A New Refining Process for Iron Oxide Using Iron Ore and Its Application to Hard Ferrites

S. Nakashima, Y. Ikeda, S. Hirose, H. Nakamura, and T. Ito

Kawasaki Steel Corporation and Kawatetsu Mining Co., Ltd. have developed a new refining process to extract iron oxide from iron ore to meet the increase in demand for iron oxide for high-grade hard ferrites. This article discusses the quality of iron oxides and the characteristics of the hard ferrite magnets produced from them.

1 Introduction

THE hard ferrite market in Japan has been leveling off since 1987, as shown in Fig. 1; nonetheless, it amounts to 80 to 90 thousand tons per year. Moreover, Fig. 2 indicates that Japan's share of ferrite shipments in the world market is 50%. Kawasaki Steel Corporation (KSC) is engaged in the manufacturing and marketing of iron oxide used to produce soft and hard ferrites, as well as hard ferrite calcined powder. The company has a large share of the Japanese market, as shown in Fig. 3. Because of the robust business environment of automobiles, electric and electronic products, and OA equipment industries in Japan, the demand for hard ferrites that are used in these areas has been increasing in recent years. This trend is expected to continue in the future as well. It is imperative that we diversify and increase the raw material source of iron oxide to be used for hard ferrites to meet the ever-increasing demand. At present, we are producing iron oxide from carbon steel pickling liquors.[1,2] However, the limits of this supply source are foreseeable, if we want to further expand the production.

In view of the above, KSC and Kawatetsu Mining Co., Ltd. (KMC) have developed the manufacturing technology to produce refined iron ore to produce hard ferrites from iron ore. Refined iron ore has been used in the production of low-grade magnetic materials or as loading materials for general-purpose magnetic materials when the refined iron ore is pulverized.[3] However, because of the presence of large amounts of impurities in the ore, it enjoys only limited use in the production of general-purpose ferrite. Moreover, even as an extending material, it is impossible to use in large quantities. To overcome these problems, KSC and KMC have tried to develop a new technology to remove impurities. The companies have, for the most part, been successful in their effort. In this article, the manufacturing technology of refined iron ore and the features of the hard ferrite produced with it are described.

2 Iron Ore Refining Technology

This article will explain the process of manufacturing refined iron ore,[4] the raw material for producing hard ferrite, which comes from refining iron ore. Figure 4 shows the basic

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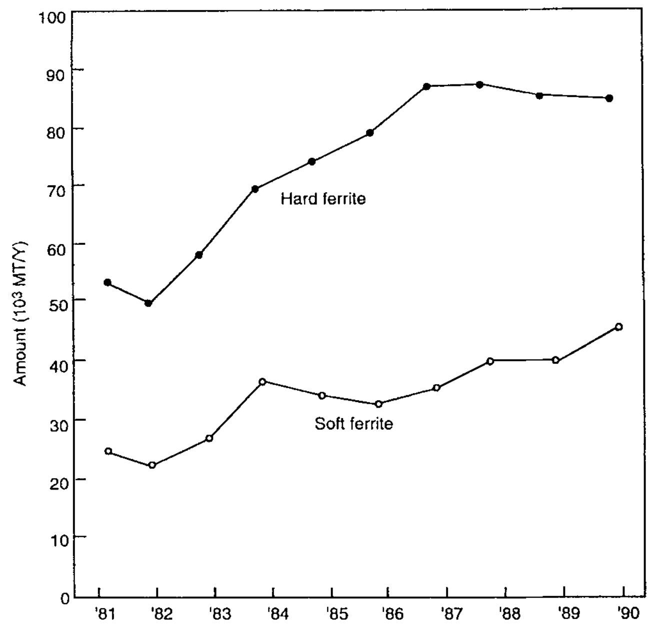

Fig. 1 Ferrite market in Japan.

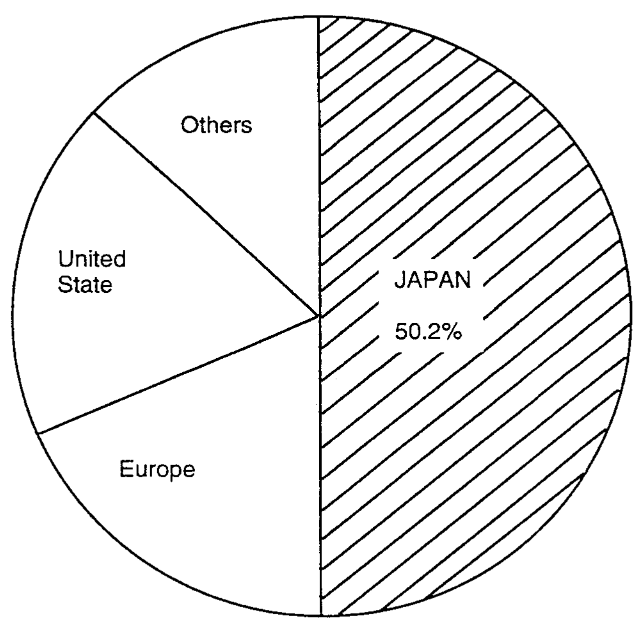

Fig. 2 Worldwide breakdown of Japanese ferrite shipments.

flow of the iron ore refining process. In principle, the process consists of the following five operations:

- Grinding: Separation of the basic components of the gangue mineral
- Cyclone grading: Removal of the gangue mineral
- Wet high-magnetic ore separation: Removal of impurities
- Pulverization: Adjustment of particle size
- Drying: Drying for refined iron ore

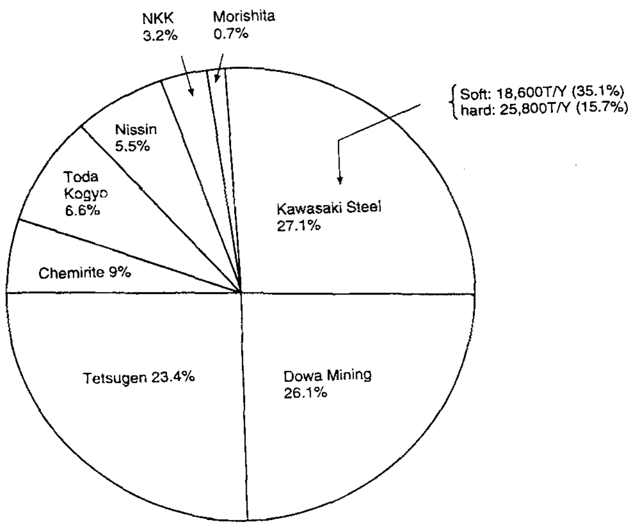

Fig. 3 Production of primary iron oxide producers in 1988.

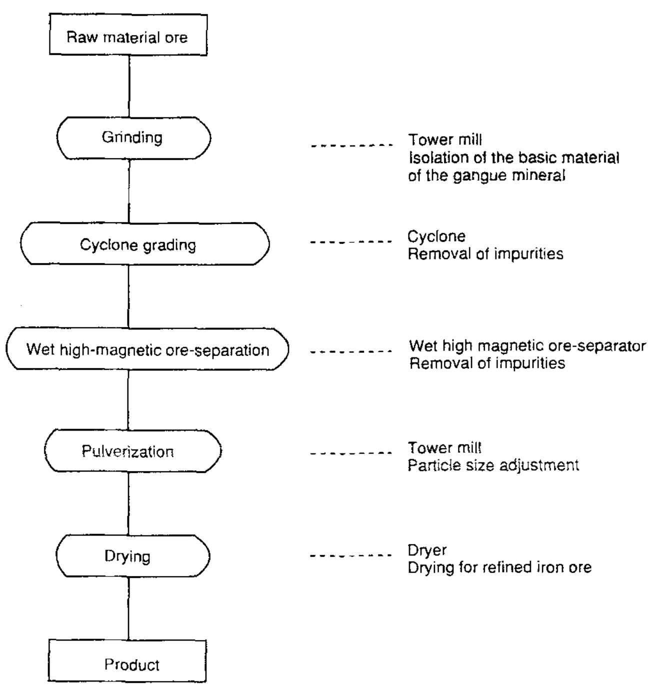

Fig. 4 Basic flowchart of iron ore refining.

The following features are unique to the technology that KSC has developed.

2.1 *Selection of Raw Material Iron Ore*

The important thing about selecting the raw material ore is that it must be hematite ore. Hematite contains relatively small amounts of gangue mineral and is easy to grind. After considering these factors in the search for a suitable iron ore, we selected iron ore A, whose chemical composition is shown in Table 1.

2.2 *Grinding*

Careful inspection of the ore with a polarization microscope shows that the size of gangue minerals varies between 10 and 100 μm. As a result, the raw material ore is ground to 10 to 50 μm first, and this size concentration becomes the ore supplying size.

Moreover, because the gangue mineral in the ore is brittle, it is ground selectively. Its separation proceeds faster than others, and it is condensed to a fine particle. Figure 5 shows the impurity distribution in the raw material ore before and after the grinding operation. Before the grinding operation, the particle size of SiO_2 and Al_2O_3 varied. However, after the grinding operation, it averaged about 20 μm.

Table 1 Chemical Composition of Ore A

	Composition, wt.%					
Sample	**T-Fe**	**FeO**	**SiO_2**	**Al_2O_3**	**CaO**	**MgO**
A	67.31	0.38	0.65	0.50	0.05	0.03

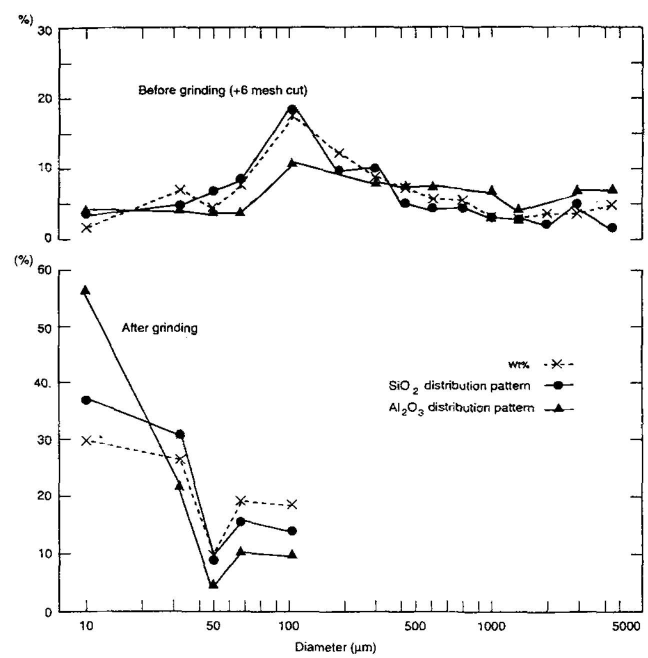

Fig. 5 Impurity distribution pattern.

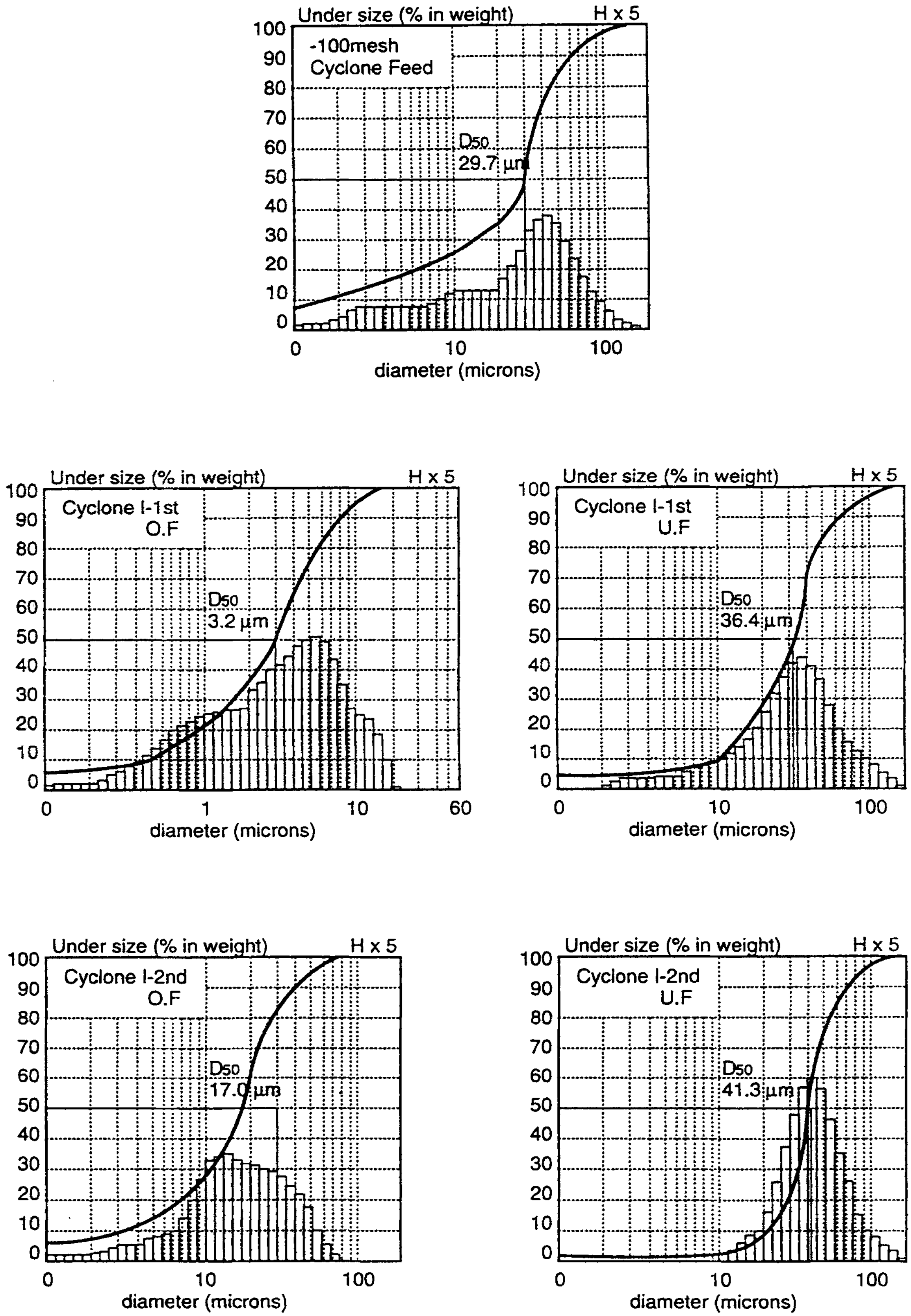

Fig. 6 Particle distribution of the test samples subjected to cyclone grading.

2.3 *Cyclone Grading*

The impurities that have been concentrated in fine particles during the selective grinding are further separated from the gangue mineral. During this process, a wet cyclone is used for grading. The following section explains the cyclone operation, which performs effective grading and the separation using the principle of specific gravity. In the cyclone operation, it is important to pay attention to the underflow style. Usually, the underflow is performed in a spray style. However, the diameter of the apex is small, the ore supply concentration is set high, and the underflow is maintained in a rope style during this process. By so doing, the specific gravity of the liquid in the cyclone becomes high, the separation resulting from differences in specific gravity becomes effective, and gangue minerals with a lower specific gravity are separated from the overflow even though the particles are rough.

A two-step cyclone method can be used in this process, and a very effective concentration can be obtained by operating the first step in the spray style and the second step in the rope style. Figure 6 shows the particle distribution and product quality that is obtained when using cyclone grading. These figures indicate that the product quality of the underflow is fairly good and that separation resulting from differences in specific gravity has occurred quite effectively in the two-step cyclone method. Moreover, the amount of impurities can be controlled, and the quality of the underflow products, which are produced during the two-step cyclone method, can be maintained within a range of 0.60 to 0.25% as far as SiO_2 is concerned and within a range of 0.30 to 0.11% as far as $Al_2O_3$is concerned.

2.4 *Wet, High-Magnetic Ore Separation*

In the wet, high-magnetic ore separator, a tray filled with matrix is rotated between two poles of a magnet. The slurry of ore that is to be separated is supplied from the top of the tray, and the magnetized particles are captured on the matrix. The nonmagnetic particles are then allowed to pass as they are through the matrix. In this way, they can be separated. Figure 7 illustrates the magnetic separator. In the next section, the influ-

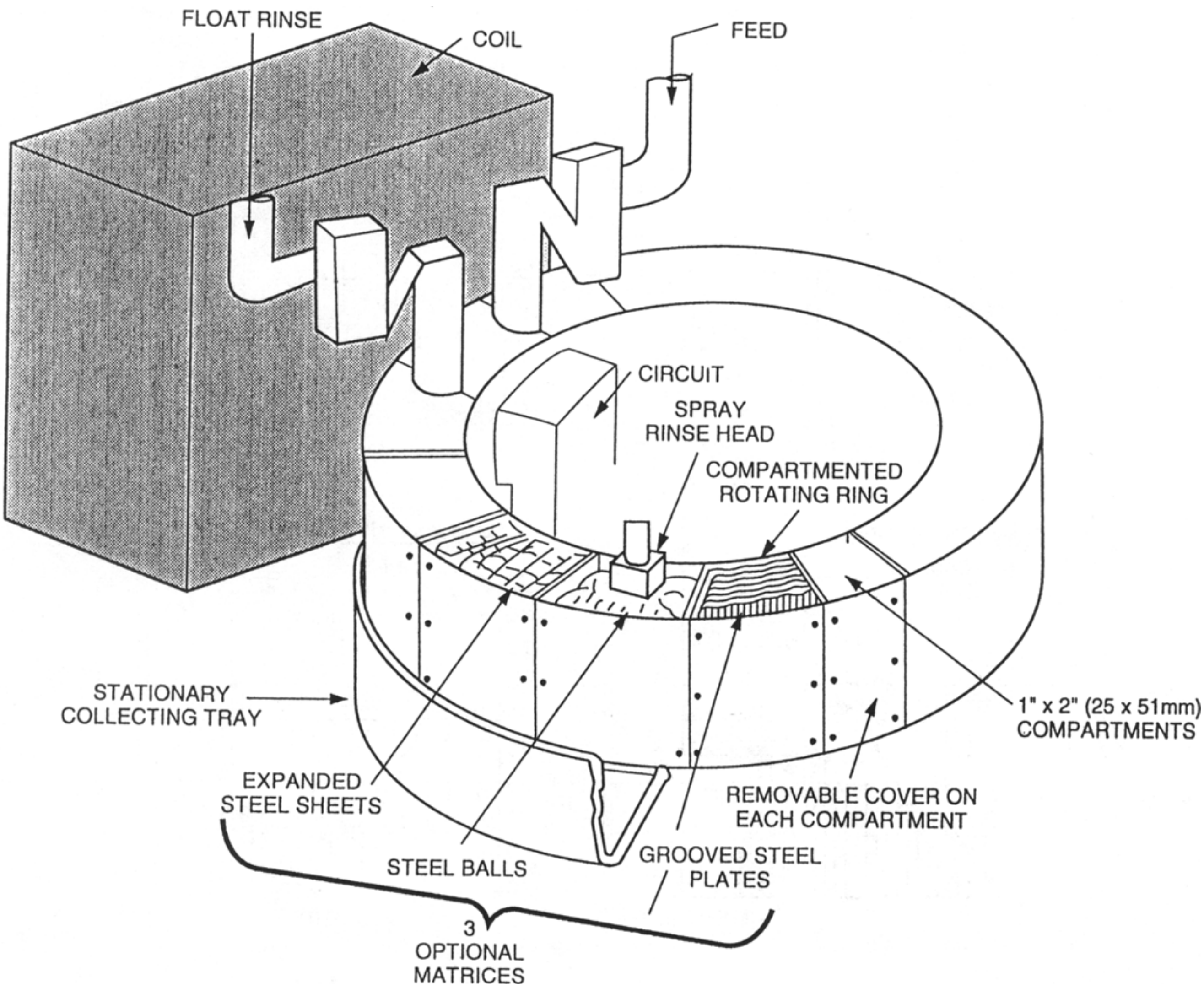

Fig. 7 Schematic of continuous magnetic ore separator.

ence of fine particle removal by cyclone grading on the magnetic separation performance will be discussed, as well as the influence of operation parameters of the magnetic separator on the magnetic separation performance.

Figure 8 shows the influence of cyclone grading on the magnetic separation of samples under 5000 Gauss. If the overall yields are kept the same, the contents of SiO_2 and Al_2O_3 in the samples are reduced by about half after cyclone grading is carried out. This leads to very good impurity removal. The slime in the magnetic separation field is removed during cyclone grading, and magnetic coagulation of hematite with fine particles in the magnetic field is reduced.

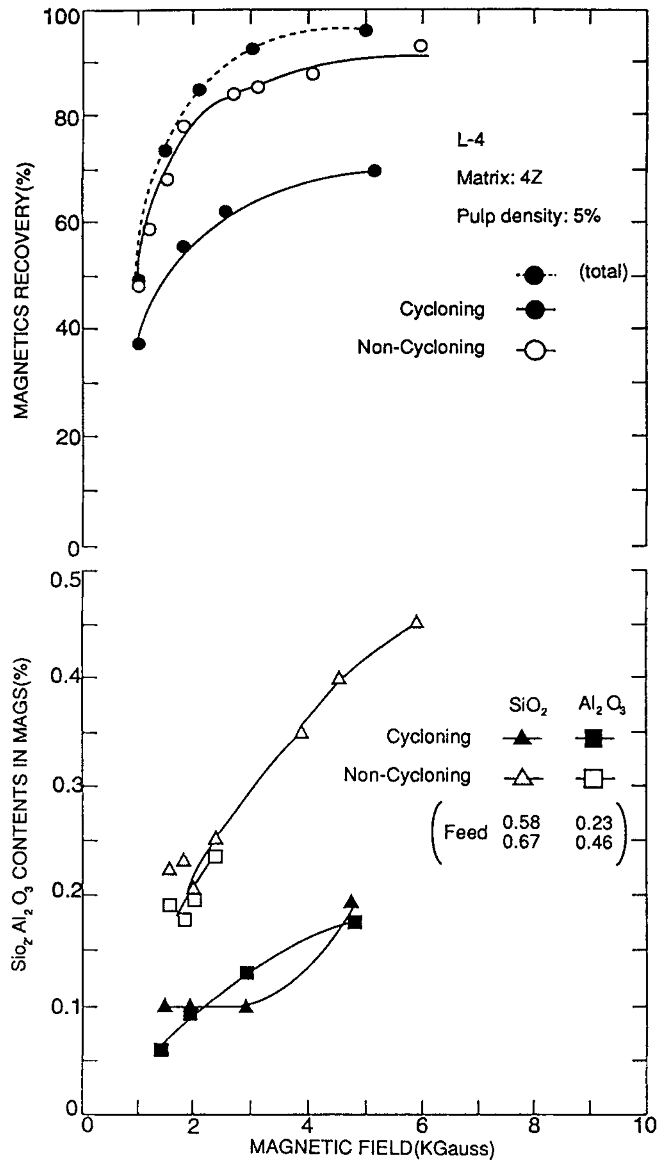

Fig. 8 Cyclone grading effects in magnetic separation.

2.5 *Quality of Refined Iron Ore*

Kawasaki Steel Corp. has decided to call the product manufactured by the process mentioned above "KRIO" (Kawasaki Refined Iron Ore). The yardstick to determine the quality of the refined ore is degree of particle distribution and the level of the impurities, such as SiO_2 and Al_2O_3. To obtain the required quality, KSC has developed technology that can be explained by the following.

- Particle distribution
- Reduction of Al_2O_3: Two-step cyclone technology
- Reduction of SiO_2: Magnetic separation technology

Details concerning particle distribution are not covered in this article; however, the technology combines tower mill grinding and cyclone grading. Using these technologies, the KRIO process can provide iron oxide of a quality that is the same as the iron oxide for producing hard ferrite (KSC product name, KH-DC) that is made from carbon steel pickling liquors. Table 2 illustrates a typical composition.

3 Application to Hard Ferrites

This section will explain how good the refined iron ore is used in the production of hard ferrites.[5,6] Figure 9 shows the production flow used to produce hard ferrite calcined powder. KSC has been engaged in the production of two kinds of hard ferrite calcined powders—barium-base powder and strontium-base powder.

The features of KRIO as the raw material of hard ferrites include a high content of the sinter slowdown components (SiO_2, Al_2O_3) and a low CaO content, which acts to stimulate the sintering process. Furthermore, particle size is usually larger than that of KH-DC. Given these features, the KRIO sintering reactivity is smaller than that of KH-DC. The authors have carried out studies that reveal how influential the molar ratio, conditions, and addition conditions are on calcining KRIO sintering and magnetic properties in comparison with KH-DC.

Table 2 Typical Analysis of Refined Iron Ore

Ore	Composition, wt.% Fe_2O_3	SiO_2	Al_2O_3	CaO	Cl	Particle size (a), µm
KRIO	≥98.5	≤0.25	≤0.20	≤0.01	Trace	1.3 to 1.6
KH-DC	≥99.1	≤0.02	≤0.03	≤0.05	≤0.1	0.8 to 1.0

(a) Particle size analysis: Values obtained using the air permeation method (Shimazu SS-100).

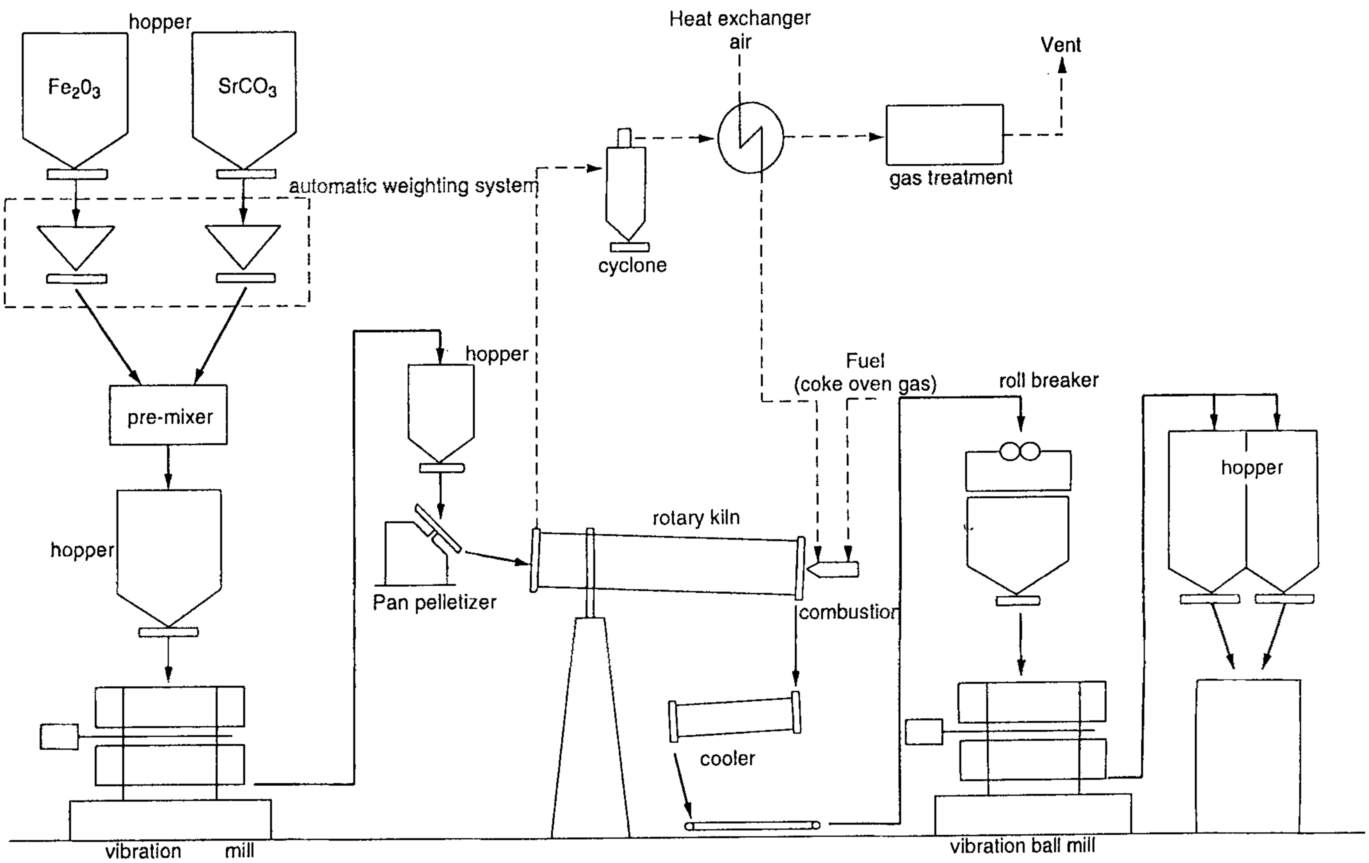

Fig. 9 Flow diagram of calcining process for hard ferrites.

3.1 *Comparison under the Same Conditions*

Figure 10 shows the physical properties of the barium-base product when the molar ratio, calcining temperature, and amount of additive SiO_2 and $CaCO_3$ are kept at the same level. Figure 11 shows the physical properties of the strontium-base product when these factors are kept at the same level. The features common to the two graphs are that *Br* decreases and *BHc* increases when KRIO is used. Moreover, the notable feature among the sintering characteristics is that the shrinkage ratio of the core diameter (Sh-D) also increases. These findings indicate that, to ensure that calcining powder properties and characteristics will be the same as those of KH-DC, it is necessary to change the molar ratio, the calcining temperature, and the addition conditions of the additives.

3.2 *Effect of Molar Ratio*

Figure 12 shows the relationship between the molar ratio and the magnetic and sintering properties with respect to barium-base hard ferrite. Increasing the molar ratio will decrease both *Br* and *BHc*. It will also decrease the shrinkage ratio of the core diameter of the sintering properties. This means that the particle growth of SiO_2 present in iron oxide will be reduced somewhat and that a microcrystalline structure will result when the molar ratio is low, in other words, with the BaO excess composition.

3.3 *Effect of Calcining Temperature*

Figure 13 shows the properties of KRIO and KH-DC when the calcining temperature is changed with respect to the barium-base hard ferrite. KRIO has a smaller magnetic property change due to calcining temperature than does KH-DC. The KRIO features with respect to the calcining temperature are due to the low sintering reactivity inherent in KRIO; it has the advantages of a minimal property change as well as stable product quality in the actual production work.

3.4 *Effect of Additives*

Figure 14 shows the effect on properties of KRIO and KH-DC when the amount of SiO_2, an additive, was changed with respect to the strontium-base hard ferrite. The change in the KRIO properties due to a different amount of SiO_2 is smaller than that in KH-DC. KRIO has a lower calcining or normal sintering reactivity than KH-DC. Figure 15 shows the properties of the barium-base hard ferrite. Although the differences detected are not as pronounced as those of the strontium-base hard ferrite, KRIO will have a lower *Br* depending on an amount of SiO_2 added and will have higher *BHc* values and greater shrinkage of the core diameter than KH-DC.

3.5 *Evaluation*

The hard ferrite made from KRIO has features that are the same as those of ferrite made from KH-DC if the proper molar

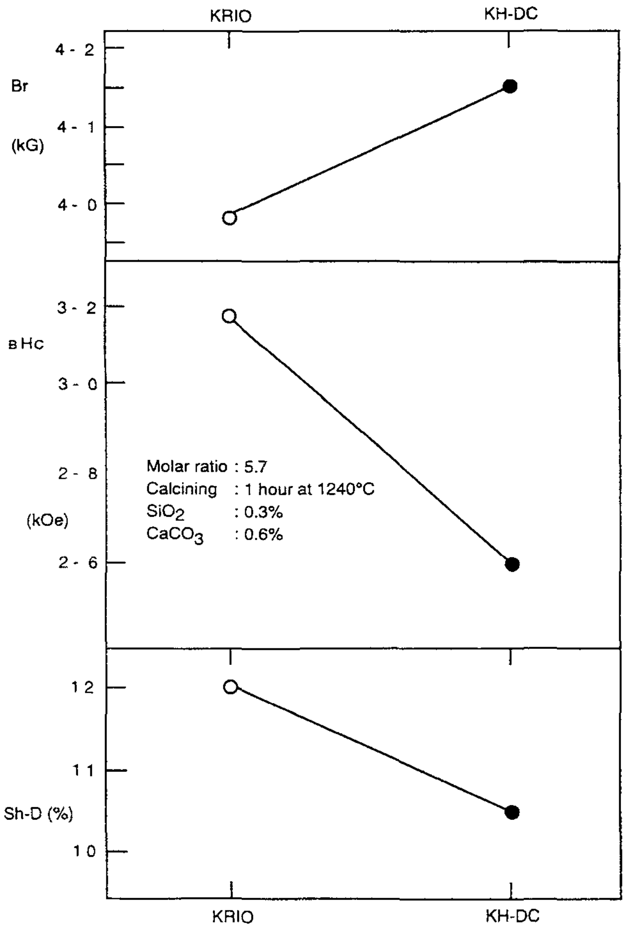

Fig. 10 KF-BA comparison of KRIO with KH-DC-16.

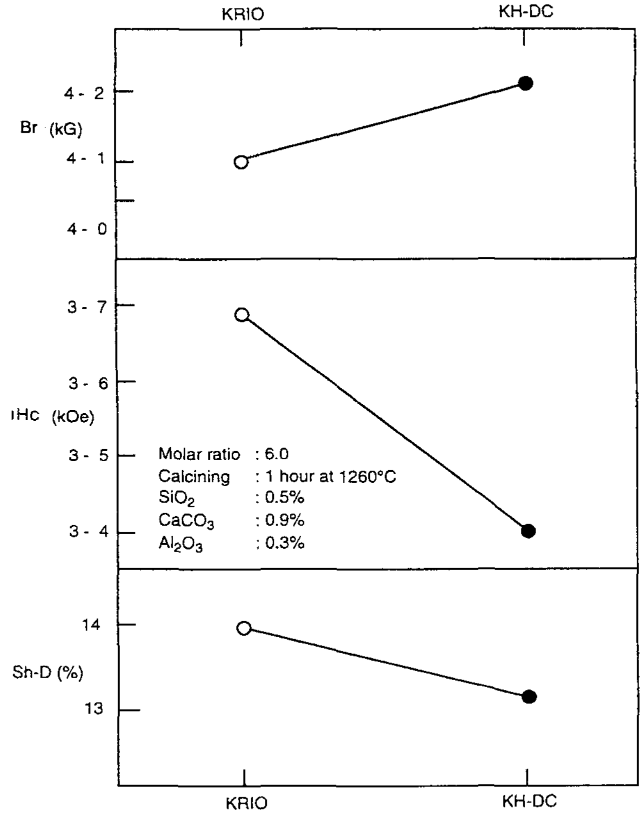

Fig. 11 KF-SR comparison of KRIO with KH-DC-16.

ratio is selected (Fe_2O_3/SrO or Fe_2O_3/BaO), as well as optimum calcining conditions, and control of additives. Features of the process using KRIO as the raw material are summarized as follows. The physical property variation due to changes in the calcining temperature is small, and product quality is stabilized. The physical property variation due to changes in the amount of additives present is small, and product quality is stabilized. SiO_2 content can be adjusted in KRIO, the raw material, and adjustment of CaO/SiO_2 in the sintering process leads to smaller quality variation in the product, thus contributing to stable product quality.

4 Conclusion

The technology that produces iron oxide by refining iron ore has been described. Iron oxide is the raw material used for producing hard ferrite. Moreover, its application to hard ferrite has been explained. When considering its application to hard ferrite, our discussion focused on molar ratio, calcining temperature, and SiO_2 content, the three factors that have the greatest influence on product quality. Production conditions required to produce products with the required quality have been discussed.

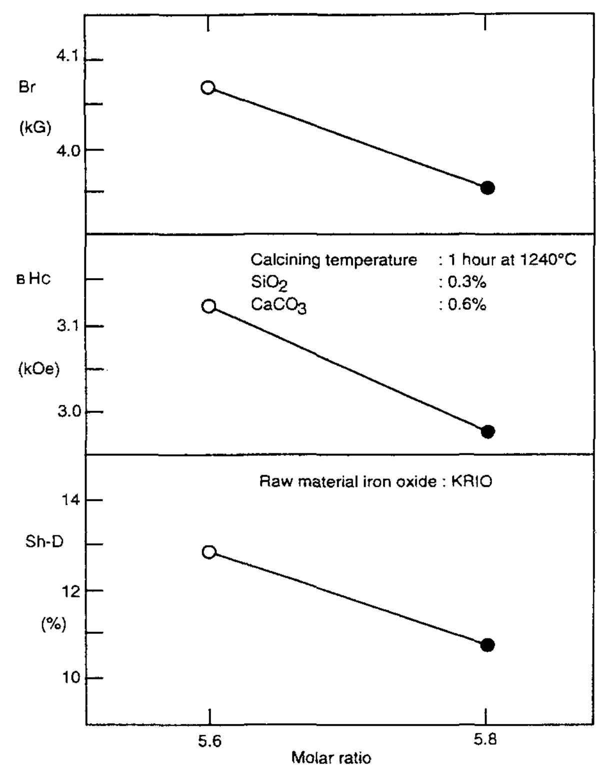

Fig. 12 Effect of molar ratio on Ba-base hard ferrite.

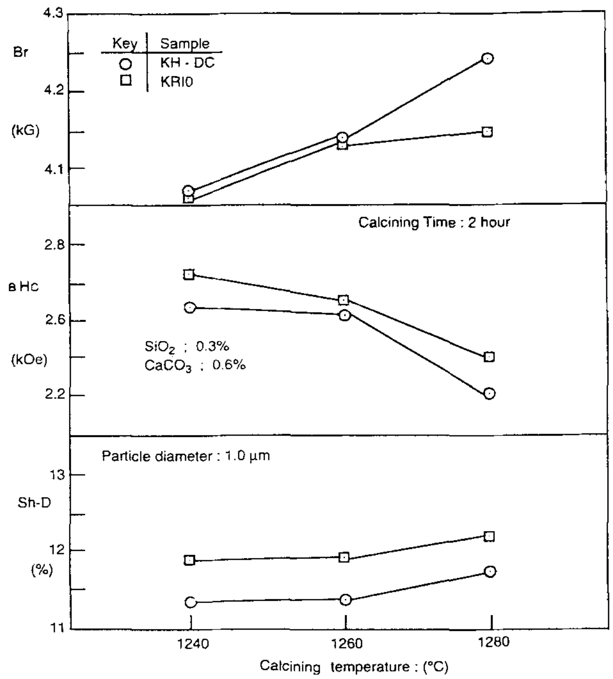

Fig. 13 Effect of calcining temperature on Ba-base hard ferrite.

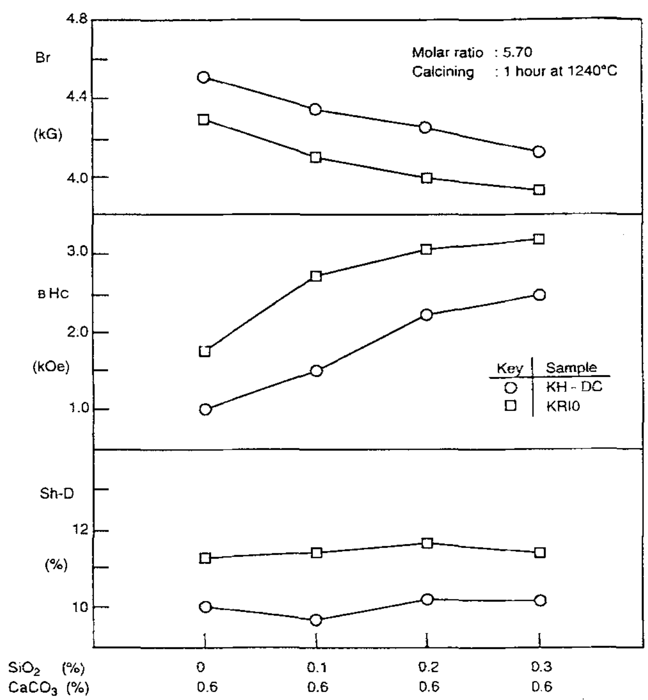

Fig. 15 Effect of additives on Ba-base hard ferrite.

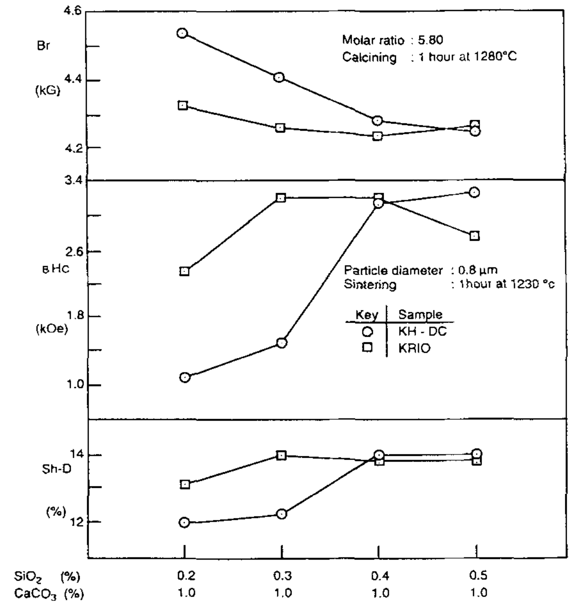

Fig. 14 Effect of additives on Sr-base hard ferrite.

To meet the increasing market demand for hard ferrites, KSC and KMC have developed a unique technology to manufacture iron oxide by refining iron ore. Currently, KSC has the largest share in the market of iron oxide used for hard ferrite production and hard ferrite calcined powder in Japan.

We at KSC sincerely hope that our new technology will continue to contribute to the further development of the ferrite business in the future.

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