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Characterisation and separation studies of Indian chromite beneficiation plant tailing

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A B S T R A C T

Detailed characterisation and recovery of chromite from the beneficiation plant tailing of Sukinda, India, was investigated. Different characterisation techniques viz. size analysis, size-wise chemical analysis, size-wise density measurement, X-ray diffraction analysis, heavy liquid separation, scanning electron microscopy, mineral analysis by QEMSCAN and thermo gravimetric analysis were carried out. Based on the results, two flow sheets comprising gravity, magnetic separation and flotation, were used to recover chromite values. A chromite concentrate of 45.0% Cr_2O_3 with a Cr:Fe ratio of 2.3 can be produced from the tailing analyzing 17.0% Cr_2O_3 and Cr:Fe ratio of 0.49.

1. Introduction

Chromite is the main source for chromium metal and chemicals and for use in refractories. Based on certain physical and chemical properties, the ore is classified for different users. The total chromite deposits of the world and beneficiation prospects have been described by various authors (Atalay and Ozbayolu, 1992; Guney et al., 2001; Murthy et al., 2011). India is the world's third largest producer of chromite ore and produces about 3.5–4 MTPA. The estimated reserve of chromite deposit in India is about 187 MT. About 98% of the reserves are from the Sukinda valley of Odisha, which is noted for its complex mineralogy (Murthy et al., 2011). During the beneficiation of chromite ore of Sukinda region, approximately 50% (by weight) of the total feed is discarded as tailing which contains a significant amount of chromite. Several studies have focused on reduction of chromite losses in the beneficiation plant tailing (Rao et al., 1987; Raghukumar et al., 2009; Tripathy et al., 2011). However, there is no specific study on the beneficiation of Indian chromite plant tailing along with detailed characterisation. In the present investigation, two process flow schemes were studied for the recovery of chromite values from the beneficiation plant tailing of Sukinda along with detailed characterisation.

2. Materials and methods

2.1. Characterisation studies

The tailing sample collected from a typical beneficiation plant of Sukinda region of India had the following assay values: 17.0% Cr_2O_3, 23.9% $Fe_{(T)}$, 24.4% Al_2O_3, 11.3% SiO_2, 3.6% MgO and 8.7% loss on ignition (LOI). The Cr-to-Fe ratio of the tailing sample is 0.49. Further, the tailing sample was subjected to particle size analysis, size-wise chemical analysis and size-wise density analysis. The results are given in Table 1. XRD study of the tailing sample is shown in Fig. 1. Thermo-gravimetric analysis (TGA) was carried out to confirm the presence of different oxide/hydroxide minerals, and the results are shown in Fig. 2. Sink-float analysis was carried out for each size fraction with a heavy liquid of density 2810 kg/m^3 (Bromoform), and the results are given in Table 2. Prior to the mineral analysis, elemental analysis was carried out for different minerals by using SEM-EDX and images along with micro-analysis are shown in Fig. 3. Mineral analysis was carried out by using QEMSCAN to quantify different mineral phases in the tailing and the results are tabulated in Table 3. Further, liberation analysis for the chromite and gangue minerals in the tailing are also analysed in Fig. 4.

2.2. Beneficiation studies

Based on the findings of the characterisation studies, two different process flow sheets were conceptualized. The first flow sheet was designed with a combination of gravity concentration and magnetic separation. The second flow sheet included gravity separation, magnetic separation and flotation. Classification and gravity separation were carried out using a hydrocyclone (diameter of 25, 50 mm) and

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Table 1
Particle size, chemical and density analyses of chromite beneficiation plant tailing.

Size (μm)	Wt. (%) retained	Density (g/cc)	Assay value (%)			
			Cr_2O_3	$Fe_{(T)}$	Al_2O_3	SiO_2
+500	10.1	2.88	10.6	26.7	27.8	14.4
−500 + 355	5.6	2.95	10.9	25.1	28.2	12.6
−355 + 250	17.7	3.41	11.8	25.5	27.6	12.3
−250 + 150	27.5	3.40	17.1	21.8	23.6	12.8
−150 + 105	16.4	3.51	23.2	21.5	23.2	10.7
−105 + 75	5.8	3.64	24.8	26.5	22.0	8.8
−75 + 53	2.5	3.61	23.2	22.1	24.0	7.4
−53 + 37	4.6	3.70	23.9	22.1	23.2	7.7
−37 + 25	1.8	3.45	16.1	38.3	14.4	8.6
−25	7.9	3.23	16.7	25.4	20.6	6.9

a multi-gravity separator (MGS) of C900 model, respectively. Both cyclone and MGS were supplied by Richard Mozley Ltd (Redruth, UK). Floatex density separator (FDS) was the LPF-0230 model and supplied by Outokumpu Technology Inc.(Jacksonville, USA), whereas the Wilfley table was (model no. 15S) was supplied by the Deister Concentrator Company Inc., USA. Magnetic separation studies were carried out using both laboratory dry induced roll magnetic separator (IRMS) supplied by the Readings of Lismore, Australia, and laboratory wet high intensity magnetic separator (WHIMS) supplied by the Rapid Box Mag separator, UK. Flotation was carried out using a Denver D-12 sub-aeration flotation cell supplied by Denver Equipment Company, Colorado. Optimised test results were considered for the flow sheets, and these flow sheets along with mass balance data are given in Figs. 5 and 6, respectively.

3. Results and discussion

3.1. Characterisation studies

Particle size distribution of the chromite tailing sample is given in Table 1. The results show that the sizes of about 80% (by weight) of the particles are <260 μm and 50% <190 μm. Chemical analysis given in Table 1 indicate that as the particle size decreased, Cr_2O_3 content increased up to 37 μm, and below that, it decreased. Further, the size-wise distribution of different radicals revealed that all the constituent were evenly distributed at all size fractions and the maximum quantity (70.76%) of the Cr_2O_3 was distributed in −355 + 75 μm size fraction. Size-wise density was measured by using 50 ml. The standard density bottle and the values are also shown in Table 1. It can be observed that the coarser size fractions have a density <3.0 g/cc, which indicates the abundance of gangue minerals whereas particles with size < 355 μm have a higher density. It is also observed that higher density particles segregated at intermediate size fractions, and the same was also replicated from size-wise chemical analysis.

The diffractogram of the XRD analysis of the tailing sample is depicted in Fig. 1, which revealed that chromite, goethite, hematite, gibbsite, quartz and kaolinite are the mineral phases present in the tailing. The weight loss graph with respect to temperature was measured in Thermo Gravimetric Analyser and depicted in Fig. 2. It is evident from Fig. 2 that there is a weight loss of about 2% due to the moisture content, which is shown as region 'a.' Above 200 °C, a weight loss of about 6% may have been due to the presence of goethite and gibbsite. These two minerals reduce to hematite and boehmite, respectively, at this temperature zone (regions 'b' and 'c'). At this temperature, kaolinite also decomposes to metakaolinite. It is also seen that at >700 °C, the weight loss is marginal. So the total weight loss is about 8%, which is resembled with the LOI value. Size-wise sink-float studies were carried out by using bromoform (density of 2.88 g/cc) to quantify the heavy (>2.88) and light (<2.88) mineral content in the tailing sample. This heavy liquid separation study indicates that the quantity of lighter minerals is 28.17% in the tailing (Table 2). It is also reported that the content of low-density minerals decreases with particle size. The maximum quantity (51.76%) of float is reported at >500 μm, indicating the presence of a higher quantity of low-density gangue, whereas minimum content (0.35%) reported at <25 μm size fraction. It is believed that the floated material mainly consists of free quartz, gibbsite, kaolinite, iron silicate minerals (olivine group minerals) and serpentine as well as these minerals in their locked forms with other minerals including chromite, hematite and goethite in different proportions.

Several tailing sample moulds were prepared and processed in the SEM-EDX, and a few salient micro-graphs along with the elemental analysis are narrated in Fig. 3. It can be seen from Fig. 3a that the chromite minerals are euhedral in shape and have interstitial/micro cracks in some grains (points 2, 5 and 6 of Fig. 3a). There are two different types of chromite grains which are present in the tailing. One type of grain is rich in Cr values with minimum amounts of Fe, Al and Mg (point 1 of 3a), whereas the other one is rich in Fe, Al and Mg along with Cr (point 6 of 3b). Some of the gangue minerals are rich in Al along with Si (point 3 of Fig. 3a and point 2 of 3b), and these grains are believed to be kaolinite. In addition to this, there are free iron-rich gangue minerals in the sample (point 1 of Fig. 3b). Further, the micro cracks inside the chromite grains are observed in SEM-EDX and found that the cracks are filled majorly with Fe (point 2 of Fig. 3c). This impurity may be attributed to the weathering of chromite in the ultramafic belt. Further, QEMSCAN was used to ascertain the mineral contents, the mineral inter-locking characteristics of the chromite. The mineral composition of the tailing is tabulated in Table 3 and found that goethite and Fe silicate–bearing minerals are predominant in the tailing along with chromite. Elemental

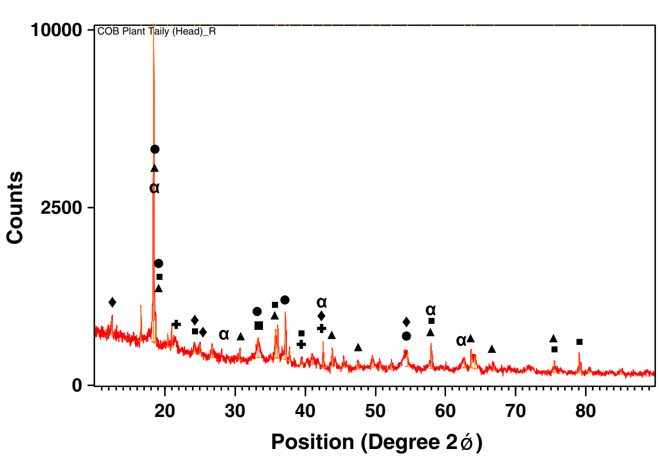

Fig. 1. X-ray diffraction (XRD) pattern of tailing sample with identified mineral phases (▲: chromite, ■:hematite, ♦: kaolinite, ●: gibbsite, ✚: quartz, α: goethite).

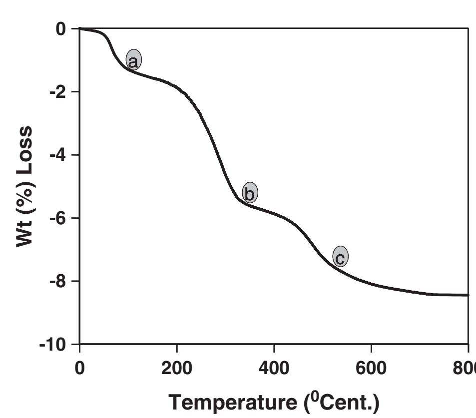

Fig. 2. Weight loss graph for the tailing sample.