Journal of Mineral Resources Engineering, 10(2): 117-135, (2025)

Imam Khomeini International University
Vol. 10, No. 2, Summer 2025

نشریه مهندسی منابع معدنی
Journal of Mineral Resources Engineering
(JMRE)

Research Paper

The Effect of the Textural Characteristics of Iron Ore Processing Tailings on the Processes of Iron Recovery From Them

Kazemi F.[1], Abdollahzadeh A.A.[2*]

1- Ph.D Student, Department of Mining Engineering, University of Kashan, Kashan, Iran
2- Associate Professor, Faculty of Mining Engineering, Amirkabir University of Technology, Tehran, Iran

Received: 22 Jun. 2024 **Accepted: 19 Sep. 2024**

Abstract: The present study aims to identify and quantify the textural characteristics of granulated iron ore tailing depots to investigate these characteristics' effect on the tailings reprocessing behavior. After sampling from the tailings depots and classifying them into six size fractions, chemical analyses, and optical and electron microscopic studies were conducted on each fraction. By processing the images and coding in MATLAB software, a quantitative parameter related to the interlocking of the target mineral with gangues—termed the association index (AI)—was determined. Mineralogical studies indicate the presence of magnetite and hematite, along with their complex interlocking with other metallic minerals and gangue. Based on the AI calculated for each fraction, the highest interlock occurs between magnetite and hematite, attributed to the martitization of magnetite to hematite. In the size fraction above 250 microns, the highest AI is observed for magnetite with the following minerals: calcite, diopside, garnet, and quartz. In this fraction, the ratio of AI to the grades of pyrite and chalcopyrite exceeds 1, indicating that magnetite is preferable to these minerals. The magnetic separation results confirmed that pyrite and chalcopyrite were recovered into the magnetic concentrate in sizes over 250 microns. This can significantly aid in copper mineral recovery as a pre-treatment step.

Keywords: Iron tailings, Textural characteristics, Association index, Grinding, Magnetic separation.

How to cite this article
Kazemi, F., and Abdollahzadeh, A. A. (2025). *"The Effect of the textural characteristics of iron ore processing tailings on the processes of iron recovery from them"*. Journal of Mineral Resources Engineering, 10(2): 117-135.
DOI: 10.30479/jmre.2024.20504.1701

*Corresponding Author Email: *abdzad@aut.ac.ir*

INTRODUCTION

The mineralogical approach, as the most comprehensive method for developing a geometallurgical program, utilizes mineralogy and combines its data to inform program development [1,2]. It means that in the construction of a geometallurgical program, the entire model should be based on mineralogical information [2,3]. Mostly, ore texture is quantified in terms of descriptors such as covariance function, proximity function, and linear intercept length distribution. However, these descriptors are mostly developed for binary systems, and there is no extension for three-dimensional ore texture volume [3,4]. Automated mineralogical methods based on electron microscopy are the most common approaches for obtaining textural information from ores in 3D. In these methods, images are processed to extract textural and mineralogical information. Image processing techniques are used to classify the objects in the image (such as grains, particles, or phases) and recover a wide range of features. In this research, the concept of association index (AI) has been used to quantify the textural information obtained from optical and electron microscopic studies of iron tailings and their application in different processing stages, including grinding and magnetic separation.

METHODS

The present study was conducted on the tailing piles of lump iron ore processing plants located in the west of Iran – Kurdistan province. The tailings are obtained from the low-intensity dry magnetic separation of magnetite iron ore, which is accumulated in piles around the processing plant. A representative sample with an approximate weight of 500 kg was selected from tailing depots. The dimensions of tailing particles are in the range of 0-15 mm, and 80% of the particles have dimensions less than 6 mm. Chemical analysis (by the method of X-ray fluorescence), mineralogical analysis (by the method of X-ray diffraction), optical image analysis (OIA), and scanning electron microscopy (SEM) were used to determine the texture characteristics. Image processing sequences, including phase discrimination, object separation, and feature extractions, were done by writing code in MATLAB.

FINDINGS AND ARGUMENT

Based on XRD analysis, the overall phases in samples of the plant tailings include magnetite, andradite garnet, diopside, clinochlore, and hedenbergite. Diopside is the most abundant phase, with a value of 20.50%. The two minerals calcite and andradite garnet are also almost equal in quantity, and they are the most abundant minerals after diopside. Sulfide minerals mainly contain pyrite and lesser amounts of chalcopyrite and pyrrhotite. Table 1 shows the results of XRF analysis for each size fraction. By reducing the size of the particles, the amount of Fe(T) increased and reached about 22.50% in the size fraction of +0.106-0.250 mm. The weight percentage of particles in this size range is 15.50%. By reducing the size of the particles to +0.045 -0.106 mm, the total iron grade decreased and increased again for the particles of -0.045 mm.

Table 1. Weight values and XRF analysis results for iron processing plant tailings in each size fraction

Size fraction (mm)	Weight (%)	SiO_2 (%)	Al_2O_3 (%)	CaO (%)	Fe(T) (%)	K_2O (%)	MgO (%)	S (%)	Cu (%)
+1	4.20	37.53	8.38	20.22	15.66	0.74	4.17	0.46	0.11
-1 +0.500	30.90	36.65	8.97	18.59	16.34	0.75	4.19	0.58	0.14
-0.500 +0.250	17.40	33.90	7.84	19.33	18.66	0.59	3.76	0.82	0.19
-0.250 +0.106	15.50	32.13	7.02	17.10	22.48	0.46	4.73	0.51	0.21
-0.106 +0.045	8.90	33.61	8.66	19.69	15.47	0.59	2.60	0.51	0.22
-0.045	23.10	31.26	6.98	18.90	25.03	0.65	5.89	0.31	0.25

Based on OIA and SEM, non-metallic minerals constitute a significant portion of the tailing piles, while metallic minerals represent only a minor fraction. The non-metallic minerals are diverse and include silicates and non-silicates. These minerals include pyroxene (diopside series), calcite, garnet, epidote, tremolite-actinolite series amphibole, quartz, sphene, chlorite, and small amounts of biotite, feldspar, and apatite. The metal minerals are mostly of the oxide type, and sulfide minerals exist in smaller amounts. The volumetric percentage of two main oxide minerals, magnetite and hematite (as the main iron minerals in tailings samples), vary across different size fractions.

By processing the electron microscopic images, the relationship index was determined for iron oxides (magnetite and hematite) in the studied iron tailings. The association index is a quantified parameter of the texture obtained from the ore texture information resulting from mineralogical studies [3]. Image processing sequences, including phase discrimination, object separation, and feature extractions, were done by writing code in MATLAB. The code can analyze ore texture and particulate samples to give numeric or textural features and liberation. For BSE images, phase separation was initiated by assigning multiple threshold values according to a range of grey levels corresponding to each phase. A new value representing a phase was assigned to the pixel values in the image that corresponded to each threshold interval. The epoxy area was assigned a value of zero for easier processing of objects during image processing (Figure 1). In the next step, the surface of each phase (the number of pixels occupied by the phase) in a particle is determined. To convert this value into weight percentage, mineral density has been used as a weight factor in the composition calculation. Also, the value of the boundary of minerals with each other has been measured.

Table 2 shows the AI values of magnetite and hematite minerals with other minerals in different size fractions. Based on the results of microscopic studies as well as the segmentation of minerals by MATLAB software, the highest level of interlocking in all size fractions is between two iron oxide minerals, namely magnetite and hematite, which is caused by martitization of magnetite to hematite. By reducing the size of the particles, the AI of magnetite with all the minerals in the sample has decreased. It is obvious that by reducing the size of the particles, the degree of liberation increases and the degree of interlocking of minerals decreases. The highest AI is related to magnetite with calcite and diopside minerals in dimensions of +250 microns. In the mentioned size fraction, magnetite has the highest association values with garnet and quartz. The lowest level of the AI is related to magnetite with feldspar.

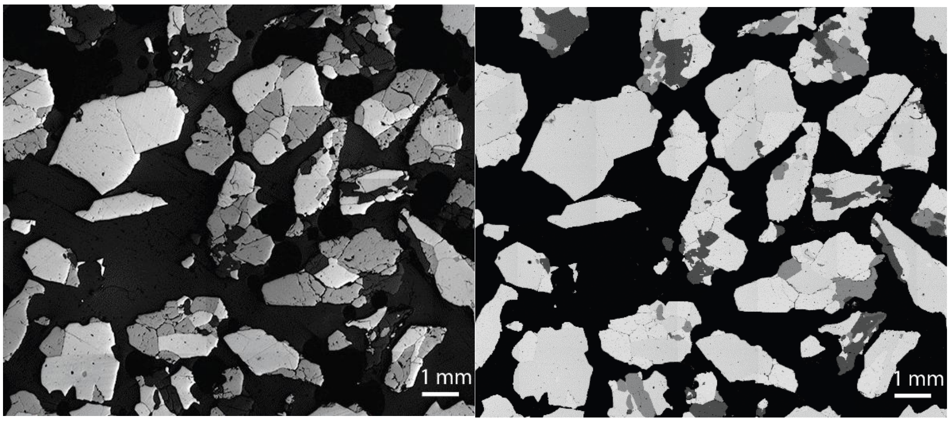

Figure 1. BSE image processing with grey color spectrum in MATLAB software (granulation fraction +1 mm)

Table 2. The association index of iron oxide minerals with other minerals in the tailings in different size fractions

Size fraction (mm)	Pyrite	Chalcopyrite	Calcite/ Diopside	Chlorite	Biotite	Feldspar	Garnet/ Quartz
+1	0.90	0.40	25.00	3.00	3.00	0.00	20.00
-1 +0.500	0.80	0.40	22.00	3.00	1.00	0.00	18.00
-0.500 +0.250	0.80	0.30	20.00	2.00	0.30	0.00	17.00
-0.250 +0.106	0.30	0.20	15.00	1.00	0.20	1.00	10.00
-0.106 +0.045	0.30	0.20	10.00	0.50	0.10	0.10	12.00
-0.045	0.05	0.10	5.00	0.50	0.10	0.05	4.00

Table 3 presents, the ratio of AI of iron oxide minerals (magnetite and hematite) to the grade of accompanying minerals in different fractions of iron tailings. It can be seen that with the reduction of particle size, the ratio of AI to grade has decreased. Based on the presented concept, this parameter has a direct relationship with the AI of two minerals and an inverse relationship with the grade of accompanying minerals. By determining the number 1 as an index for this ratio, it is clear that values greater than 1 indicate the preference for the target mineral (here, iron oxide minerals) over the companion mineral, and values less than 1 generally indicate the preference for the companion mineral. The meaning of preference is the predominance of the desired mineral property (here, magnetic property) in the particles involved; if the separation process is carried out, these particles will be transferred to the relevant section. According to Table 3, iron oxide minerals in the range of +250 microns are preferable to pyrite minerals and in the range of +45 microns to chalcopyrite minerals. In other words, the amount of iron oxide minerals in these fractions is greater than the associated mineral. By reducing the size of the particles and, as a result, reducing the ratio of AI to grade, preference has changed to the accompanying phase of iron oxide minerals. That is, during the processing processes, the behavior and properties of the accompanying minerals will prevail. Concerning other available phases (non-metallic minerals and gangue), gangue minerals are preferred in all size fractions, and iron oxide minerals are associated phases.

To validate the prediction obtained from the quantification of texture information of iron tailings and its effect on processing behavior, a magnetic separation test was conducted on a sample of iron tailings with a d80 of 2 mm, using a drum separator at a magnetic intensity of 2000 Gauss. 33.5% by weight of the feed to the drum was recovered in the concentrate with a grade of 31% Fe(T). The concentrate and tailings of the magnetic separation were classified into size fractions of +1, +0.5 -1, +0.25 -0.5, and -0.250 mm, followed by XRF analysis (Table 4). According to Table 4, the amount of gangue compounds recovered in the concentrate for the +0.250 mm fraction is higher than for the -0.250 mm fraction. This is due to the interlocking of gangue minerals with magnetite in the coarser particles, as mentioned in the previous section. In particles smaller than 0.250 mm, the trend reverses: with increasing degrees of liberation, the majority of the gangue minerals are transferred to the tailings.

Table 3. Ratio of AI of iron oxide minerals to the grade of the accompanying mineral in different size fractions

Size fraction (mm)	Pyrite	Chalcopyrite	Calcite/ Diopside	Chlorite	Biotite	Feldspar	Garnet/ Quartz
+1	1.55	4.00	0.70	0.33	0.40	0.00	0.79
-1 +0.500	1.70	3.63	0.59	0.34	0.13	0.00	0.73
-0.500 +0.250	1.27	2.73	0.52	0.25	0.05	0.00	0.74
-0.250 +0.106	0.64	2.00	0.42	0.14	0.03	0.99	0.42
-0.106 +0.045	0.56	1.67	0.27	0.06	0.03	0.08	0.46
-0.045	0.16	0.83	0.15	0.03	0.00	0.03	0.15

Table 4. XRF analysis of each size fraction of concentrate and tailing of magnetic separation test

Size fraction (mm)		SiO_2 (%)	Al_2O_3 (%)	CaO (%)	Fe(T) (%)	K_2O (%)	MgO (%)	S (%)	Cu (%)
d_{80} = -2	Feed	33.61	6.68	16.96	17.83	0.59	3.79	1.20	0.28
+1	Con.	27.85	4.29	14.37	31.47	0.23	4.77	0.70	0.11
	Tail	41.42	9.38	22.90	10.14	0.95	4.51	0.25	0.06
-1 +0.500	Con.	24.97	4.46	11.86	35.26	0.25	4.67	0.53	0.12
	Tail	40.16	9.00	22.44	11.53	0.76	3.74	0.47	0.04
-0.500 +0.250	Con.	26.47	5.53	12.50	31.47	0.39	4.68	0.49	0.11
	Tail	38.43	8.48	23.15	12.47	0.55	4.54	1.04	0.13
-0.250	Con.	23.21	4.59	10.21	37.98	0.29	3.99	0.42	0.16
	Tail	39.13	9.21	23.82	12.58	0.65	3.64	1.03	0.20

CONCLUSIONS

Recovery of iron from its processing tailings faces many challenges due to the low grade of iron and complex mineralization. In the current research, an effort was made to determine the mineralogical properties and identify the texture of iron tailings to develop an algorithm for reprocessing these secondary iron deposits and addressing their challenges. Conducting mineralogical studies, including XRD and optical microscopy, has obtained fundamental information regarding the presence of magnetite in iron tailings and its interlocking with gangue minerals. Based on the electron microscopic studies, a new parameter called the association index was calculated. This index refers to determining the degree of interlocking of the target mineral - here magnetite - with other valuable minerals and gangue. According to the investigations, the highest amount for AI is related to the hematite, calcite, diopside, garnet, and quartz minerals in dimensions of 250+ microns. By decreasing the dimensions of the particles, the AI of magnetite with all the minerals identified in the sample decreases. The ratio of AI to grade of interlocked mineral with magnetite can be used as a useful parameter to investigate the magnetic separation behavior of magnetite. If magnetic separation is performed in dimensions of +250 microns, pyrite and chalcopyrite will be transferred to the magnetic concentrate for the processing of the studied tailings. By reducing the size of the particles to -106 microns, despite the high grade of calcite, diopside, and quartz minerals, with the magnetic separation of iron tailings, a smaller part of these minerals will enter the concentrate.

REFERENCES

[1] Bonnici, N., Hunt, J. A., Walters, S. G., Berry, R., and Collett, D. (2008). *“Relating textural attributes to mineral processing: Developing a more effective approach for the Cadia East Cu–Au porphyry deposit”.* In: Proceedings of the Ninth International Congress for Applied Mineralogy Conference (ICAM), 4-5.

[2] Lamberg, P. (2011). *“Particles-the bridge between geology and metallurgy”.* In: Conference in Minerals Engineering 2011, Luleå, Sweden, 1-16.

[3] Parian, M., Mwanga, A., Lamberg, P., and Rosenkranz, J. (2018). *“Ore texture breakage characterization and fragmentation into multiphase particles”.* Powder Technology, 327: 57-69.

[4] Kazemi, F., and Abdollahzadeh, A. A. (2024). *“Valorisation of iron ore tailing piles: utilisation of element-to-mineral conversion and association index to building mineralogical modal”.* Canadian Metallurgical Quarterly, 1-14.