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Recovery of Heavy Minerals from Korean Beach Sand

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Abstract

In order to establish the optimized recovery process for heavy minerals from beach sand, we investigated the physical separation methods such as gravity and magnetic separation followed by mineralogical characterization. There was clear relationship between the particle size and the heavy mineral content that the heavy minerals were mostly concentrated in the particles below 100mesh. Gravity separation using the spiral and shaking table separators made it possible to concentrate heavy minerals by rejecting the light and coarse particles consist mainly of quartz. The high-intensity magnetic separator and subsequent induced magnetic separator were applied to fractionate magnetic particles into three fractions according to their magnetic susceptibility. The content of TiO_2 of high magnetic susceptible ilmenite-rich fraction was 43.98wt.% while those of ZrO_2 of non-magnetic and magnetic residue were 6.78wt.% and 3.11wt.%, respectively.

Keywords: *Heavy Minerals, Gravity Separation, Magnetic Separation, Ilmenite, Zircon*

INTRODUCTION

Demand on new resources has been increased in recent years because of not only outbreak of new industries but also rapid expansion of advanced technologies. Especially, heavy minerals have been gaining much attention because of rapid growth of electric, electronic and ceramic industries. Generally, the term "heavy minerals" refers to minerals with a specific gravity (S.G.) greater than that of quartz (S.G.$\approx$2.7g/cm^3). In addition, these heavy minerals are chemically stable and mechanically resistant enough to persist into beach accumulates. These types of deposits are predominantly mined for their titanium-bearing minerals such as ilmenite and rutile to supply titanium feedstock for the production of titanium metal. An important co-product of this industry is zircon, which is mainly used in the ceramic industry for the production of opacifiers (Reyneke and Westhuizen, 2001). It is well known that ilmenite, rutile and zircon are found in a variety of igneous, metamorphic and sedimentary rocks. In many of these rocks, concentrations of these valuable minerals are low or they cannot be fully recovered. Fortunately, however, these minerals are common in beach sand deposits where they have been concentrated to such a degree that they can be economically exploited.

Recently, due to the discovery of several heavy mineral deposits in Korea, we surveyed the mineralogical occurrences and chemical compositions of Korean beach sands contain economic concentrations of ilmenite, rutile and zircon along the west side of Korean peninsular even though the beach sands in Korea are now used about 2,000tons per year as building materials. The following paper presents one of the optimized processes for the recovery of heavy minerals from Korean beach sands. In order to establish the recovery process for heavy minerals, we investigated the physical separation methods such as gravity and magnetic separation followed by mineralogical characterization of beach sands. This paper will also discuss the performance and effectiveness of separation methods to provide experimental information on the recovery of heavy minerals and for further development of their separation processes.

SAMPLE AND PROCEDURES

The beach sand of Jaeun Island which is located on about 43km northwest of Mokpo, Korea was used in the present study. Preliminary examination of this sampling site revealed that the beach sand of present study was composed of very fine particles and in addition was found to contain relatively higher portion of heavy minerals such as ilmenite and zircon compare to those of other neighboring sampling sites. Table 1 shows the chemical composition of the raw sample obtained from XRF analysis. The particle size analysis of the sample was made using standard sieving technique.

Table 1: Chemical Composition of Raw Sand

	SiO_2	Al_2O_3	K_2O_3	Fe_2O_3	Na_2O	CaO	MgO	TiO_2
Wt.%	91.57	3.36	1.06	1.10	0.41	0.56	0.07	0.85

Fig. 1 shows the schematic diagram of the sample preparation. The sand sample was screened and coarse fractions above 70mesh (212μm) regarded as usually non-valuable minerals even though occur in much greater quantities in beach sand deposits were rejected. The fine fractions were subjected to gravity separation using a spiral and a shaking table separator in order to obtain primary gravity concentrate. Subsequently, this heavy mineral-bearing concentrate was magnetically fractionated using a laboratory scale dry high-intensity permanent magnetic roll separator and a induced magnetic roll separator (cross-belt magnetic separator) at field strength settings of 9000 and 12000Gauss to produce three fractions, namely high susceptible magnetic fractions less susceptible magnetic and/or magnetic-others and finally magnetic residues. The non-magnetic and magnetic residues from both magnetic separations were composed mainly of quartz and zircon. Finally, they were screened at 140mesh into two fractions that the zircon-rich fraction could be recovered.

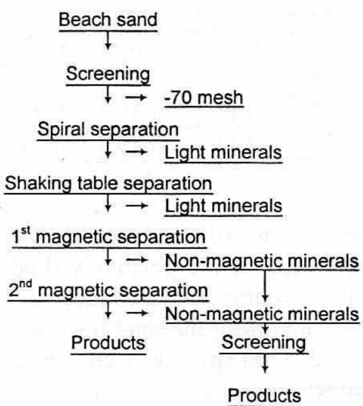

Fig. 1: Schematic Diagram for the Sample Preparation

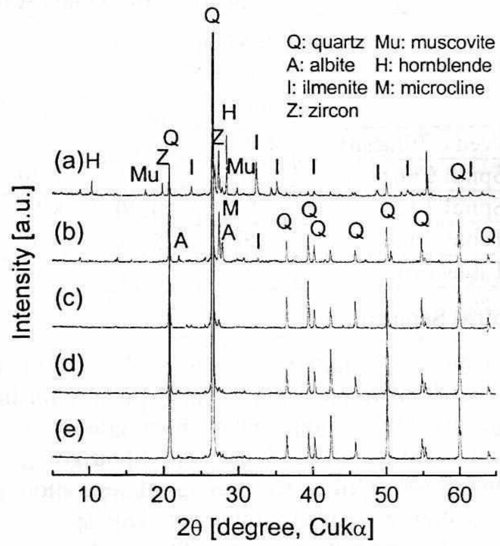

Fig. 2: XRD Patterns of the Fractionated Particles Obtained by Screening ((A) -140mesh, (B) -100/+140mesh, (C) -70/+100mesh, (D) -50/+70mesh, (E) +50mesh)

RESULTS AND DISCUSSION

Screening

Among the conventional mineral processing techniques, screening is perhaps one of the most efficient and simple process. The screening has not only been utilized to prepare a uniformly sized feed to certain process, but also to upgrade the content of target materials to be recovered. Fig. 2 shows the XRD patterns of the fractionated particles obtained from screening of raw sand. From the XRD profile, the peaks of quartz, microcline and albite are observed as the main peaks of the particles fractionated above 70mesh whereas the peaks of ilmenite and zircon are in the particles fractionated below 100mesh even though the peak intensities are very low. However, it could be possible to say that there is clear relationship between the particle size and the heavy mineral content of the sample of this study, suggesting that the abundance of heavy minerals might be increased as the particle size decreases.

The brief summaries of component minerals and chemical compositions of the fractionated particles together with their weight percent values are provided in Table 2 and 3. From the XRD and XRF analyses, it could be also possible to say that the relative portion of heavy minerals increases as the particle size of the sample decreases even though the total weight percent value of fine fractions below 100mesh was much lower than that of coarse fractions. These results imply that the pre-elimination of coarse fractions by screening prior to the application of further beneficiation processes such as gravity and magnetic separations could be needed in this study.

Table 2: Component Minerals and their Weight Percent of the Fractionated Particles.

Mesh	Component minerals	Wt.%
+50	Quartz, Microcline, Albite	3.6
-50/+70	Quartz, Microcline, Albite	40.1
-70/+100	Quartz, Microcline, Albite	48.7
-100/+140	Quartz, Microcline, Albite, Muscovite, Ilmenite	6.4
-140	Quartz, Microcline, Albite, Muscovite, Ilmenite, Zircon	1.2

Table 3: Yield and Chemical Compositions of the Fractionated Particles

	Wt.	Chemical composition (wt.%)							
	(%)	SiO_2	Al_2O_3	K_2O	Fe_2O_3	Na_2O	CaO	MgO	TiO_2
Feed (-70mesh)	100.0	90.67	4.10	1.35	1.43	0.24	0.70	0.21	1.06
Spiral Conc.	22.9	62.86	11.09	1.04	8.89	0.38	4.60	0.78	9.23
Spiral Tail	77.1	94.20	3.17	1.36	0.53	0.20	0.21	0.14	0.17
Table Conc.	6.6	32.68	15.06	0.39	17.81	0.13	9.10	0.96	22.40
Table Tail	16.3	77.68	10.68	1.24	3.28	0.41	3.19	0.77	2.47

Spiral Separation

In many of the gravity separators, the spiral concentrator has traditionally been recognized as a low cost and environmentally friendly process for the separation of minerals. Its relatively simplicity and high efficiency compared to other gravity separators led to its widespread use under a variety of circuit configurations (Atasoy and Spottiswood, 1995). In our experiment, the sand fractionated below 70mesh was used as feed for spiral separation. A Humphreys LC3700 spiral was chosen for the pre-concentration of heavy minerals. This spiral has a large diameter and flatter profile with a shallow pitch and seven turns. It was fitted with two splitters at discharge splitter box. The separated three streams were connected via hoses to the separated samplers from which the sand collected into the middling sampler was returned to the slurry tank for further beneficiation. In order to examine the effect of this spiral separation, the final products were separately screened through a set of screens consisting of 100, 140 and 200mesh sieves and each size fraction obtained was subjected to XRD analysis. Fig. 3 presents the weight percent of each size fraction obtained from spiral separation. It can be seen that most of the light minerals, in other words tailing which was collected in the outer region of the spiral consists of coarse fraction above 100mesh. This finding implies that finer and heavier particles could be concentrated in the inner region since the coarse and light particles like quartz would move towards the outer region of spiral whereas finer and heavier fractions were placed in the inner region when the residence time of the feed on the spiral flow increases (Richards et al., 2000). In order to examine the effect of this gravity separation, XRD analysis of two particles separated into light and heavy particles with the same size fraction ranged from below 100 to above 140mesh was conducted and the result is shown in Fig. 4. It is noted that light particles mostly consist of quartz, whereas heavy particles show variety of minerals like epidote, microcline and ilmenite which are relatively heavier than quartz, implying that the application of this separation would be estimable for pre-concentration of heavy minerals in this study.

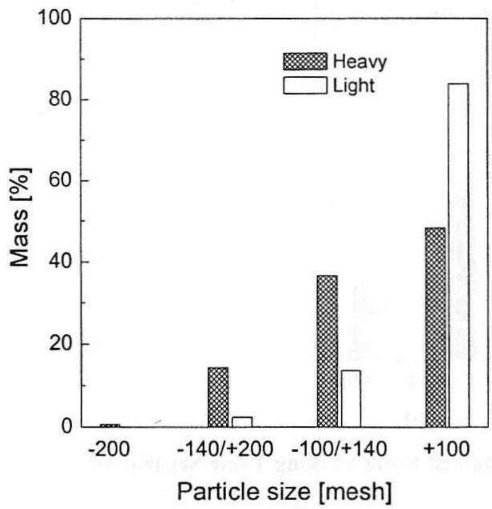

Fig. 3: Weight Percent of each Size Fraction Obtained from Spiral Separation

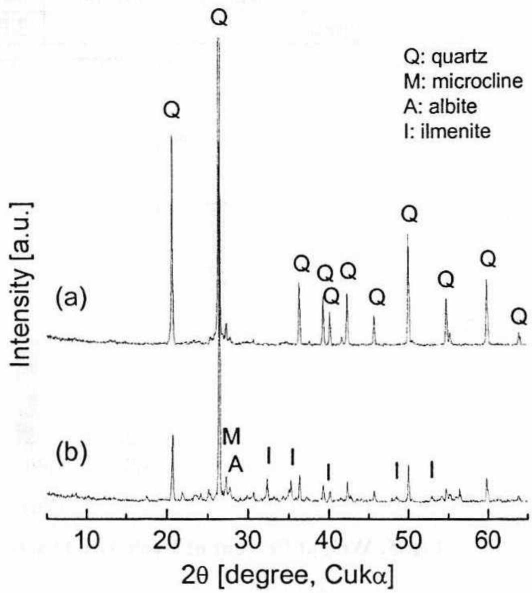

Fig. 4: XRD Patterns of the Particles Separated by Spiral Separation ((A) Light Particles, (B) Heavy Particles)

Shaking Table Separation

Spiral or shaking table concentration separate materials of different specific gravity by their relative movement in response to the force of gravity and one or more other forces, the latter often is the resistance to the motion offered by a fluid such as water or air. The motion of a particle in a fluid is dependent not only on the particle's density, but also on its size and shape, large particles being affected more than smaller ones. So, in practice, close size control of feed to gravity processes is strongly required especially when a shaking table separator is used as a cleaner. In this study, a 13A Standard Wilfley Concentrating Table was used for the subsequent cleaning of pre-concentrated rougher feed obtained from spiral separator. The deck inclination, stroke length and dressing water flow for the operation of shaking table are previously adjusted to the optimum operating conditions in order to reduce the size effect and make the relative motion of the particles specific gravity dependent (Chatterjee, 1998).

Fig. 5 shows the weight percent of each size fraction obtained from shaking table separation. It can be seen that the size distribution of heavy particles varies, whereas that of light particles is much narrow above 140mesh. Fig. 6(a) and 6(b) show the XRD patterns of each size fraction obtained from shaking table separation. The peaks of ilmenite and zircon are clearly observed as the particle size fraction become smaller in the XRD profile in Fig. 6(a), while no peaks of these heavy minerals are detected in the XRD profile of fractionated tailing in Fig. 6(b) even though considerable portion of fine particles size ranged from below 100 to above 140mesh was split into tailing. Table 4 summarizes the yield and chemical compositions of each product obtained from both gravity separations.

Table 4: Mineralogical Composition of the Magnetically Fractionated Particles

Fraction		Wt.%	Major	Minor
Feed (Gravity concentrate)		100.00	-	-
Magnetic	High susceptible	27.60	Ilmenite	Hornblende
	Less susceptible	36.09	Epidote, Ilmenite	Hornblende
	Magnetic residue	34.29	Quartz, Zircon	Microcline
Non-magnetic		2.02	Quartz, Zircon	Microcline

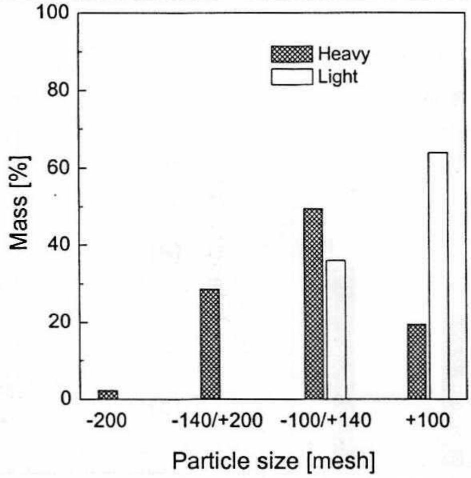

Fig. 5: Weight Percent of Each Size Fraction Obtained From Shaking Table Separation

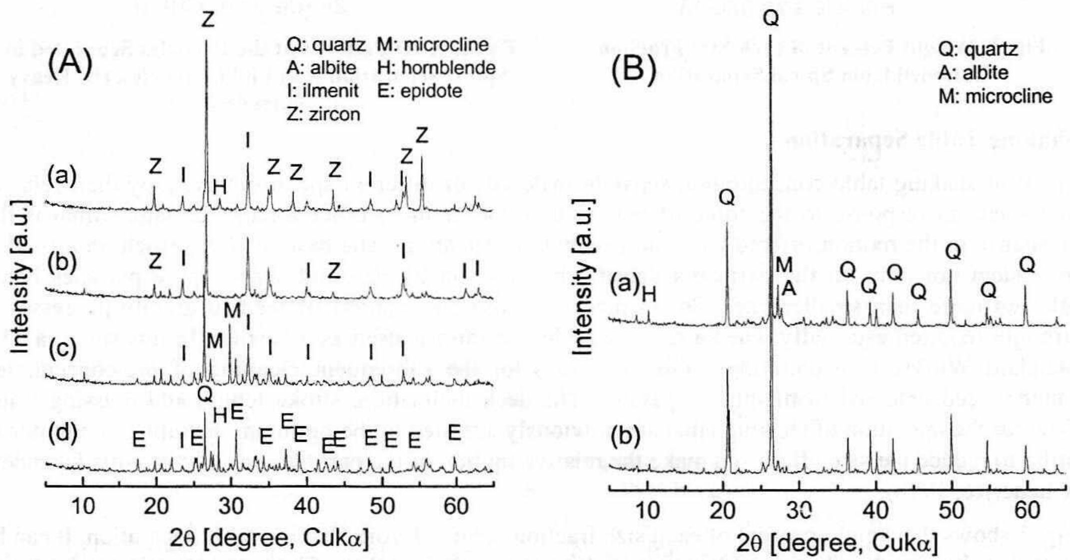

Fig. 6: XRD Patterns of Each Size Fraction Obtained From Shaking Table Separation ((A): Heavy Particles, (A) -200mesh, (B) -140/+200mesh, (C) -100/+140, (D) +100mesh, (B) Light Particles, (A) -100/+140, (D) +100mesh)

Magnetic Separation

There have been many advances in the design and operation of high-intensity magnetic roll separators, mainly as a result of the introduction of rare earth alloy permanent magnets capable of providing very high magnetic field strengths and gradients (Arvidson and Henderson, 1997). The use of high-intensity magnetic separator makes it possible to separate most of magnetic and ferrous particles from the primary heavy mineral concentrate obtained from gravity separations. Fig. 7 shows the XRD patterns of magnetic and non-magnetic particles which are separated by using high-intensity magnetic separator. It can be seen from the XRD profiles that this intense magnetic separation could be achievable at least for the following three mineral groups.

- Ilmenite particles with relatively high magnetic susceptibility
- Magnetic and magnetic-others with relatively less magnetic susceptibility
- Non-magnetic particles without magnetic susceptibility

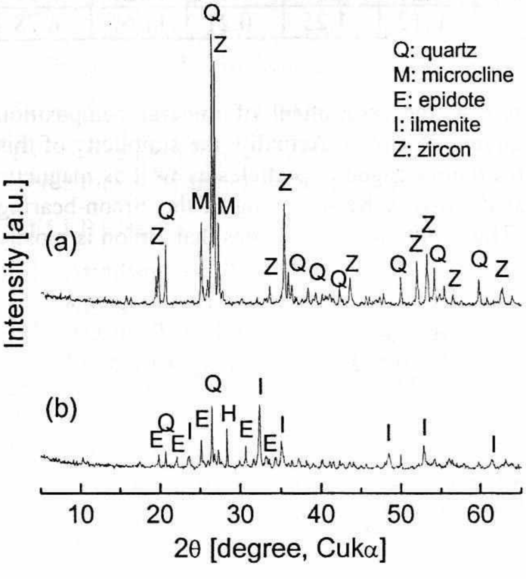

Fig. 7: XRD Patterns of Non-Magnetic and Magnetic Particles Separated by High-Intensity Magnetic Separation. ((A) Non-Magnetic Particles, (B) Magnetic Particles)

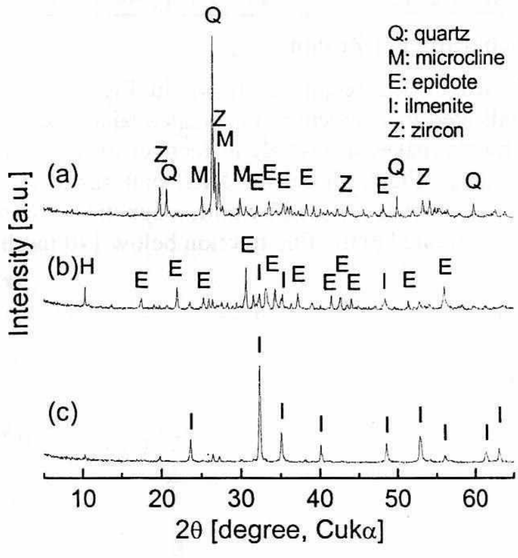

Fig. 8: XRD Patterns of Fractionated Magnetic Particles by Induced Magnetic Separation ((A) Magnetic Residue, (B) 1200Gauss, (C) 9000Gauss)

The former two mineral groups which are composed of ilmenite, epidote and hornblende were collected into magnetic fractions and the latter mainly composed of zircon and quartz was into non-magnetic fraction. Subsequently, the former two fractions were fractionated by induced roll magnetic separator and the result is presented in Fig. 8. It can be seen that ilmenite is a main peak of the particles separated at the magnetic field strength of 9000Gauss, suggesting that the high susceptible ilmenite and ilmenite-bearing particles were almost recovered at this separation condition. Table 4 and 5 show the mineralogical and chemical compositions of the fractionated particles by both magnetic separations. It can be seen that high susceptible particles consisted mainly of ilmenite exhibit TiO_2 content of 43.98wt.% whereas magnetic-others exhibit TiO_2 content of 8.45wt.%. It is also noticeable that zircon and quartz are the main components in the non-magnetic particles as well as magnetic residues which are not fractionated into magnetic particles at magnetic field strength of 12000Gauss. Their mineralogical compositions are also reflected in TiO_2 and ZrO_2 contents of 17.63wt.% and 6.78wt.% in the non-magnetic particles and 16.52wt.% and 3.11wt.% in the magnetic residues, respectively. However, it is estimable that contents of TiO_2, Al_2O_3 and CaO are still high in the non-magnetic and magnetic residue. It strongly implies that these particles would contain appreciable amounts of rutile, garnet and sillimanite as minor heavy minerals in addition to ilmenite and zircon even though the peaks of the minor minerals were not detected in XRD profiles. Thus further investigations involving an optical microscopic particle counting and EDS analysis would be needed to obtain quantitative information on the amount of different species present in these fractions.

Table 5: Chemical Composition of the Magnetically Fractionated Particles

	SiO_2	Al_2O_3	K_2O	Fe_2O_3	Na_2O	CaO	MgO	TiO_2	ZrO_2
Feed	30.26	13.95	0.36	15.45	0.12	8.43	0.89	20.74	1.10
High susceptible	5.54	2.59	009	31.60	0.01	0.82	0.48	43.98	0.05
Less susceptible	33.60	21.71	0.17	15.13	0.08	15.59	1.30	8.45	0.06
Magnetic residue	48.17	13.49	0.83	2.51	0.31	5.87	0.68	16.52	3.11
Non-magnetic	43.30	13.49	0.50	0.56	0.12	1.25	0.21	17.63	6.78

Separation of Zircon

Based on the result as shown in Fig. 6(b) and Table 4, the assessment of mineral composition indicated that screening becomes available for the recovery of zircon. Actually, the simplicity of this process makes it possible to recover most of zircon from non-magnetic particles as well as magnetic residues. Fig. 9 shows the XRD patterns of fractionated particles by screening of the zircon-bearing fractions once rejected by both magnetic separations. The result clearly indicates that zircon is mostly concentrated in the fine fraction below 140 mesh.

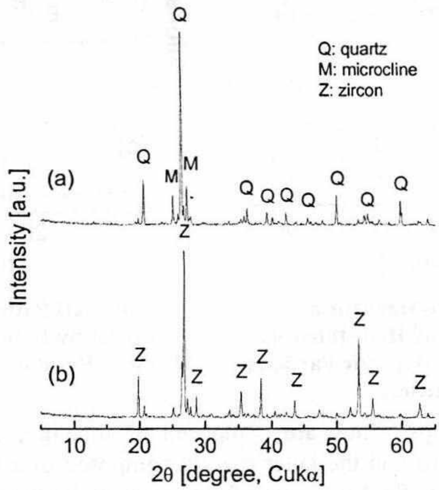

Fig. 9: XRD Patterns of the Fractionated Particles by Screening of Zircon-Bearing Fractions ((A) +140mesh, (B) -140mesh)

CONCLUSION

In order to establish the optimized recovery process for heavy minerals from beach sand, we investigated the physical separation methods such as gravity and magnetic separation followed by mineralogical characterization. The experimental results are summarized as follows;

1. Particle size analysis of sand sample revealed that there was clear relationship between the particle size and the heavy mineral content. The heavy minerals were mostly concentrated in the particles below 100mesh. Screening was performed in order to reject above 70mesh fraction are mainly composed of quartz and to make uniformly sized feed to subsequent gravity separations.

2. The use of spiral separator made it possible to concentrate heavy minerals by rejecting the light and/or coarse particles consist mainly of quartz size ranged from below 100 to above 140 mesh. Shaking table separation was subsequently conducted to obtain final gravity concentrate. The recovery performance and effectiveness of both gravity separations were confirmed by the assessment of mineralogical and chemical compositions of the products.

3. Most of particles with magnetic susceptibility were recovered by high-intensity magnetic roll separator. The induced magnetic roll separator was subsequently applied to fractionate the magnetic particles into three fractions according to their magnetic susceptibility. TiO_2 content of high magnetic susceptible ilmenite-rich fraction was 43.98wt.% while those of low magnetic susceptible and magnetic residue were 8.48wt.% and 16.52wt.%, respectively.

4. The mineralogical and chemical compositions of non-magnetic and magnetic residue once rejected in both magnetic separations are similar in that these fractions consist mainly of zircon and exhibit ZrO_2 contents of 6.78wt.% and 3.11wt.%, respectively. Since zircon was mostly concentrated in the particles below 140mesh, it could be simply recovered by screening.

ACKNOWLEDGEMENTS

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