International Journal of Academic Engineering Research (IJAER)
ISSN: 2643-9085
Vol. 4, Issue 5, May – 2020, Pages: 13-19

Characterization and Bond Work Index Determination of Low Grade Sudanese iron Ore: a case study

Mahmoud Motasim Hassan Al-Tigani[1], Amin Al-Gak Abdueldaem[2], Abdelshakour Awdekarim[3], Ahmed Abdullah Sadeek Seifelnasr[4]

[1]*Department of Mining Engineering, Faculty of Engineering Sciences, Omdurman Islamic University, Khartoum, Sudan*
E-mail: mahmoud.motasim@oiu.edu.sd
[2]*Department of Mining Engineering, Faculty of Engineering Sciences, Omdurman Islamic University, Khartoum, Sudan*
[3]*Department of Chemical Engineering, Faculty of Engineering, University of Khartoum, Khartoum, Sudan*
[4]*Department of Mining Engineering, Faculty of Petroleum and Mining, Suez Canal University, Suez, Egypt*

Abstract: *In this study, the mineralogical, chemical characterization and physical properties of Sudanese iron ore in west of Omdurman city were studied using microscopic investigations, X-ray Diffraction analysis (XRD), X-ray Fluorescence (XRF) analysis, Atomic Absorption Spectrophotometer analysis (AAS) and the test of Bulk density. As well as, the Bond Work Index (BWI) and consumed power to grind one tone of iron ore were determined via standard Bond mill. The results showed that the ore is hematitic ore with Goethite and quartz minerals. The ore is low grade containing 41.41 % Fe2O3 and 50.88 SiO2. The bond work index test obtained high work index 52.60 kw.h/t and consumed power 11.72 kw.h/t to grind one ton of low grade iron ore and this attributed to the high concentration and hardness of quartz mineral which is considered the main gangue of the ore in study area.*

Keywords: Iron ore; Hematite; Goethite; XRD; AAS ; XRF; Standard Bond Mill; Grindability; Consumed power.

1. Introduction:

Liberation of the valuable minerals from the gangue is performed by comminution via crushing and grinding[1]. The operations of comminution are primarily based on the size of the treated particles but the composition, specific gravity, brittleness and other properties can also effect on the behavior of the particles comminution [2]. Grinding stage is the last step in comminution to achieve the required size in a dry or wet medium using ball and rod mills [3].

The Bond Work Index of a material is defined as the required energy to reduce one ton of that material from a notional infinite size to a P80 size of 100 µm, the Bond grindability test is conducted to determine the Bond work index (Wi) via Standard Bond Ball Mill which having the dimensions D×L=305×305 mm and a speed revolution of 70 min−1 [4, 5]. Hardness values of crystalline minerals has strongly relationship to Bond work index and the energy consumption ,which increasing of hardness value causes increasing in Bond work index and the consumed energy [6]. Berry and Bruce (1966) discovered new method for determining the work index, the concept of this method depended on the use of a reference ore of known work index[7].

Iron ore is one of the important industrial minerals used in steel industrials. Magnetite, hematite and goethite are considered the most common minerals of iron ore which have cubic, hexagonal (trigonal) and orthorhombic structures, respectively[8, 9].In Sudan ,the reserve of iron ore was estimated by four billion tons , occurs as the Magnetite, Hematite and Goethite minerals [10].Extensive work was accomplished on determination of the work index to iron ore from different countries[11]. Recently ,several attempts were studied to decrease the grinding power by utilizing the radiation of microwave oven to generate micro fraction on the particle [12] .

This study focuses to investigate the chemical and mineralogical characteristics of iron ore due to the deferent of iron ore types i.e. hematite, magnetite, siderite, and goethite; those minerals differ in their chemical and mineralogical compositions. Thus, these results are more significant in the beneficiation of iron ore if it is low grade iron ore. However, the aim of the present study was to determine the power consumption to grind one tone of iron ore via standard bond ball mill test.

2. Materials and Methods:

2.1 Iron ore sample:

About 100 kg of iron sample were taken from west of Omdurman city (Markheat Mountains) at coordination (32˚25′13″E). The sample was thoroughly mixed, then some pieces of iron sample were taken for microscopic examinations.

2.2 Sample preparation:

The sample was prepared to -3.36mm via jaw crusher, cone crusher, and roll crusher in close circuit with single screen (3.36) mm, then representative samples were carefully taken for chemical characterization . Fig. 1 shows the diagram of the sample preparation.

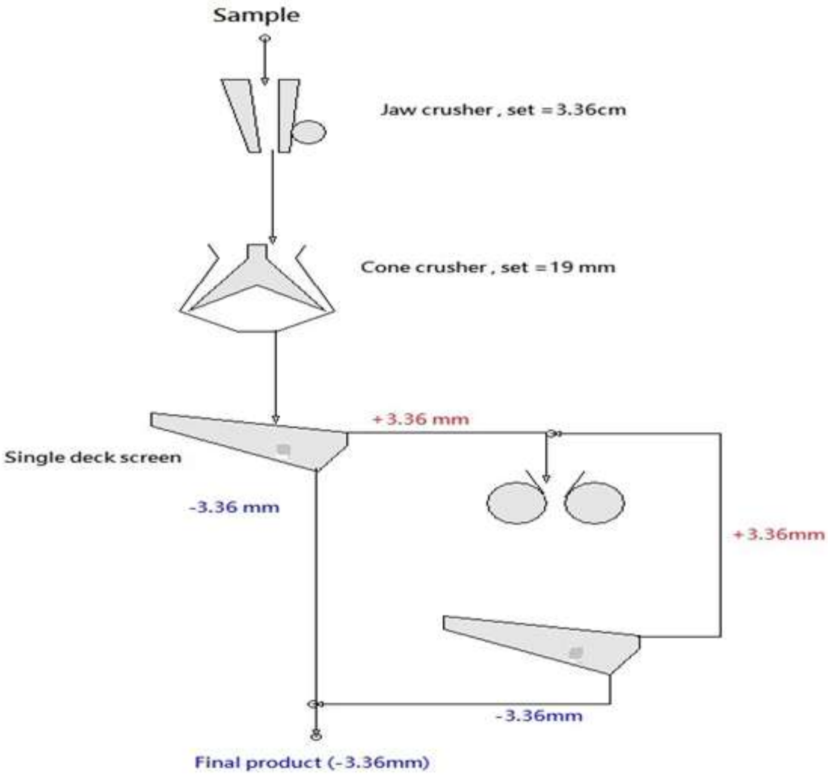


Figure 1. Diagram of the sample preparation.

2.3 Mineralogical and chemical characterization analysis methods:

Polarized transmitted microscopic and reflected microscopic produced by Nikon Company were used to mineralogical examination for the thin and polish samples. X-ray diffraction (XRD) instrument manufactured via Analytical X-ray Company was utilized to define the chemical composition of minerals. Atomic Absorption Spectrophotometer (AAS) and X-ray fluorescence (XRF)) instruments produced via GB-Company (A7638) and analytical X-ray Company were used quantitative evaluation for the mineral oxides and elements.

2.4 Bond work index test procedure:

Standard Bond Mill (305 mm diameter x 305 mm length) was used for bond work index determination at Central Metallurgical Research and Development Institute (CMRDI) in Egypt as depicted in Fig.2 .Three hundred of representative sample was taken from the fresh sample(-3.36mm) and then subjected to sieve analysis test to plot the size distribution curve of the sample. The (F80) and the cumulative weight percentage passed the screen size (147µm) were determined from the results of the sieve analysis test. For the first test, 700 mL of graduated cylinder was occupied by fresh iron sample (-3.36), weighted and then fed to standard ball mill. The mill was operated to 100 revolutions at a mill speed of 70% of the critical speed. After the grinding, the entire sample was discharged and screened via screen (147µm), then the mass of under size M2 and oversize M3 were weighted and recorded. The value of grindability (G) was calculated as the net grams of sieve undersize (M2) per mill revolution (g/rev). For the second test, the mass (M3) of oversize (+147µm) was returned again to the standard ball mill with an additional quantity of fresh sample (-3.36mm) to make the charge of mill equaled to the original mass weight of (700ml) M1. The number of mill revolutions for the second test was calculated based on two variables (circulating load (250%) and the value of grindability (gram/rev) at previous test.

The above procedure was repeated until two or three equaled values of grindability (gram/rev) were obtained, then the ground product of final test was discharged and subjected for sieve analysis test to plot the size distribution curve and determine the (P80). Standard Work Index (Wi) and the consumed energy (W) to grind one ton of iron ore were calculated via equation (1) and equation (2) respectively.

Note: The Wi Test value was measured corresponds to the motor output power Bond correlated to an average overflow discharge ball mill of 2.44 m internal diameter, wet grinding in closed circuit with a 250% circulating load.

$$W_{i\,Test} = \frac{48.95}{D^{0.23}\, G^{0.82}\, 10\left(\frac{1}{\sqrt{P_{80}}} - \frac{1}{\sqrt{F_{80}}}\right)} \text{ KWh/t} \qquad (1)$$

$$W = 10\, W_i \left(\frac{1}{\sqrt{P_{80}}} - \frac{1}{\sqrt{F_{80}}}\right) \text{ KWh/t} \qquad (2)$$

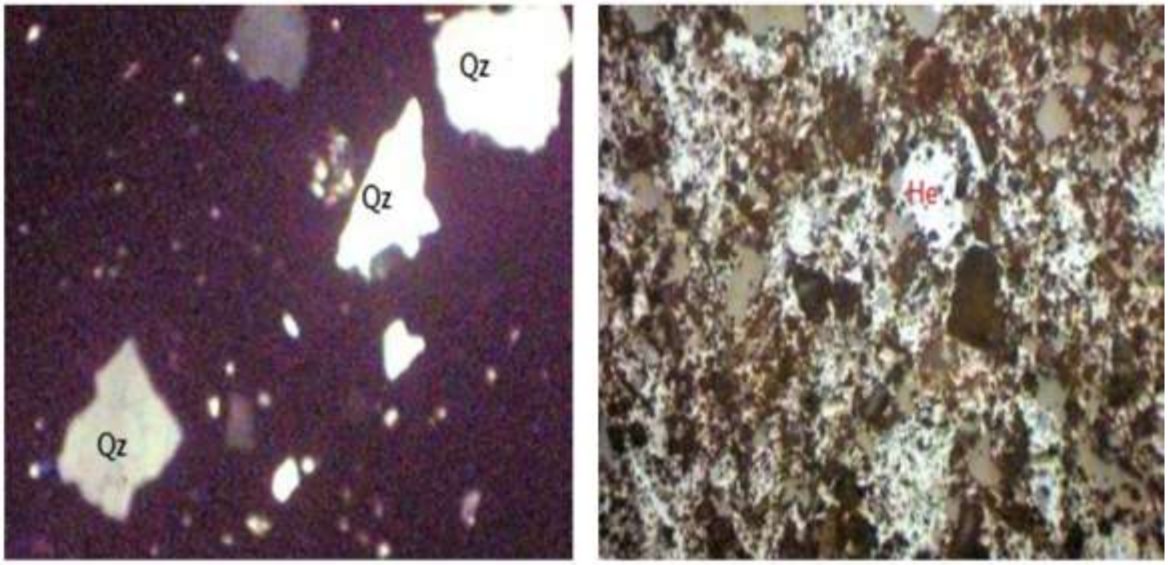
Where, F80 = Feed size (microns) through which 80% of the feed will pass,
P80 = Product size (microns) through which 80% of the product will pass.
D = Aperture (microns) of the classifying screen (147µm).
G = Net mass (grams) of undersize product per unit revolution of the mill.

Figure 1.Standard Bond Mill.

3. Results and dissections:

3.1 Characterization studies

3.1.1 Mineralogical and chemical characterization: Plate.1 shows the images of microscopic examination for thin and polish sections samples. Plat1.a (1) reveals that the quartz mineral is most mineral in the rock matrix of at thin section sample, occupying about 50% from the total sample. As well as, it appears in euhedral shape with opaqueness minerals may be: Hematite and Goethite minerals. Plate1.a (2) demonstrates that the sample consisted to hematite mineral taking about 47 % from the total of polish section sample. However, the hematite mineral appears in euhedral shape and fine disseminated texture with liberation size range between (166.6-41) µm depended on the scale of microscope (one millimeter = 120 micrometer). Also, minor amounts of native copper, muscovite and kaolinite were found in polish section sample.



a (1)   a (2)

Plate1 { SEQ Plate * ARABIC }. Microscopic images for a_1) thin section and a_2) polish section samples

Figure.1 presents the X-ray Diffraction (XRD) pattern of iron sample. It demonstrates that the mineral phases for the sample are Quartz SiO_2, Goethite FeO (OH), and Hematite Fe_2O_3 minerals. The highest peak is for quartz mineral and that indicates to high concentration of quartz mineral.

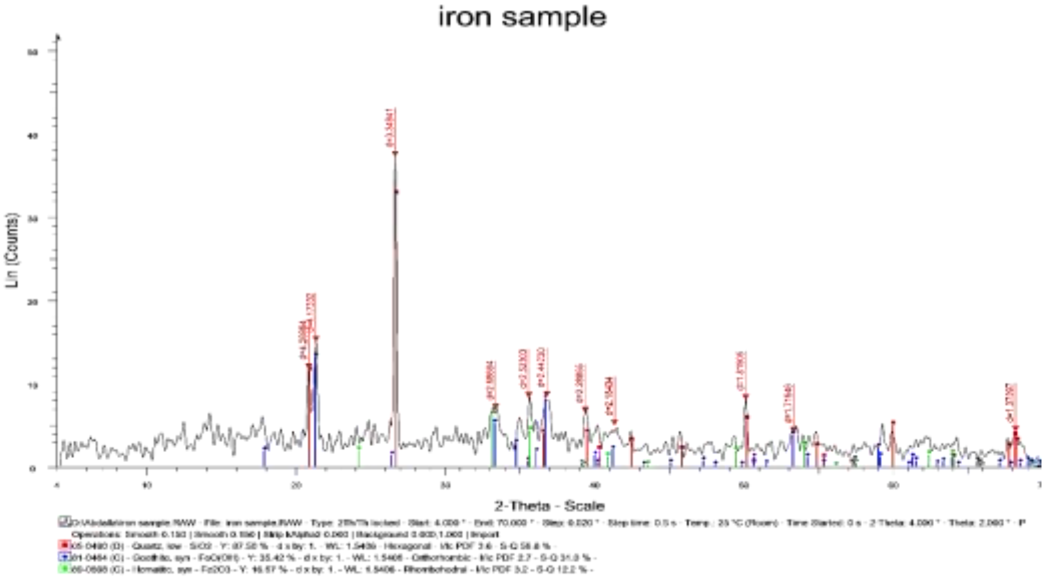


Figure 2.X-ray diffraction (XRD) pattern of iron sample.

Table.1 shows the results of Atomic Absorption Spectrophotometer (AAS).It explains that the iron ore of study area is low quality and most gangue mineral is silicon oxide which is exiting as the quartz mineral. Thus, it requires for beneficiation because it cannot be used directly in industrials.

Table 1.Results of Atomic Absorption Spectrophotometer instrument (AAS).

Element	Wight (%)	Mineral oxide	Wight (%)
Fe	29.41	Fe2O3	41.80
Si	23.74	SiO2	50.88

The analysis of the sample via X-ray fluorescence (XRF) detailed that the containing of the ore constituted from 44.12% Fe_2O_3, 44.23% SiO_2, 7.05%Al_2O_3, and 3.9% Mn_2O_3.Moreover, the aluminum oxide is existing in kaolinite mineral.

Plate.2 presents the hematite and goethite minerals sample of investigated study area. It reveals that hematite (Fe2O3) appears in red color, whereas, goethite sample (FeO (OH)) in yellowed color.


Hematite mineral
Goethite mineral

Plate 2.Hematite and goethite minerals sample of investigated study area.

3.1.2 Physical properties:

Table.2 shows the calculated bulk densities of the iron sample. It can be concluded that the ore is low density (less than 4 g/cm3 due to quartz mineral (S.G=2.65 g/cm3) (waste) which is considered the most mineral with hematite mineral in the ore in study area.

3.2 Bond work index determination:

Table 2.Calculated bulk densities.

Sample name	Bulk density g/cm3
A	2.86
B	2.86
C	2.50
D	2.86
Average	2.77

Table.3 shows the results of bond work index test. It can be concluded that the value of grindability of iron ore in study area is 1.42 g/rev because this value repeated two times during the tests.

Table 3.Results of bond work index test

Test number	Revaluation number	Grindability (g/rev)
1	100	1.07
2	324	1.28
3	255	1.25
4	268	1.32
5	251	1.41
6	235	1.41

Figure.4 and Figure.5 show the results of sieve analysis test for feed and product of bond work index test respectively. It determined the flowing: F80 = 2070 micron and P80 = 510 micron.

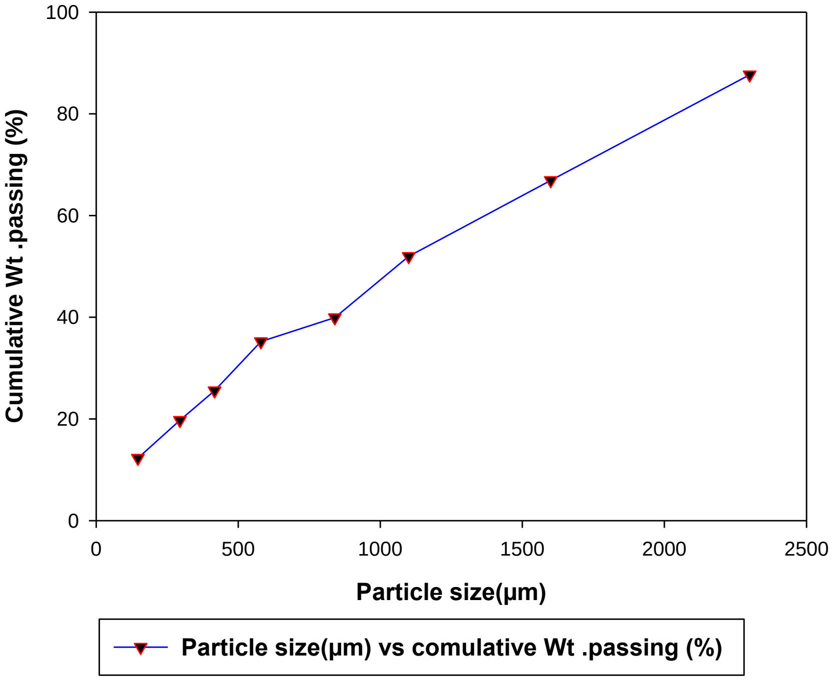


Figure 3. The size distributions for feed sample of bond work index test..

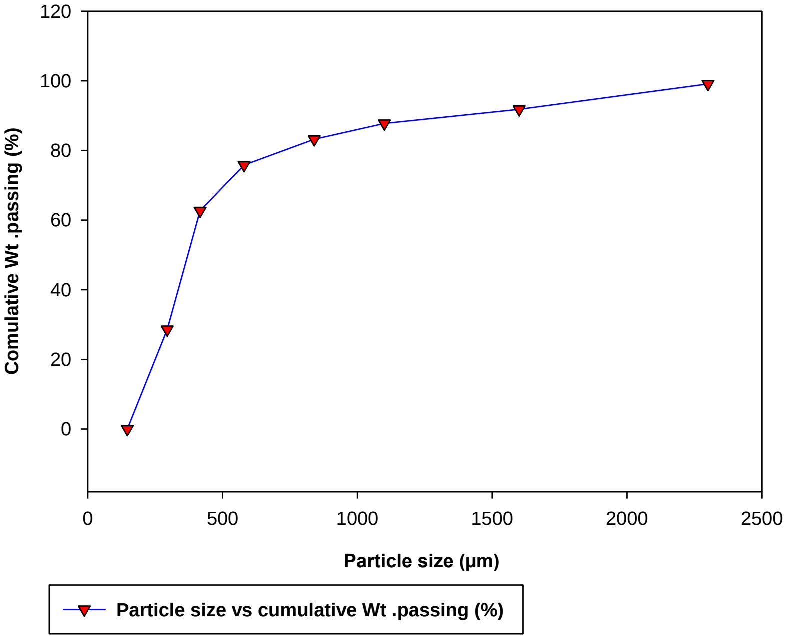


Figure 4. The size distributions for ground product sample of bond work index test

Based on the above results, the Wi and W were calculated via equation (1) and equation (2) respectively:

$$W_{i\,Test} = \frac{48.95}{D^{0.23}\ G^{0.82}\,10\left(\frac{1}{\sqrt{P_{80}}}-\frac{1}{\sqrt{F_{80}}}\right)}$$

$$= \frac{48.95}{147^{\,0.23} *1.4^{\,0.82} *10\left(\frac{1}{\sqrt{2070}} - \frac{1}{\sqrt{510}}\right)} = 52.60\ \text{kw.h/t}$$

$$W = 10\ W_i \left(\frac{1}{\sqrt{P_{80}}}-\frac{1}{\sqrt{F_{80}}}\right)$$

$$=10 * 52.6*\left(\frac{1}{\sqrt{2070}}-\frac{1}{\sqrt{510}}\right) = 11.72\ \ \text{Kw.h/t}$$

The values of work index and consumed power conformed that the iron ore of study area need high power for grinding and that is due to the high concentration of quartz mineral , hardness which is 7 by Moh's hardness scale , and fine disseminated texture of iron ore mineralization [6]. Nigerian iron ore consumed lower work index compared to Sudanese iron ore, this attributes to the texture and containing of sudanese iron ore [11, 13].

4. Conclusion and recommendations:

The iron ore in investigated study area is mainly hematite mineral with quartz mineral, the liberation size of hematite mineral was found at fine disseminated texture in range between (166.6-41) µm based on scale of eyeglass at microscope (one millimeter = 120 micrometer). The iron ore is low grade contained (41.41% Fe_2O_3) and the most gangue mineral is quartz mineral with concentration (50.88% SiO_2). Therefore, beneficiation stage for iron mineral is required. The test of bond work index obtained high work index 52.60 kw.h/t and consumed power 11.72 kw.h/t to grind one ton of low grade iron ore.

Acknowledgment

The authors are very much thankful to Central Metallurgical Research and Development Institute (CMRDI) in Egypt for valuable support in experimental work and samples analysis.

References:

[1]. Barry A. Wills, T.N.M., Mineral Processing Technology. Elsevier Science & Technology Books, 2007. 7th Edition: p. 109-119.

[2]. King, R.P., Modeling and Simulation of Mineral Processing Systems. British Library Cataloguing in Publication Data, 2001: p. 5-5.

[3]. Coulson , R., Particle Technology And Separation Process. Elsevier Science & Technology Books, 2002. 2: p. 95-97.

[4]. LEVIN.J, Observations on the Bond standard grindability test, and a proposal for a standard grindability test for fine materials. J. S. At,. Inst. Min. Metal, 1989. 89(1): p. 13-21.

[5]. Karra Ram Chandar ., S.N.D., Ashwin J. Baliga, Prediction of Bond's work index from field measurable rock properties. International Journal of Mineral Processing, 2016.

[6]. Malcolm Gent , M.M., Javier Toraño, Susana Torno, A correlation between Vickers Hardness indentation values and the Bond Work Index for the grinding of brittle minerals. Powder Technology, 2012. 224 p. 217–222.

[7]. Finch, J.A.W., Barry Alan, An Introduction to the Practical Aspects of Ore Treatment and Mineral Recovery. Elsevier Science & Technology Books, 2015. Eighth Edition: p. 113-114.

[8]. Hossein Inanloo Arabi Shad, S.F., M ataei, M karamoozain, Effect of magnetite content on Bond work index and preconditioning:Case study on Chadormalu iron ore mine. J. Cent. South Univ, 2018. 25: p. 795−804.

[9]. Tadao Sugimoto , A.M., Kazuo Sakata , Daisuke Sh, Characterization of Hemtite Particles of Different shapes. Journal of Colloid and Interface Sciene, 1993. 158: p. 420-428.

[10]. Ahmed.AAM, Sudan Industrial Mineral & Rocks. Center for Strategic Studied, Khartuom, Sudan, 1998.

[11]. Olatunji. K.J, A.G.D., Determination of Bond index of Birnin- Gwari Iron Ore in Nigeria. Journal of Minerals & Materials Characterization & Engineering, 2010. 9(7): p. 635-642.

[12]. Kumar.P , B.K.S., S. Dea, D.D. Kar , S. Chakraborty , B.C. Meikap, Iron ore grindability improvement by microwave pre-treatment. Journal of Industrial and Engineering Chemistry, 2010. 16: p. 805–812.

[13]. Abdelhaffez, G.S., Studying the effect of ore texture on the Bond Work Index at the Mahd Ad Dahab Gold Mine : a case study. The Mining Geology Petroleum Engineering Bulletin, 2020: p. 111-121.