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Beneficiation Experiment by High Gradient Magnetic Separation (HGMS) for the Talc Ores from the Yesan-Gongju-Cheongyang Area

예산-공주-청양 지역에서 산출되는 활석 광석에 대한 고구배자력분리를 이용한 정제 실험

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ABSTRACT : Several large talc deposits are distributed in the Yesan-Gongju-Cheongyang area. Talc ores from this area are hydrothermal alteration products of serpentinite which was originated from ultramafic rocks. They contain a lot of impurity silicates such as chlorite, mica, and amphibole. In order to separate such iron-bearing silicates from the talc ore and thus to increase the commercial value of the talc ore, the high gradient magnetic separation (HGMS) method was applied using a high gradient magnetic separator which was manufactured in the laboratory.

Beneficiation experiment was performed for the artificial standard mixture samples and talc raw samples. HGMS processing shows an increase in the content of talc in concentrates and the whiteness of the talc ores from 60.6 to 65.5 for the Daeheung talc ore, from 61.6 to 65.0 for the Pyeongan talc ore, and from 71.2 to 74.5 for the Sinyang talc ore.

It has been experimentally confirmed that the Fe-bearing silicates can be separated from talc ore efficiently with HGMS and that additional ultrasonic treatment improves the grade of concentrates. It suggests that the separation of impurity Fe-bearing silicates from low grade talc ores by HGMS enhances the grade of talc concentrate, although the improvement of whiteness was not so good enough. The reasons for the insufficient increment in whiteness are inferred to be due to several factors : wide range of Fe content in chlorite, fine-intergrowth of talc and chlorite, particle size problem, and other experimental variable parameters of HGMS.

요약 : 예산-공주-청양지역에는 여러 큰 규모의 활석 광상이 분포한다. 이 지역에서 산출되는 활석 광석은 초염기성암 기원의 사문암이 열수변질작용을 받아서 주로 생성된 것으로 알려져 있으며 녹니석, 운모, 각섬석 등의 규산염 광물들을 불순물로 다량 함유하고 있다. 활석 광석에 포함되어 있는 이들 함철규산염 광물들을 분리해 내고 활석 광석의 품질을 향상시키기 위하여 고구배자력분리방법을 실험적으로 적용함으로써 활석 광석의 정제법을 강구하고자 하였다.

활석광석을 구성하고 있는 광물들의 자기적, 광물학적 특성을 토대로 하여 인공 혼합 표준시료와 활석 광석 시료를 준비하고 이들을 대상으로 각각 실험하였다.

정제 실험 결과 고구배자력분리기를 통과한 정광의 경우 활석의 양이 증가하였고 다른 불순광물들의 양은 현저히 감소하였으며 활석 광석의 백색도에 있어서는 대흥광산의 원광석의 경우 60.6에서 65.5로, 평안광산의 경우 61.6에서 65.0으로, 신양광산의 경우 71.2에서 74.5로 향상되었다.

고구배자력분리방법에 의해 함철규산염광물들이 효과적으로 분리될 수 있으며 또한 초음파 처리를 병행하는 것이 효과적임이 실험적으로 밝혀졌다. 이러한 결과는 활석 광석의 백색도에 있어서 비록 커다란 향상이 있지는 않았지만 저품위 활석 광석에서 함철규산염광물이 제거될 수 있음을 시사해 준다. 백색도가 현저하게 향상되지 않은 원인은 활석 광석의 구성 광물들이 매우 광범위한 철분 함량을 가지고 있다는 사실과, 서로 유사한 결정구조를 갖기 때문에 서로 밀접하게 구조적으로 혼합되어 있어서 단체 분리가 어려운 점, 그밖에 고구배자력분리에 관한 매우 가변적인 실험적 변수 등의 측면에서 고찰될 수 있다.

INTRODUCTION

Many talc deposits occur in ultramafic rocks or magnesian carbonates in Korea. Among these, talc ores from magnesian carbonates are of good quality. On the other hand, the most abundant occurrence of talc, though very low grade, is in ultramafic rocks. Especially, there are some large talc deposits in the Yesan-Gongju-Cheongyang area. Talc ores of this area are known as products of hydrothermal alteration of serpentinite which was originated from ultramafic rocks(Chi et. al., 1977; Woo et. al., 1991).

Table 1 shows the characteristics of talc ores from three representative talc mines (Daeheung, Pyeongan, Sinyang) in this area. As shown in Table 1, the talc ores contain a lot of impurity minerals such as chlorite, phlogopite, amphibole, and serpentine, etc., so they show very low values of whiteness. Therefore these talc ores have been important objects of beneficiation study.

Table 1. Characteristics of the talc ores from three representative talc mines in the Yesan-Gongju-Cheongyang area.

	Daeheung	Pyeongan	Sinyang
Ore Form	massive, schistose, nodular	massive, schistose, nodular	banded, massive
Talc	++++++	++++++	++++++
Chlorite	++++	++++	+++
Phlogopite	++	+++	+
Tremolite	++	+	+
Serpentine	+	+	++
Dolomite	++	++	+
Magnesite	+	+	++
Calcite	+	+	+
Minor Minerals	Smectite, Chlorite/Smectite, Smectite/Illite, Magnetite, Chromite		

In the present study the high gradient magnetic separation (HGMS) method was applied to the beneficiation of the talc ore. The main purpose of this study is to separate the iron-bearing silicates from talc ore, to enhance the whiteness of talc, and ultimately to increase the commercial value of talc ores.

Magnetic separation is an old technique for the removal of iron and for the concentration of iron ores. Conventional magnetic separation devices are generally restricted to separating strongly magnetic materials, such as iron and magnetite. A recent advance in the technique of magnetic separation opens the way to applying it to the beneficiation of many minerals which are too fine and/or weakly magnetic to be economically separable by any existing method. The new technique is known as High Gradient Magnetic Separation (HGMS).

Since the advent of HGMS in the 1960s, the HGMS principles have been carefully investigated both theoretically and experimentally (Watson, 1975; Gerber & Birss, 1983; Obertuffer, 1973, 1974; Gerber, 1982; Kelland, 1973; Kolm, 1975). For example Friedlaender and Takayosu (1979) recorded the particles traces and particle build up on single wires by video. The HGMS has been developed, aiming at separating economically various materials that are only weakly magnetic and even some materials that are not magnetic at all down to colloidal particle size.

The separation capability of HGMS depends on numerous factors such as matrix configuration, field intensity, flow velocity, particle size, susceptibility and density, viscosity of the field media, magnetic field gradient and others (Nishijima et. al, 1987). The relationships between certain factors are examined experi-mentally in this work.

HGMS has already been used to the purification of kaolin (Kim et. al, 1987). Other potential applications include the desulfurization and deashing of coal, the decontamination of water, industrial waste and municipal sewage, and even the decontamination of rivers and lakes (Kelland, 1982; Trindade and Kolm, 1973; Bahaj et. al, 1991; Kerk et. al, 1982; de Latour, 1973; de Latour and Kolm, 1975). Superconducting magnets will ultimately be used for larger applications (Gerber, 1982; Watson and Hocking, 1975).

APPARATUS AND EXPERIMENTAL METHOD

The principle of operation of magnetic separation devices is the interaction between magnetic forces and competing gravitational, hydrodynamic, and interparticle forces within the magnetic separator (Oberteuffer, 1974). These forces are dependent on both the nature of the feed to be separated as well as the character of the separation device. The nature of the feed includes its size and magnetic susceptibility to an applied magnetic field. The character of the magnetic separation device includes both the design and its variable parameters, particularly the magnetic field and the process rate. In addition, another important physical property governing magnetic separation is the net force exerted on a magnetized particle by a magnetic field. According to Kolm (1975), it is proportional to three quantities: the intensity of the magnetic field, the volume of the particle and the gradient of the field, that is, the difference between the intensity of the field at one end of the particle and the intensity of the other. HGMS is based on the local field gradients produced by ferromagnetic matrices in external magnetic fields.

HGMS devices capable of separating even very weakly paramagnetic particles have been designed to maximize the magnetic forces. The HGMS used in the present study was manufactured in the Mineralogical Laboratory of Seoul National University. The schematic illustration of the experimental setup used in this study is shown in Fig. 1. A magnet designed to produce a strong adjustable field in the canister volume was used. The canister contains about 5 % by volume of ferromagnetic stainless-steel wool. Although other types of matrices are possible, filamentary ferromagnetic materials is used for two important reasons. First, they produce large surface areas of high magnetic gradients along their edges. Second, they resist compression and clumping in the applied magnetic field (Oberteuffer, 1973). The canister is situated in the region of maximum field paralleled to the axis of the magnet of solenoid type. When the diameter of the filament (cross section circular) is approximately 2.7 times as large as the feed particles, the magnetic forces are optimum (Nishijima et. al, 1987). In this work,

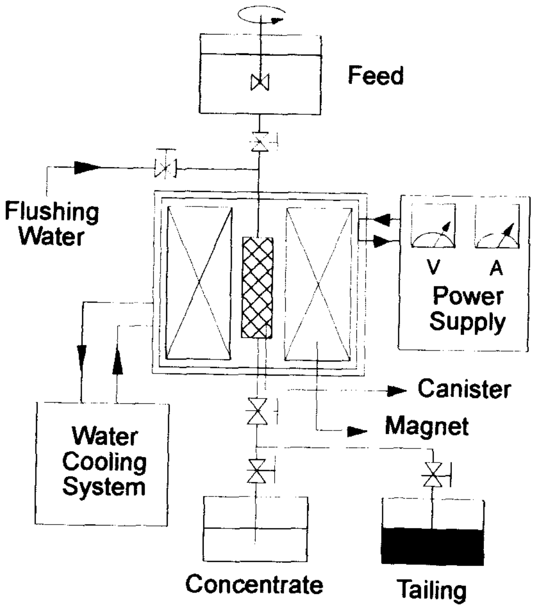


Fig. 1. Schematic illustration of experimental setup.

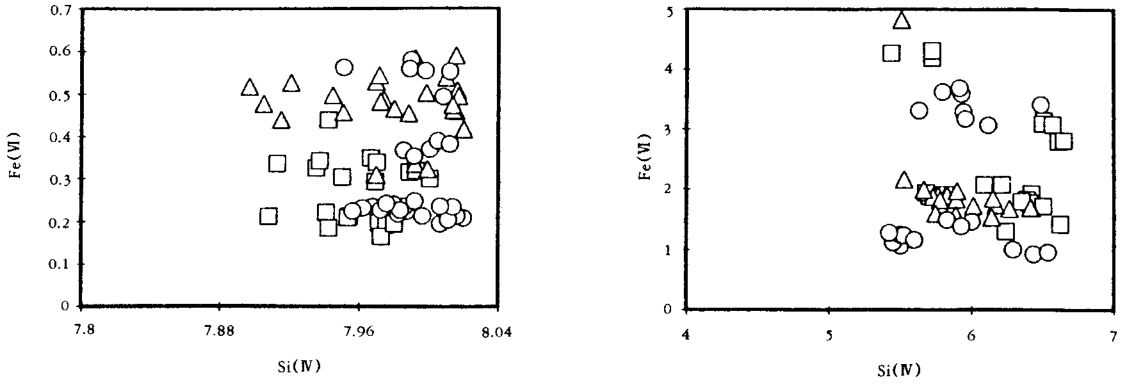
stainless steel wool of an average diameter 90μm was chosen. The cross section of the filament is not circular but triangular. Strong magnetic forces produced by the high field gradients at the edges of the filaments are effective in trapping very fine (<44 micron) particles of even very weakly magnetic substances. The feed in the form of fluid was controlled in the amount of flow with the valve and introduced into the canister which was set in the water-cooling system. Because of the very large void volume of the matrix the slurry is passed down easily through the canister while the magnetic components are efficiently trapped. The fluid and nonmagnetic particles pass through the relatively open structure of the matrix as tailings. When the matrix is saturated, the trapped materials are then easily removed from the matrix by decreasing the applied field to zero and washing the canister. Both the processed tailings and concentrates were examined in mineral composition to determine the extraction efficiency. After the canister was washed out sufficiently, the next extraction experiment was started.

Before the HGMS experiments are made, the chemical properties of the talc raw ores were investigated. Chemical compositions of the talc raw ores from the three representative talc mines of the study area are shown in Table 2. Their Fe contents vary from 5.73 to 8.31 wt%, which are much higher than those of talc ores originated from magnesian carbonates. DH O-1, PA O-1, and CD BLO samples were chosen for the typical ones of Daeheung, Pyeongan, and Sinyang (Cheongdang) mines respectively and they were used for the HGMS experiments. Fig. 2 shows Fe contents of main constituent minerals of the talc ores, and that these minerals have very wide range of Fe contents. As shown in Figs. 2(B), (C), (D), the impurity silicates such as chlorite, mica, and amphibole of the talc ores contain iron in considerable quantities, both in the ferrous and ferric state which substitutes for aluminum. In the absence of the iron, these silicates are diamagnetic but the iron is present in sufficient quantity to give a paramagnetic volume susceptibility. For example, iron-bearing kaolinite have a paramagnetic volume susceptibility 10^{-4} (MKS) (Watson and Hocking, 1975).

Standard samples as well as the artificial samples which have already known mineral composition were prepared for the XRD quantitative analysis. The artificial samples are the mixture of 80 wt% standard talc and 20 wt% each impurity silicate minerals. They were used for determining experimentally the pertinent separating condition. The efficiency of separation on different

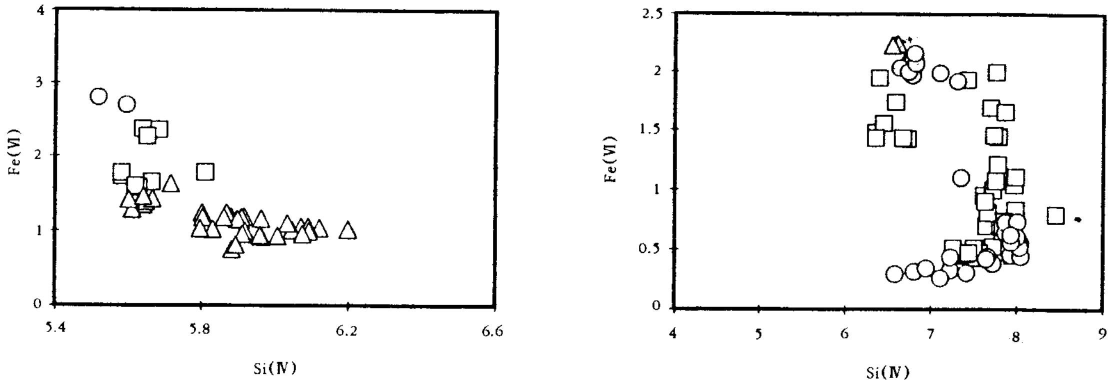
Table 2. Chemical compositions of talc raw ores.

	Daeheung		Pyeongan				Sinyang				
	DH O-1	DH-E23	PA O-1	PA O-2	PA O-3	PA-B15	CD BLO	CD BDO	CD-C2	CD-C5	CD-GR
SiO_2	50.59	52.57	49.42	45.05	34.51	54.59	38.23	33.81	40.20	44.17	57.89
Al_2O_3	5.55	3.44	4.71	5.11	1.65	2.88	9.33	0.72	0.61	7.62	0.91
Fe_2O_3	6.51	8.31	7.07	7.06	7.63	5.73	6.93	7.31	6.59	7.95	5.97
TiO_2	0.12	0.12	0.13	0.16	0.01	0.05	0.02	0.01	0.00	0.02	0.01
MnO	0.11	0.17	0.10	0.22	0.13	0.08	0.08	0.05	0.10	0.14	0.06
CaO	1.91	5.25	1.60	4.59	1.53	3.32	1.55	0.06	0.56	4.48	1.06
MgO	25.69	24.98	26.92	24.01	33.09	27.95	31.68	34.89	34.96	27.08	28.18
K_2O	2.07	0.12	1.45	0.35	0.01	0.03	0.06	0.00	0.00	0.01	0.01
Na_2O	0.34	0.01	0.24	0.00	0.00	0.04	0.00	0.00	0.00	0.00	0.00
P_2O_5	0.10	0.01	0.09	0.12	0.01	0.02	0.02	0.01	0.01	0.01	0.01
Ig Loss	6.46	4.07	8.06	13.14	20.99	4.53	11.29	22.68	16.08	7.30	5.22
Total	99.45	99.05	99.79	99.81	99.56	99.22	99.19	99.54	99.11	98.78	99.32



(A) Fe contents of talc

(B) Fe contents of chlorite



(C) Fe contents of mica

(D) Fe contents of amphibole

□ Daeheung mine △ Pyeongan mine ○ Sinyang mine

Fig. 2. Fe contents vs. Si(IV) of constituent minerals of talc ores.

currents was tested for these artificial samples.

All samples used were ground to -325 mesh. The 10 gr portion of the ground sample was dispersed in 2000 ml distilled water which was constantly stirred to maintain uniform density. This slurry was passed through the separator and the separated products were collected for further analysis or treatment.

The enhancement of the magnetism of iron-bearing silicates has been attempted by microwave irradiation (Zavitsanos et. al., 1978; Bluhm et. al., 1981; Ergun and Bean, 1968). Ergun and Bean (1968) showed enhancement of the magnetism of pyrite by selectively heating with microwaves. Though some different point of view, using the hydrophobic and hydrophilic properties of the constituent minerals, the experimental test for the ultrasonic treatment effect on the beneficiation by HGMS was also carried out. The objective of such performance was to make HGMS separation more effective.

The whole experimental method is illustrated on a flow chart in Fig. 3.

RESULTS AND DISCUSSION

In order to study the magnetic and mineralogical properties of the magnetically pro-

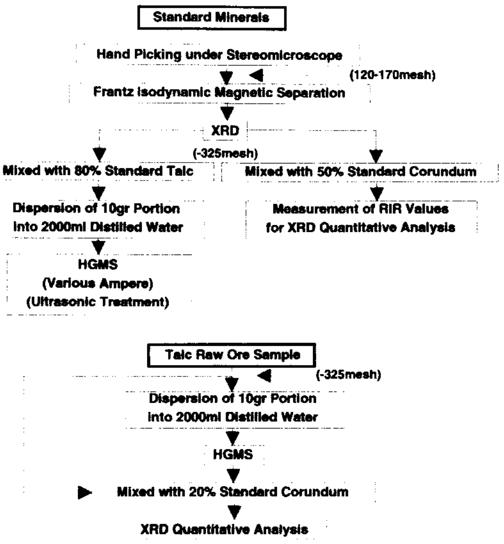
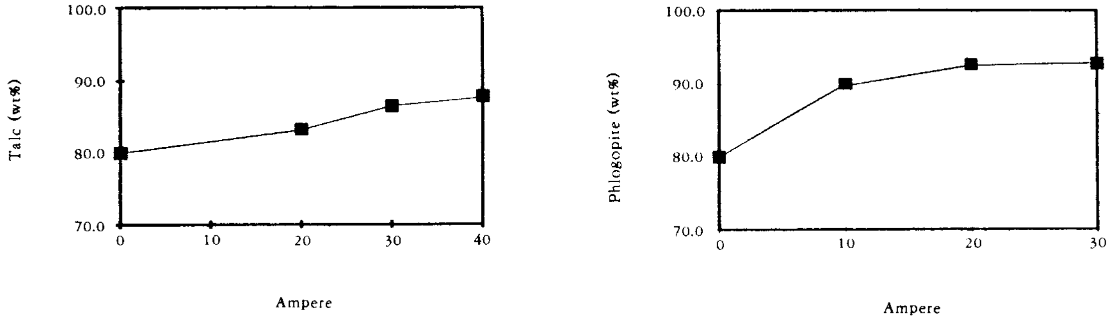


Fig. 3. Experimental method for beneficiation of talc ores.

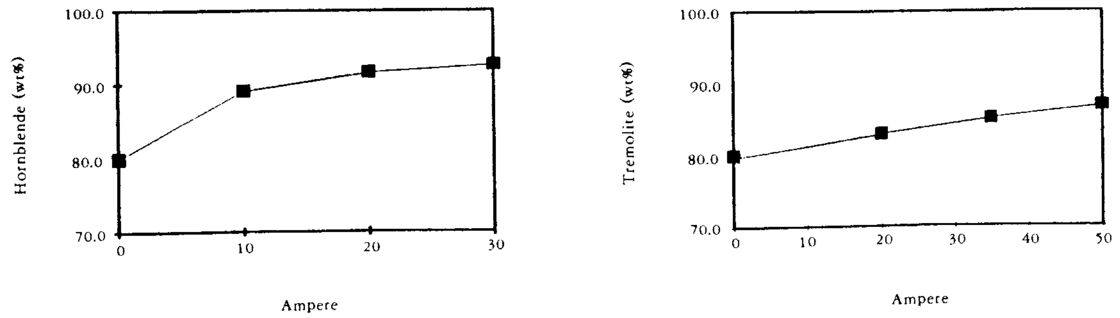
cessed fractions the samples were examined experimentally from three aspects: the capture efficiency as a function of the applied magnetic field, the change of mineral composition examined by XRD quantitative analysis, and the improvement of whiteness.

The effects of the external magnetic fields on extraction efficiency are shown in Fig. 4. Though the recovery of the magnetic component increased with applied field and decreased with increasing flow velocity, the proper current range and flow velocity was from 20 to 30 ampere and 200ml/min, respectively on an economic point of view. In practical application, it would be possible to extract several minerals at the same time depending on the particle size and susceptibility. The materials of different susceptibility can be



(A) Talc(80)-Chlorite(20) Mixture

(B) Talc(80)-Phlogopite(20) Mixture



(C) Talc(80)-Hornblende(20) Mixture

(D) Talc(80)-Tremolite(20) Mixture

Fig. 4. HGMS separation of talc from the artificially-mixed standard samples.

separated by stepwise changing of the magnetic gradient of the applied field. The magnetic forces to the particles can be controlled depending on the size and the susceptibility by this method.

Fig. 5 shows the mineral compositions of magnetically processed tailings and the magnetically and ultrasonic treated tailings. As previously mentioned, because talc as well as other impurity minerals contains variable amount of iron, a large amount of talc was included in both tailings. However, talc in the ultrasonic treated tailings was decreased remarkably. This indicates that beneficiation of talc ores can be improved by ultrasonic treatment.

Table 3 presents the comparison of mineral compositions between raw talc ores and concen-

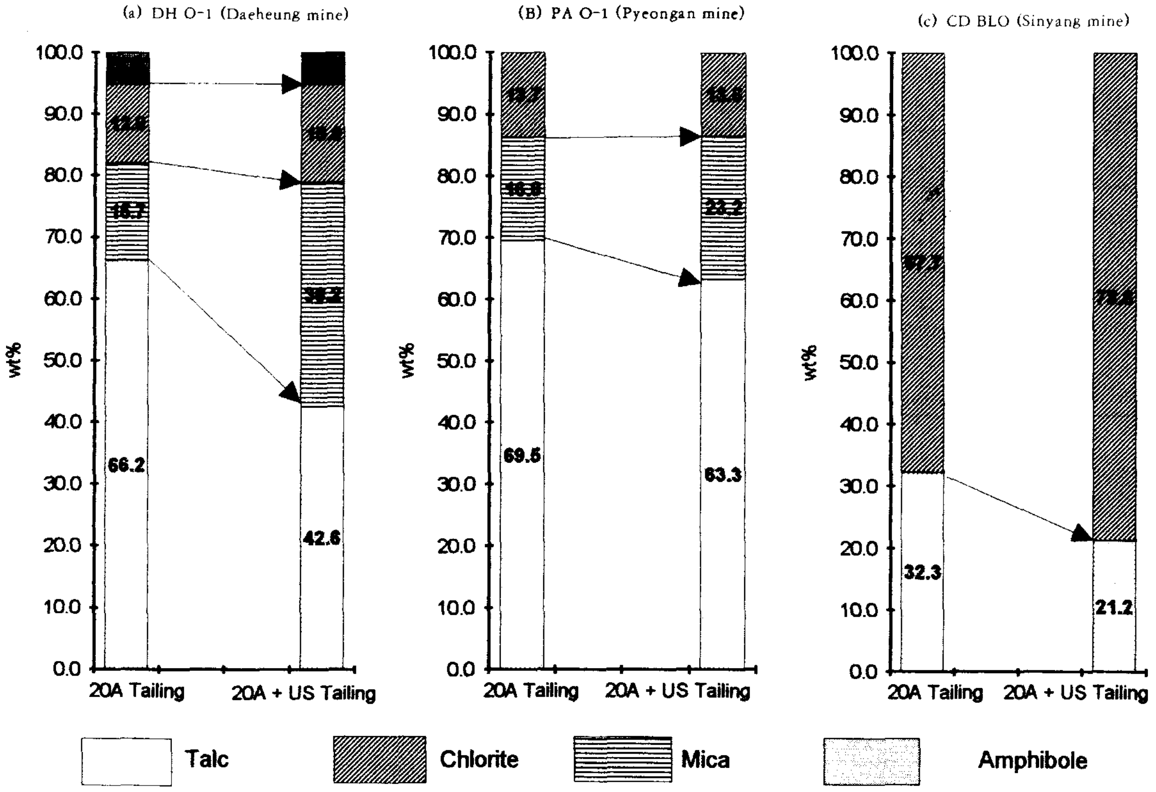


Fig. 5. Comparison of mineral compositions of raw ores and tailings.

Table 3. X-ray quantitative analyses of talc raw ores and concentrates.

	DH O-1		PA O-1		CD BLO	
	Raw(%)	Concentrate(%)	Raw(%)	Concentrate(%)	Raw(%)	Concentrate(%)
Talc	66.7	80.7	68.7	84.6	37.5	57.2
Chlorite	11.1	8.9	10.5	8.6	57.0	40.1
Mica	14.9	8.9	10.3	4.8	0.4	0.5
Amphibole	5.1	0.5	0.0	0.0	0.0	0.0
Serpentine	0.0	0.0	0.0	0.0	0.0	0.0
Calcite	0.7	0.2	0.0	0.0	0.0	0.0
Dolomite	1.4	0.8	4.5	0.8	5.0	2.3
Magnesite	0.0	0.0	5.9	1.3	0.0	0.0

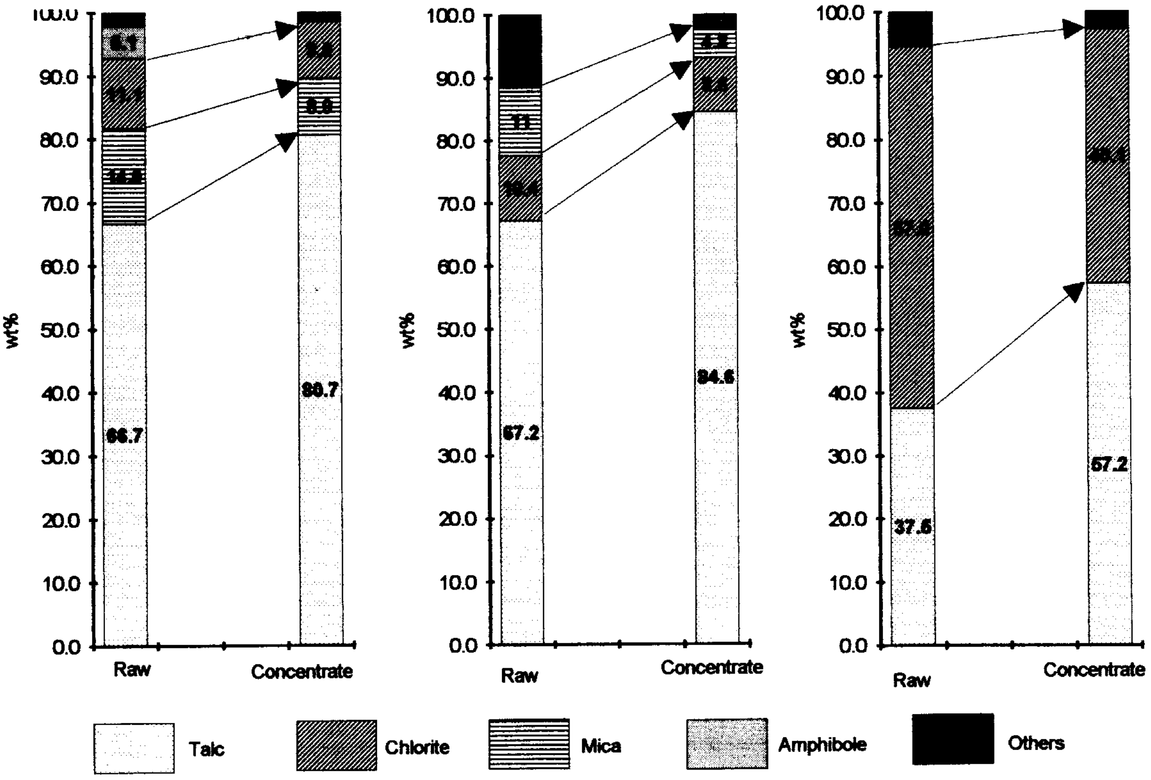


Fig. 6. Comparison of mineral compositions of raw talc ores and concentrates at 20 A.

Table 4. Whiteness of talc raw ores and concentrates.

	Daeheung (DH O-1)	Pyeongan (PA O-1)	Sinyang (CD BLO)
Raw Ore	60.6	61.1	71.2
Concentrate	65.5	65.0	74.5

trates. Talc was increased and impurity silicates were decreased notably in HGMS processed concentrates. These results are conspicuously shown in Fig. 6.

Whiteness of talc ores was increased from 60.6 to 65.5 for the Daeheung talc ore, from 61.1 to 65.0 for the Pyeongan talc ore, and from 71.2 to 74.5 for the Sinyang talc ore (Table 4). However, as shown in Table 4, the improvement in whiteness was not so good as expected. The reasons for the insufficient increment in whiteness are inferred from several aspects.

First, the main impurity mineral lowering the value of whiteness is the most abundant chlorite. Chlorites in the talc ores from the study area belong to clinochlore (Fig. 2 (B)), but they can be divided into two groups: clinochlore and Fe-rich clinochlore. Chlorites of two groups may have different behaviors for the applied magnetic field. In the external magnetic field Fe-rich clinochlore is well trapped in the matrix whereas clinochlore passes easily through the matrix. So the clinochlore behaving in the same manner as talc is the main factor for the low whiteness of the HGMS processed concentrates.

Second, all of the main constituent minerals of the talc ores have similar crystal structure. Under the microscope they are interlayered and/or admixtures of very fine particles. Therefore, in order to liberate into monomineral particles the particles should be finer.

Finally, the trapping efficiency of even a simple separator depends on a number of variables. These include the external magnetic field, the superficial slurry flow velocity, the amount of material already trapped in the matrix, the nature and geometry of the matrix, and the relative direction of the applied magnetic field. The nature of the slurry fluid and magnetic and physical properties of its components will also affect the characteristics of the separation. It seems that the more investigation on the relation of these variables should be performed.

CONCLUSIONS

The applicability of high gradient magnetic separation (HGMS) to talc ore beneficiation was examined experimentally in this study. This magnetic processing increased the whiteness of the talc ores from 60.6 to 65.5 for the Daeheung talc ore, from 61.6 to 65.0 for the Pyeongan talc ore, and from 71.2 to 74.5 for the Sinyang talc ore.

It has been confirmed experimentally that the Fe-bearing silicates can be separated efficiently with HGMS and that the additional ultrasonic treatment could improve beneficiation of talc ores. These results strongly suggest that Fe-bearing silicates can be separated from low grade talc ores, even though the result of the experiment for the improvement of whiteness was not so good enough.

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