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Recovery of titanium from beach sand by physical separation

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ABSTRACT

Extensive experimentation has been carried out in order to optimise the application of various separators, namely magnetic, electrostatic and gravity separators, to the beneficiation of titanium bearing minerals from the beach sand deposits of Sri Lanka. An improved flowsheet was established for the recovery of titanium bearing minerals from the deposit, producing commercial grade ilmenite concentrates (up to 63.7% TiO_2) and rutile grade concentrates (up to 93.4% TiO_2). It was found that, for fine particles, the titanium grade increased greatly when titanium-bearing minerals were separated from the deposit by a Knelson concentrator. The result of the mineralogical and chemical analysis studies for the beach sand deposit revealed that, more than 99% of titanium content of the deposit was contained in the particle size less than 355 microns. © 2004 SDU. All rights reserved.

Keywords: Titanium; Recovery; Beach sand; Physical separation

1. INTRODUCTION

Ilmenite ($FeTiO_3$) and rutile (TiO_2) are the only naturally occurring titanium bearing minerals that have been seriously considered as suitable feedstock for either the titanium metal producing or titanium pigment industries (Ismail *et al.*, 1983). Ilmenite commonly occurs altered to mixtures of TiO_2, FeO and Fe_2O_3, with the TiO_2 content increasing from 49 to 75% as the mineral oxidises and iron is leached out by groundwater. Altered ilmenite (60-75% TiO_2) is usually amorphous, but the leucoxene (76-90% TiO_2) stage begins to show the definite crystalline structure of rutile.

The name "pseudorutile" has been proposed for ilmenite alteration products containing 75-92% TiO_2 (Anon, 1988; Jayawardana, 1998). The bulk of the world's production of titanium minerals is derived from beach sands (Anon, 1988). Beach sand deposits available in Sri Lanka have been known for many years as rich sources of many industrial minerals such as ilmenite, rutile, zircon, monazite, garnet and sillimanite (Herath, 1996; Jayawardane, 1998). The major deposits are in the north-east coast at Pulmoddai in Sri Lanka, which have been exploited economically since 1958 (Meyer, 1983; Lanka Mineral Sand Ltd., 1999). In Sri Lanka, separation of beach sands into its constituent minerals at the Pulmoddai mineral separation plant is accomplished through a combination of gravity, magnetic and electrostatic methods. Wet spiral concentrators are employed to separate light fragments like quartz and fine seashells from the heavy minerals.

Ilmenite is recovered from the concentrate using wet magnetic separation, after drying, the non-magnetic concentrate is passed through electrostatic separators to separate rutile and zircon (Lanka Mineral Sand Ltd., 1999). In some plant operations, dry magnetic separation is employed, particularly for recovering of titanium bearing minerals such as ilmenite and leucoxene from heavy mineral concentrates (Stradling, 1991). However, flowsheets for the recovery of titanium bearing minerals from beach sands differ with respect to the sequence of operations according to the mineralogical characteristics of the beach sand deposit (Jain, 1987).

Since only a few investigations have so far been carried out, there is still lack of detailed data on the beneficiation process of titanium bearing minerals from beach sand deposits of Sri Lanka. The objective of this investigation was to study mineralogical and chemical characteristics of the beach sand deposits from Sri Lanka. This study was also intended to investigate the application and optimisation of different separators, namely magnetic, electrostatic and gravity separators, to establish an improved flowsheet for the recovery of titanium bearing minerals from the deposit effectively and efficiently.

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2. EXPERIMENTAL

2.1. Mineralogical and chemical analysis

The heavy mineral beach sand sample from Pulmoddai deposit in Sri Lanka, which was supplied by Lanka Mineral Sand Ltd., was used for this experimental work.

Particle size analysis was carried out on beach sands by the dry sieving method. The particle size fraction 63-355 microns was considered for the mineralogical and chemical analysis. These were carried out according to the flowsheet given in Figure 1. Dense medium separation was first carried out using 1,1,2,2 -tetrabromoethane (TBE) for the float sink analysis. Heavy fraction from dense medium separation was used for the low intensity magnetic separation using a hand magnet to separate highly magnetic minerals. The remaining non-magnetic fraction has been separated into four individual fractions employing a Cook isodynamic magnetic separator (Figure 2) at 0.1, 0.3 and 0.5 tesla magnetic field strengths.
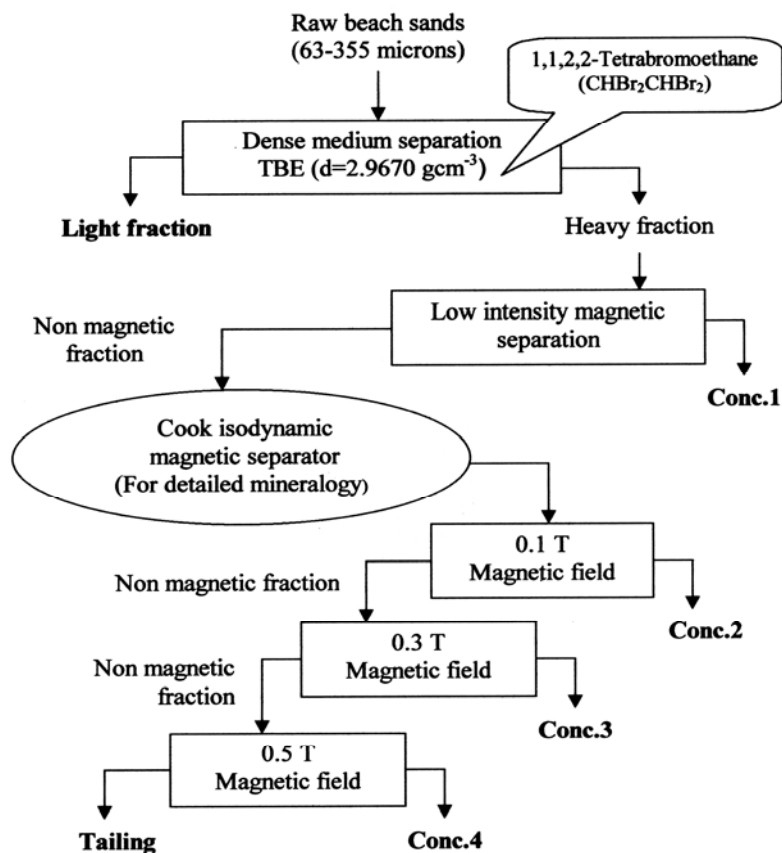

Figure 1. Flowsheet of mineralogical analysis of beach sand

The six fractions separated for mineralogical analysis were chemically assessed to determine titanium and iron content. Mineral samples were decomposed by fusion with $KHSO_4$ at 800°C and the melt was dissolved in 20% H_2SO_4 acid (Jeffery and Hutchison, 1981). Titanium analysis was carried out in a UV/ Visible Spectrophotometer based on the yellow colour complex formed by titanium with H_2O_2 (Mendham *et al.*, 2000). Total iron was analysed utilising an Atomic Absorption Spectrophotometer. The relative errors of analysis of titanium and iron were ± 3.5% and ± 2.0% respectively.

X-ray powder diffraction techniques, employing a Philips Analytical X-ray machine were used to examine each individual fraction to determine mineral phases.
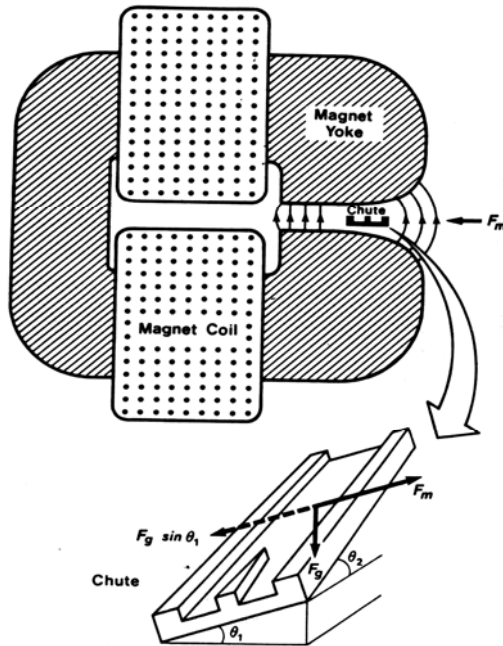
Figure 2. Cook isodynamic magnetic separator

2.2. Magnetic separation

A disc magnetic separator (Wills, 1992) was employed to separate paramagnetic titanium bearing minerals from the deposit. In this separator magnetic field strengths up to 0.8 tesla were attainable in the gap between disc and flat pole stationary magnets placed below the disc. Representative beach sand samples were used for this test work. Samples were fed through a vibrating feeder. Magnetic minerals were picked up and transported by the revolving disc and deposited as a magnetic fraction, whereas non magnetic materials followed the path of the feed and were discharged by gravitational force.

2.3. Electrostatic separation

Electrostatic separation was carried out utilising a high-tension roll separator (Kelly and Spottiswood, 1989; Wills, 1992) for the recovery of conductive titanium bearing minerals from the deposit. The applied voltage on the electrode was varied from 14 to 26kV, keeping the other equipment variables constant (rotor speed was 100rpm and polarity of the electrode was negative). This unit used corona-charging technique to charge particles. Three size fractions of beach sand (-355+250, -250+125 and −125+63 microns) were used for this test work. Representative samples were fed through a vibrating feeder and particles passed through a corona zone and acquired a charge of similar polarity. Conductive particles lost their charge on an earthed rotor surface and were thrown clear by the rotation of the rotor as a conductive fraction. The remaining fraction consisting of non-conductive charged particles were held on the rotor surface and discharged via a brush.

2.4. Density separation

2.4.1. Mozley table

A 'V' profile Mozley table gravity separator was used to separate titanium bearing minerals from the deposit. Three-size fractions of beach sands (-355+250, -250+125 and −125+63 microns) were used for this test work. A representative sample of beach sands was used for each test run. Only table shaking processing time was varied, keeping the other equipment variables constant (table shaking speed was 70rpm, table slope was 2 degree and water flow rate was 1.2L/min). High-density particles sank to the tray surface and were thrown towards the upstream end of the tray by the knock action. Low-density particles were carried down the tray by the flow of irrigation water to discharge via the launder.

2.4.2. Knelson concentrator

The second technique employed in gravity separation was Knelson concentrator for the beneficiation of titanium bearing minerals from the deposit. The Knelson concentrator is a compact centrifugal separator with an active fluidised bed to capture heavy minerals (Knelson, 1992; Knelson and Jones, 1994). It contained of a central perforated cone containing horizontal ribs along the inside wall. Two size fractions of beach sand (-250+125 and −125+63 microns) were subjected to testing on the Knelson concentrator. The applied water pressure which was the main control variable of the unit was varied from 41.4 to 82.8kPa in this study. A representative sample of beach sand was fed into the concentrator for each test run. Heavy particles were forced out against the walls and were trapped between ribs. Lighter particles were carried out, over the top of the cone, by the water flow.

3. RESULTS AND DISCUSSION

3.1. Mineralogical and chemical analysis

Particle size distribution of Sri Lankan raw beach sand was investigated. A maximum of 29.1% by weight of raw beach sand was found in particle size fraction of -125+90 microns. It was found that more than 71% mass of raw beach sands is attributable to particle size less than 355 microns (Table 1). Therefore, in the recovery of titanium minerals from the deposit comminution process is not needed due to weathering and natural concentration of the beach sand deposit.

Table 1
Titanium and iron distribution of beach sand

Sieve aperture size (microns)	Weight (%)	Ti grade (%)	Ti distribution (%)	Fe grade (%)	Fe distribution (%)
+1000	16.2	0.43	0.37	3.82	6.43
-1000 +710	3.6	0.28	0.05	1.32	0.49
-710 +500	3.9	0.33	0.07	1.29	0.52
-500 +355	5.1	0.55	0.15	1.51	0.81
-355 +250	6.8	2.85	1.03	3.00	2.11
-250 +180	8.5	10.74	4.92	6.72	5.97
-180 +125	14.1	26.50	20.02	12.11	17.76
-125 +90	29.1	34.20	53.36	14.55	44.07
-90 +63	11.1	30.54	18.09	16.88	19.41
-63	1.6	21.87	1.93	14.09	2.42
Total	100.0		100.00		100.00

The titanium and iron distribution of raw beach sand was studied. The results of titanium and iron distribution in different size fractions of raw beach sand are presented in Table 1. It was found that titanium and iron assays were 0.43% and 3.82% respectively in the +1000 microns particle size fraction. No obvious change in titanium and iron grades was observed for the particle size fractions of −1000+710, -710+500 and -500+355 microns. In all these three fractions, titanium grade was less than 1%. The highest titanium assay (34.20%) was found in the particle size fraction of −125+90 microns. According to the titanium distribution of the deposit, more than 99% of titanium content of the deposit was contained in the particle size fraction less than 355 microns.

Therefore, particle size less than 355 microns of raw beach sand is selected for economical recovery of titanium from the deposit by physical and chemical processing. Chemical and mineralogical analysis of Sri Lankan beach sand deposit was investigated and results are given in Table 2 and Table 3.

Dense medium separation of beach sand in the −355+63 microns size range gave a light fraction (density<2.9670g/cm^3) of 23.5% by weight. Only quartz was found in this light fraction according to the X-ray diffraction analysis dada given in Table 3. The titanium (1.13%) and iron (1.99%) content in the light fraction is partly due to the presence of lock particles and inefficient separation.

Low intensity magnetic separation of raw beach sand using a hand magnet (0.04 tesla magnetic field strength) displayed that less than 1% mass of highly magnetic minerals is present in the deposit. The magnetite and the ilmenite minerals were found in this magnetic fraction (Conc.1).

Table 2
Chemical analysis of different fraction of beach sand (refer to Figure 1)

Mineral fraction	Weight (%)	Ti grade (%)	Fe grade (%)
Light fraction	23.5	1.13	1.99
Conc.1	0.7	19.47	40.42
Conc.2	13.8	37.07	25.69
Conc.3	25.5	38.54	24.77
Conc.4	15.5	39.29	17.73
Tailing	21.0	28.33	2.3

Table 3
X-ray diffraction analysis of different fraction of beach sand (refer to Figure 1)

Mineral fraction	Mineral phases (Types of minerals)
Light fraction	Quartz (SiO_2)
Conc.1	Magnetite (Fe_3O_4), Ilmenite ($FeTiO_3$)
Conc.2	Ilmenite ($FeTiO_3$)
Conc.3	Ilmenite ($FeTiO_3$), PseudoRutile ($Fe_2Ti_3O_9$)
Conc.4	Ilmenite ($FeTiO_3$), PseudoRutile ($Fe_2Ti_3O_9$)
Tailing	Rutile (TiO_2), Zircon ($ZrSiO_4$)

The magnetic fractions: Conc.2, Conc.3 and Conc.4 separated by a Cook isodynamic magnetic separator at different magnetic field strengths contain the bulk of the ilmenite. According to the chemical analysis only insignificant variations of the titanium content occur in these three different fractions, whereas the iron content decreases substantially with increasing field intensity (Table 2). An X-ray diffraction analysis of these three samples revealed that Conc.2 contained only ilmenite, whereas ilmenite and pseudorutile were present in Conc.3 and Conc.4.

The non-magnetic fraction (Tailing) separated at field strength of 0.5 tesla in the Cook isodynamic magnetic separator contained 28.33% titanium and 2.3% iron. Only rutile and zircon was confirmed as being present in this tailing fraction.

3.2. Magnetic separation

The recovery and the grade of titanium in different magnetic fractions are shown in Figure 3 when paramagnetic titanium bearing minerals were separated from raw beach sand of particle size less than 355 microns, employing the disc magnetic separator. In this study titanium grade in magnetic fraction was increased from 33.2% to 38.3% with increasing magnetic field strength from 0.2 to 0.8 tesla.
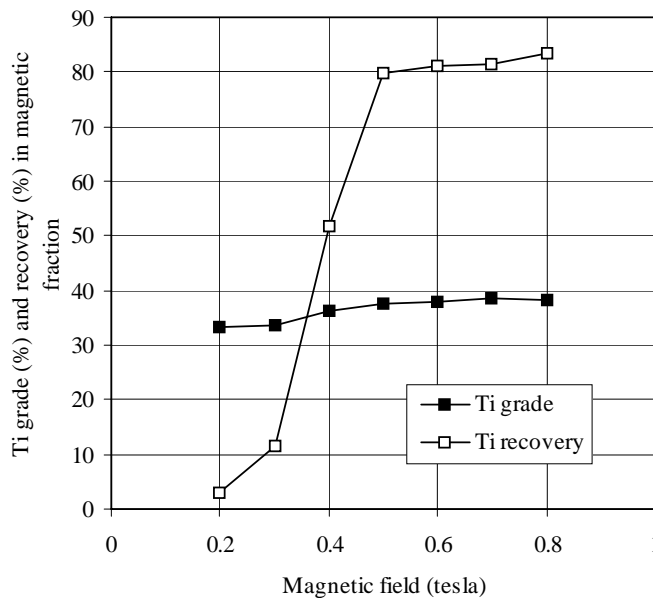

Figure 3. Ti grade and recovery in magnetic fraction from disc magnetic separation

There is a significant improvement in recovery of titanium in magnetic fraction with increasing the magnetic field strength up to 0.5 tesla. The recovery of titanium was 79.8% with a grade of 37.6% during 0.5 tesla magnetic field strength. The recovery and the grade of titanium in magnetic fraction changed slightly from 0.5 to 0.8 tesla magnetic field strength.

However, using the disc magnetic separator at the maximum field strength of 0.8 tesla, the maximum recovery of titanium was 83.4% with a grade of 38.3%. Therefore, magnetic field strength of 0.5 tesla was considered as the optimum condition for the recovery of paramagnetic titanium bearing minerals from beach sand using a disc magnetic separator.

3.3. Electrostatic separation

Figures 4 and 5 present the grade and recovery of titanium in different conductive fractions when conductive titanium bearing minerals were separated from raw beach sand using a high-tension separator. The titanium grade in the conductive fraction increased from 8.0% to 29.9% with increasing applied voltage from 18 to 26kV, whereas the titanium recovery varied from 87.5% to 53.6% over this range of applied voltage for the −355+250 microns size fraction of beach sand. Therefore, for the separation of conductive titanium bearing minerals from beach sand with a maximum grade of 29.9%, 26kV can be used as the optimum voltage in high-tension separation for the particle size fraction of −355 to +250 microns.
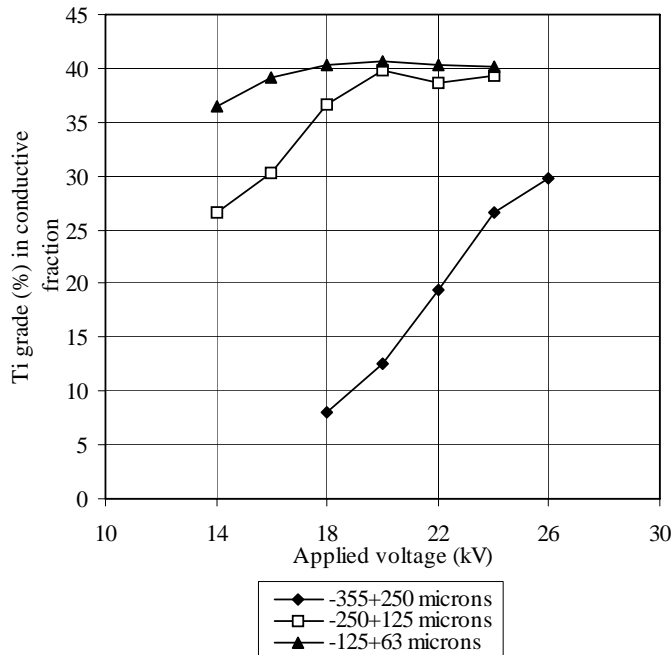

Figure 4. Ti grade in conductive fraction from high-tension separation

For the −250+125 microns size fraction of raw beach sand, the titanium grade increased from 26.5% to 39.9% in the conductive fraction with increasing applied voltage from 14 to 20kV. There was no significant variation in grade of titanium in the conductive fraction above the applied voltage of 20kV. A grade of titanium of 39.9% was achieved with a recovery of 28.4% in the conductive fraction for this size fraction. Therefore, for the particle size fraction of −250+125 micron of beach sand, an applied voltage of 20kV was considered as the optimum condition for the beneficiation of titanium bearing minerals from the deposit.

For the particle size fraction of −125+63 microns of raw beach sand; a titanium grade of 40.3% was achieved in conductive fraction at the applied voltage of 18kV. There was no obvious change in titanium grade above the applied voltage of 18kV, whereas titanium recovery was 23.8% in the conductive fraction at this applied voltage. Therefore, an applied voltage of 18kV was used as the optimum condition for the recovery of titanium in the −125+63 size fraction of the beach sand deposit.

The operating conditions for these tests were optimised, however this study showed that titanium recovery decreased in the conductive fraction with decreasing particle size.
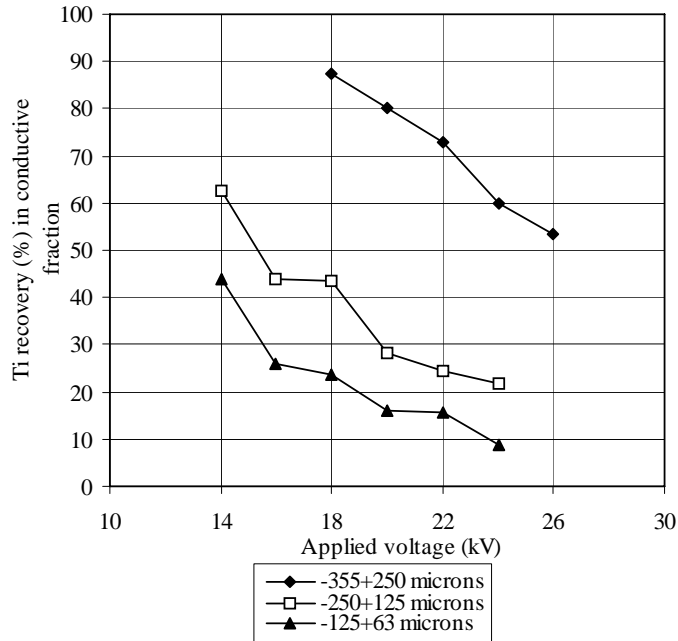
Figure 5. Ti recovery in conductive fraction from high-tension separation

3.4. Density separation

3.4.1. Mozley table

Figures 6 and 7 show the grade and recovery of titanium in different heavy fractions when titanium-bearing minerals were separated from beach sand using the Mozley table separator.
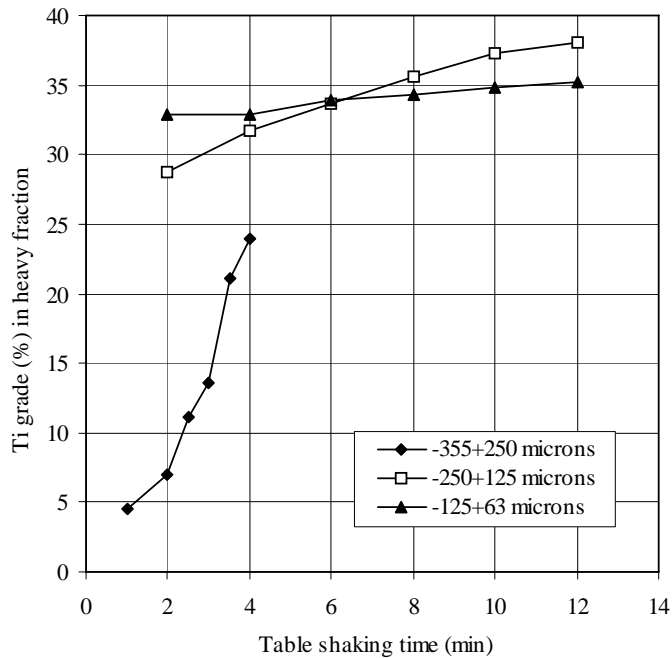

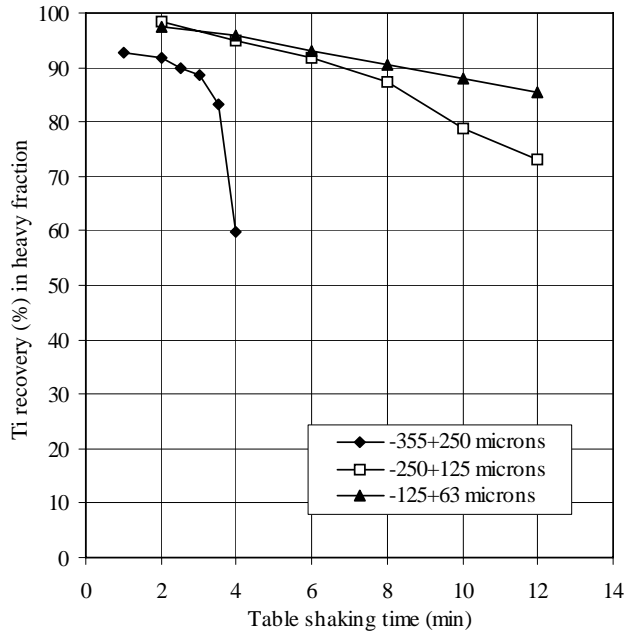Figure 6. Ti grade in heavy fraction from Mozley table separation

Figure 7. Ti recovery in heavy fraction from Mozley table separation

For the -355+250 microns particle size fraction of raw beach sand; the titanium grade in the heavy fraction increased from 4.5% to 23.9% with increasing table shaking time from 1 to 4 minutes. However, there was a sudden and significant decrease in recovery of titanium after table shaking time of 3.5 minutes for this particle size fraction. The titanium grade was 21.1% with a recovery of 83.4% in the heavy fraction for table shaking time of 3.5 minutes. Therefore, a table shaking time of 3.5 minutes was considered as the optimum condition for the recovery of titanium bearing minerals for the −355 to +250 microns particle size fraction.

The titanium grade in the heavy fraction increased from 28.7% to 38.0% with increasing table shaking time from 2 to 12 minutes, whereas the titanium recovery decreased from 98.4% to 73.0% over this period of table shaking time for the −-250+125 microns size fraction of beach sand. Therefore, for the particle size of −250+125 microns, a table-shaking time of 10 minutes was optimised for the recovery of titanium minerals. For this size fraction, the titanium grade was 37.1% with a recovery of 78.6% in heavy fraction for table shaking time of 10 minutes.

There was no obvious improvement in the grade of titanium in the heavy fraction for the −125+63 microns size fraction of beach sand with increasing table shaking time, whereas the titanium recovery in the heavy fraction decreased gradually with table shaking time. Therefore, Mozley table can not be employed effectively for fine particle size fraction (-125+63 micron) to beneficiate titanium bearing minerals from the beach sand deposit.

3.4.2. Knelson concentrator

The grade and the recovery of titanium in different heavy fractions are shown in Figures 8 and 9 when titanium-bearing minerals were separated from raw beach sand employing the Knelson concentrator.

The titanium grade in the heavy fraction increased from 35.0% to 40.3% with increasing water pressure from 41.4 to 62.1kPa, whereas the titanium recovery decreased from 96.2% to 79.6% over this range of water pressure for the −125+63 microns size fraction of beach sand. Experimental data showed that there was a sudden and significant decrease in recovery of titanium in heavy fraction above 62.1kPa water pressure. There was also no obvious change in the grade of titanium in heavy fraction above 62.1kPa for this particle size fraction. Therefore, a water pressure of 62.1kPa was considered as the optimum condition for the beneficiation of titanium bearing minerals for the −125+63 microns particle size fraction.

For the particle size fraction of −250+125 microns of raw beach sand; the maximum titanium grade of 35.8% was achieved in the heavy fraction at a water pressure of 82.8 kPa, whereas the titanium recovery in this fraction was 32.0%. Therefore, for the −250+125 microns size fraction of beach sand, employing a Knelson concentrator to beneficiate titanium bearing minerals is not effective compared to the Mozley table.

However, for fine particles, the titanium grade increased greatly when titanium-bearing minerals were separated from the deposit by a Knelson concentrator.
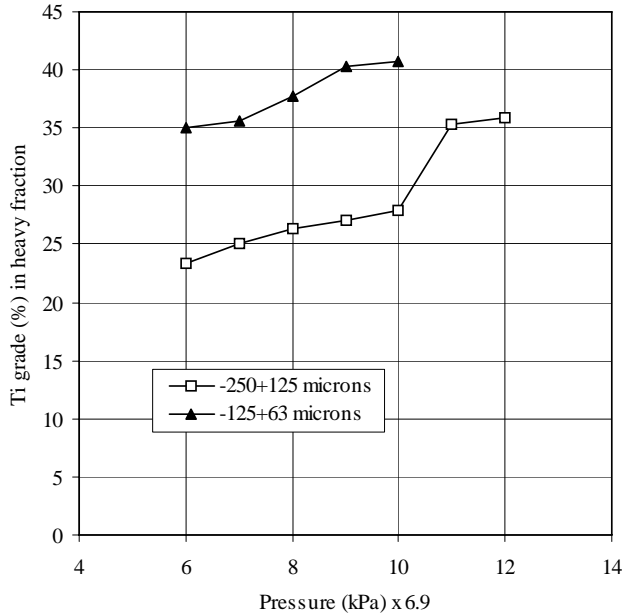

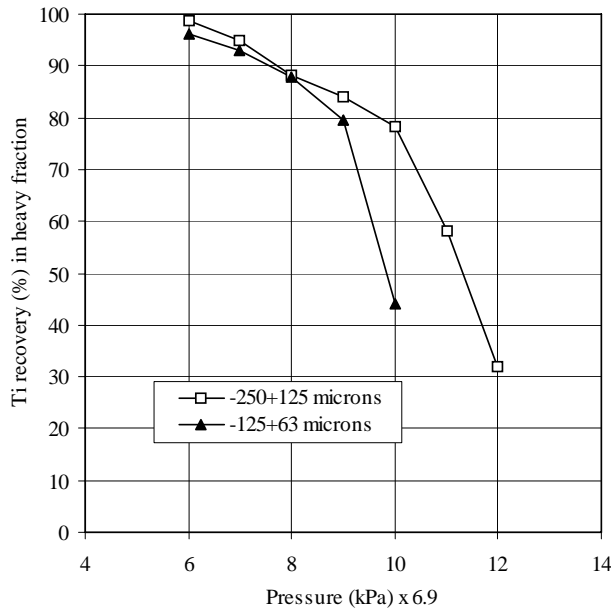Figure 8. Ti grade in heavy fraction from Knelson concentrator

Figure 9. Ti recovery in heavy fraction from Knelson concentrator

The flowsheet established for the beneficiation of titanium bearing minerals from the beach sand deposit is presented in Figure 10. In this investigation, a commercial grade ilmenite concentrate (up to 63.7% TiO_2 with 27.9% Fe) was achieved using a disc magnetic separator at a magnetic field strength of 0.5 tesla, avoiding unnecessary processing and operating cost.

The Mozley table separator at its optimised operation conditions was employed for upgrading titanium-bearing minerals only for −355+250 and −250+125 microns size fractions. The Knelson concentrator, for fine particles size fraction (-125+63 micron), was used for further beneficiation of titanium bearing minerals. However, recoverable titanium bearing minerals left as ilmenite or pseudorutile in upgraded heavy fractions were separated using the disc magnetic separator at a field strength of 0.7 tesla. Two concentrates of commercial standard (up to 55.3% TiO_2 with a particle size of −250+125 microns and up to 63.1% TiO_2 with a particle size of −125+63 microns) were achieved at this magnetic field strength.

Finally, two commercial standard rutile grade concentrates were achieved employing a high-tension separator. Then, a rutile grade concentrate (up to 93.4% TiO_2 with 1.1% Fe) with a particle size of −250+125 was produced at an applied voltage of 20kV. The second rutile grade concentrate (up to 90.9% TiO_2 with 1.7 % Fe) with a particle size of −125+63 microns was achieved at an applied voltage of 18kV. However, recovery of titanium in two-rutile grade concentrates was comparatively low. One possible way towards increasing the recovery of titanium in these concentrates is a multiple pass separation, which is a costly procedure.

4. CONCLUSIONS

The behaviour of the various titanium bearing mineral phases from beach sand deposits of Sri Lanka was monitored on standard and novel magnetic, electrical and gravitational processing equipment.

It was found that, for fine particles, the titanium grade increased greatly when titanium-bearing minerals were separated from the deposit by a Knelson concentrator. An improved flowsheet was established that produced commercial grade concentrates for the beneficiation of titanium bearing minerals from the deposit.

Commercial grade titanium concentrates (up to 63.7% TiO_2) were achieved employing a disc magnetic separator. A successful separation of commercial standard rutile grade concentrates (up to 93.4% TiO_2) was achieved by magnetic, gravity and electrical combined separation.

It was found that more than 99% of titanium content of the deposit was contained in particle size less than 355 microns. X-ray diffraction analysis was utilised to ascertain the mineral phases occurring in the beach sand deposit. Only quartz, magnetite, ilmenite, pseudorutile, rutile and zircon were confirmed as being present.

ACKNOWLEDGEMENTS

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