Mwanga, 2014).

Literature gaps

The studies show the relationship between the Bond Work Index and the indirect test of the metals, however, they do not show why both the two aspects are interrelated to each other. In simple terms, this is seen that the Bond Work Index and the feature like hardness, young modulus, tensile strength are related to each other, however, this is not stated why the Bond

Work Index and the communiation behavior of the metals are directly proportional to each other.

Summery

According to the authors…. The Bond work index is a quantity of ore resistance to devastating and crushing and is interpreted by use of the grindability test. Value of the same constitutes characteristic of ore and is generally used for the industrial comminution of designing of plants. Identifying the value of Bond work index is relatively complicated as well as time-consuming and thus requires a trained operating personnel. Therefore it is subjected to the errors in such case. A fast method for this Bond work index estimates the value identification. This is based on the first order of the grinding kinetics. It is shown in the paper by the respective authors. Relative experiments for this Bond work index value identification by using the quick and standard procedures have been carried out on the samples of the andesite and limestone. On the composite samples it was containing both ores in the different mass proportions. The mentioned quick procedure in the literary work can be achieved with a random number of the milling cycles. The procedure is to be done depending on the desired accuracy (TODOROVIC, TRUMIC, ANDRIC, MILOSEVIC & TRUMIC, 2016). The below mentioned equation is a apart of the equation done by the authors to determine the relativeness of the matter in issue.

$$W_i = 1{,}1\frac{44{,}5}{P_c^{0{,}23}G^{0{,}82}\left(\frac{10}{\sqrt{P_{80}}}-\frac{10}{\sqrt{F_{80}}}\right)} \qquad (1)$$

where W_i – Bond work index (kWh/t)
P_c – test sieve mesh size (µm)
G – weight of the test sieve fresh undersize per mill revolution (g/rev)
F_{80} – sieve mesh size passing 80% of the feed before grinding(µm)
P_{80} – opening of the sieve size passing 80% of the last cycle test sieve undersize product (µm).

Identification of energy ingestion for the ore grinding in case of a Bond ball mill needs tasters of standard size. The requirements is due to the changes in the extent of the tasters' results in

the alteration of the Bond work index. It is further analysed that because of the Bond test length and complexity, as well as the possibility to make mistakes during performance, a number of scientists have previously tried to shorten and simpligfy this method. The authors analysed an approximate procedure where the data of an unidentified ore grindability are associated to orientation ore of recognized grindability. This method can be carried out in any of the laboratory ball mill. This gave a similar procedure, but lasting a bit longer, where reference ore data and data of the ore for which the value of the Bond Index is determined, are also compared. The study has compared the data obtained through the standard Bond test and those have created a form of an open-cycle milling(TODOROVIC, TRUMIC, ANDRIC, MILOSEVIC & TRUMIC, 2016). The authors has further analyzed the collected data in their study by obtaining the same during the implementation of the Bond standard examination. The study has helped to develop an algorithm in the mathematical form, which pretends this method and, based on it, measured the Bond work index. The study has tried to analyse the modification of the method taking into consideration that the Bond standard examination spherical load is solider than the previous samples and therefore is grounded more gradually (TODOROVIC, TRUMIC, ANDRIC, MILOSEVIC & TRUMIC, 2016). Thus the author has tried to identify the relativeness of the study with the subject matter.

Dependability confirmation of this process on limestone and andesite composite tasters along with their respective and different figure portions. The authors has taken the found facts into consideration for identifying the validity of the same.

Limitations

One of the most significant limitations of the literature study is very few studies have pondered upon the correlation of Bond Work Index for Gold ores through indirect tensile tests in the context of the gold ore. Most of the studies have emphasized on the correlation between the two aspects for different metals, except Gold. Even, Abdel Haffez, (2012), in his article, has demonstrated on the ores like quartz, granodiorite, bauxite, granite, kaolinite, magnetite and feldspar. This could also happen that the gold ore may show different correlation than other the examined ores. Moreover, the article have disclosed the correlation between Bond work index and Indirect tests of the ores extracted from Saudi Arabia, and this may not be imposed on the ores extracted from the otherregions. Another limitation of the literature review is the lack of availability of most relevant pieces of literature and previous research works. Very few studies have been conducted previously, that considers the correlation between the specified two aspects of Gold. A small number of articles have put stress only on the framed research question of the study. However, this is the rationale of the study, as the study will disclose the connection between indirect tensile test and Bond work index, particularly of gold.

According to the Todorovic, Trumic, Andric, Milosevic &Trumic, (2016) the Bond work index is a quantity of ore resistance to devastating and crushing and is interpreted by use of the grindability test. Value of the same constitutes characteristic of ore and is generally used for the industrial comminution of designing of plants. Identifying the value of Bond work index is relatively complicated as well as time-consuming and thus requires trained operating personnel. Therefore it is subjected to the errors in such case. A fast method for this Bond work index estimates the value identification. This is based on the first order of the grinding kinetics. It is shown in the paper by the respective authors. Relative experiments for this Bond work index value identification by using the quick and standard procedures have

been carried out on the samples of the andesite and limestone. On the composite samples it was containing both ores in the different mass proportions. The mentioned quick procedure in the literary work can be achieved with a random number of the milling cycles. The procedure is to be done depending on the desired accuracy(Todorovic, Trumic, Andric, Milosevic &Trumic, 2016). The below mentioned equation is apart of the equation done by the authors to determine the relativeness of the matter in issue.

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Research Gap

Review of the research sources suggests that several numbers of studies had carried out in order to find out the correlation between golden ores and bond work index. As evidence from the pieces of works of literature, the understanding of the association has been appeared as different. As a result, the research gap found in the areas of practical factors in which the indirect tests could reveal the correlation between the factors mentioned earlier.

On the other hand, scopes of the research are limited to either the dynamic factors or the lack of developed theory and the framework. Furthermore, it is seen that there are only a few studies that could be perceived while implementing the interconnection of the chosen factors. Concerning all of these facts, the current research requires to provide insight based on the specific indirect tests.

Research Questions

Primary Research Question:

- ✓ How is the bond work index related to indirect tests?

Research Sub-Question:

- ✓ Is the correlation between bond work index and indirect tests same for each of the ores?

Through these aforementioned research questions, the researchers would set up a notion in order to mark out the respective correlation. Besides, associated methods of indirect tests would be revealed by finding the solutions to these structured questions

Methodology

Research philosophy

The research would be conducted to evaluate the efficacy of Bond Work Index, which mostly used as the prominent tool in the meral industry. Moreover, the research phenomenon will involve the quantitative data collection process to procure the prominent and numerical data regarding the meral industry to influence the research approach. The Bond work Index had been considered as the measure for Gold ores which used in meral industry. The involvement of this measuring process helps to utilize grinding and crushing of metals such as gold (Borri, Corradi, Castori& De Maria, 2015).The Bond work index had been revealed as the sophisticated measuring process which often used as the tool to demonstrate the designing of the plants and to bring the equivalent measurement of the minerals. The embracement of a quantitative method for inaugurating the data collection had been perceived as the prominent way to influence the research study by perceiving sufficient knowledge about the Bond work index and its importance.In order to prevail the numerical and important data to prosper the research perspective, the quantitative method will be inaugurated.The inclusion of survey helps to demonstrate the knowledge on the main aspect of the research. Thus it had been perceived as the device to influence the main objective of the research.Moreover, the descriptive design assists in demonstrating the research culture. The inclusion of descriptive design helps to derive the characteristics of the phenomenon. The research method also embraced the qualitative method to perpetuate the value of the research study. Hence the inauguration of the interview also assists in demonstrating the knowledge on the research perspective.

Research design

Research design consisted the overall strategy to integrate the value of the research study. There are several types of research design, and those are exploratory, correlation,

descriptive. The descriptive research design will be embraced in the research to study to develop the conception of the research study (Stavrakakis, Andreadis&Katsambekis, 2017).Hence it will explore the significant information from the massive data of the research study.Moreover, the descriptive design assists to demonstrate theresearch culture. The inclusion of descriptive design helps to derive the characteristics of the phenomenon. Inauguration of descriptive design would help to perpetuate the study based on the Bond work index and its importance in meral industry.Hence it would also evaluate the usefulness this measure in the context of gold ores.

Research approach

There are several types of research approach. The research approach consists of qualitative, quantitative, and mixed methods. The qualitative and quantitative research approach would help to collect numerical data about the Bond work index and hence it will evaluate the reinforcement of Bond work Index in meral industry. Thus the research study will include the qualitative and quantitative approach to intensify the value of the research study (Nowell, Norris, White &Moules, 2017). Hence the embracement of qualitative and quantitative approach carries the positive view on the research study. The perpetuation of numerical data helps to perceive the utmost view to enhance the research study. Eventually, the inauguration of secondary sources had been taken as another prominent aspect to increase the validity of the learning. Hence the inclusion of secondary sources, quantitative and qualitative method would assist in generating the data on the usefulness of Bond work index in the context of gold ores.

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