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GRAVITY CONCENTRATION OF MUSLIMBAGH (BALUCHISTAN) CHROMITE

A. Hafeez, Saqib Ahmad and K. Hussain

PCSIR Laboratories Complex, Lahore

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Muslimbagh chromite ore has been beneficiated by gravity mineral processing technique using Wilfley table and Humphreys spiral concentrator. Tests were carried out to optimize the process parameters like feed rate, water flow rate, stroke length, motor speed and the deck inclination. The effect of the grind size on the concentration behaviour of the ore was then studied by using Wilfley table and the Humphreys spiral concentrator under the predetermined optimized process variables. Better grades and recoveries have been obtained by using the Wilfley table. The regrinding and retabling of the tailings have indicated the possibility of concentrating the ore at the coarser sizes. The ore, initially containing 35% Cr_2O_3, has been upgraded to a concentrate containing 50.65% Cr_2O_3 recovery of 84.6%.

Key words: Chromite, Tabling, Spiraling, Regrinding.

INTRDOCUTION

The chromite ore in the Zhob valley igneous complex is found in the form of lenticular masses [1-37]. The nature of ore in these lenses varies with respect to its chemical composition and physical characteristics [4]. The ore contain varying proportions of Cr_2O_3 and associated gangue minerals, the common gangue minerals being serpentine, olivine, dunite, harzburgite, pyroxenite and talc.

A number of studies [5-7] have been carried out at the Minerals and Metallurgy Research Centre of the PCSIR Laboratories Complex, Lahore, on the processing of low grade chromite ores occuring at various places in the two important ultramafic complexes of the country, *viz.* Zhob Valley and Malakand. This study is based on yet another chromite deposit in the Muslim Bagh area of the Zhob Valley complex.

MATERIALS AND METHODS

Mineralogy. The ore is seen to be partly massive and sometimes a low grade desseminated type. The grain size varies from 0.2 mm to 1.5 mm occasionally 2 mm. The ore is partly altered to ferrichromite indicating secondary alteration processes. The gangue is consequently altered to serpentine, talc and magnesite indicating the mobility of magnesium in the area.

The thin section study of the ore samples reveals the presence of serpentine with globular chromite. The serpentine shows yellowish brown to yellowish green colour and is probably antigorite, which is in all cases a product of alteration of some other silicate minerals. The chromite is seen to be black with metallic luster in reflected light.

Liberation studies

Particle size counting. In order to study the liberation of chromite, a representative sample of the ore was crushed and ground to minus 0.7 mm (20 mesh). The sample so obtained was sieved through a set of sieves and a number of close size fractions were obtained as presented in Table 1. Material from each fraction was sprinkled on a ruled slide and 300 to 500 particles were counted under the microscope. The particles representing different classes, i.e. clean chromite, locked chromite, and gangue, were calculated on percentage basis of the total particles counted. The application of the formula given at the bottom of Table 1 gave the percent liberation of chromite. As a result of particle counting, the mesh of liberation is found to be 350 microns. (44 mesh B.S.S.).

Table 1. Calculation of percent chromite libration.

Particle size (microns)	Free chromite grains (%)	Compound grains (%)	Free gangue (%)	Chromite liberation (%)
–700+500	15.07	67.12	17.81	18.29
–500+350	25.00	56.25	18.75	30.77
–350+250	52.03	28.46	19.50	64.64
–250+180	52.72	13.61	33.67	79.48
–180+150	52.09	6.62	41.28	88.72

Percent chromite liberation calculated by the formula [8].

$$\text{\% Chromite liberation} = \frac{\text{\% free chromite}}{\text{free chromite + \% locked chromite}} \times 100$$

Sample preparation. A truck load of a representative sample of chromite ore, weighing about 10 tonnes, was received through the courtesy of Pakistan Chrome Mines, Muslimbagh, Baluchistan.

The ore as received had a wide size range and comprised about 30%, 40% and 30% material in the size ranges 150-200mm, 75-150 mm and minus 70 mm respectively.

The ore was prepared for processing by using a jaw crusher, a roll crusher, a double deck vibrating screen and a rod mill to obtain products 100 percent passing 1.4, 1.0, 0.7, 0.5, and 0.35 mm respectively. The sequence of feed preparation has been indicated in Fig. 1. The sieve analyses of the material so prepared has been given in Table 2 and Table 3 indicates the average chemical analysis of the ore.

Table 2. Size analysis of feed material.

Sieve aperture	Feed material 100 percent passing (%)				
mm	1.4 mm	1.0 mm	0.7 mm	0.50 mm	0.35 mm
−1.400+1.000	5.0	–	–	–	–
−1.000+0.700	10.2	15.4	–	–	–
−0.700+0.500	17.2	15.8	9.2	–	–
−0.500+0.350	16.2	12.4	13.7	19.8	–
−0.350+0.252	13.8	15.0	16.0	20.6	26.8
−0.252+0.170	11.4	11.6	15.4	18.6	21.8
−0.170+0.152	3.8	4.0	6.2	4.9	7.1
−0.152+0.105	6.8	6.4	14.0	12.3	17.9
−0.105	15.5	14.4	25.5	23.8	26.4
	100.0	100.0	100.0	100.0	100.0

Table 3. Chemical analysis of ore.

Constituents	Percentage
Cr_2O_3	35.46
Fe_2O_3	17.80
Al_2O_3	10.60
SiO_2	7.65
MgO	22.25
L/I	6.19

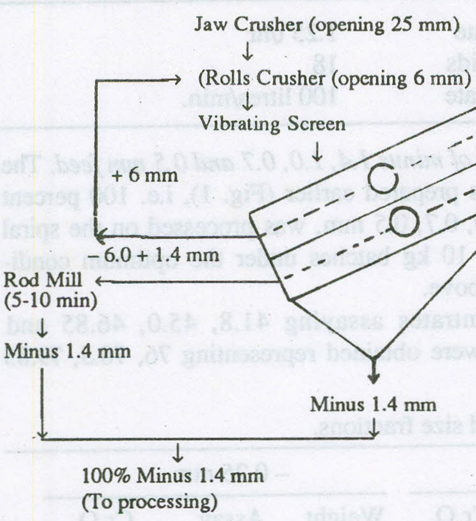

Fig. 1. Crushing and grinding circuit.

Processing of the ore: The beneficiation of the ore was carried out using a laboratory scale Wilfley Table 13 and a standard Humphreys spiral. The test work carried out to obtain a concentrate with an acceptable grade and recovery is described.

Processing of the ore on Wilfley Table

Processing of minus 1.4, 1.0, 0.7, 0.5 and 0.35 mm feed: A number of tests were carried out to optimise the process parameters such as feed rate, water flow rate, stroke length, motor speed, and deck inclination. Under the optimum working conditions, as reported below:

Optimum processing variables.	
Feed rate	120 kg/hr
Water flow rate	16 L/min.
Stroke length	8-10 mm
Motor speed	300 rev/min.
Deck inclination	4° to horizontal

10 kg each of the feed material 100% passing 1.4, 1.0, 0.7, 0.5, and 0.35 mm was processed on a Wilfley table. As a result concentrates assaying 44.3, 46.3, 50.65, 48.8, and 50.65% Cr_2O_3 were obtained with recoveries of 82.4, 81.70, 84.60, 81.43 and 67.3% respectively.

The metallurgiocal balance pertaining to these tests is being given in Table 4.

Processing of tailings: The tailings obtained as a result of processing the 100% passing 1.4 and 1.0 mm material were reground in a rod mill to obtain a material 100% passing 0.7 mm and processed again on the Table. Concentrates assaying 42.77 and 42.51% Cr_2O_3 were obtained.

When the results of these tests are combined with those obtained from the processing of the 1.4 and 1.0 mm ore, the overall metallurgical balance obtained may be presented as in Tables 5 and 6. The grade and recovery achieved as a consequence of regrinding and processing the tails points to the possibility of beneficiating the ore at coarser sizes.

Tabling experiments on closed size fractions. The 100% passing 0.7 mm material prepared earlier was sieved to get -0.7 + 0.35 mm, –0.35 + 0.25 mm, and -0.25mm fractions.

5.0 kg of each fraction was run on the Wilfley table under the optimum conditions already given. The concentrates assaying 44.32%, 45.60 and 50.02% Cr_2O_3 representing 77.8, 78.07 and 65.60% recoveries were obtained respectively. The test results have been reported in the form of metallurgical balance sheet. (Table 7).

Although grades of the concentrates produced by processing the ore in close size fractions may be acceptable yet the recoveries are poor. It is seen that the processing of material as fine as minus 0.25 mm yields a grade of 50.02% Cr_2O_3 at a considerably reduced recovery of 65.6 percent. This fall in recovery may be attributed to the loss of fine material in the slimes fraction (24 percent by weight at a grade of 17.73 percent Cr_2O_3).

It is also seen from this Table that the materials reporting to tailings are 40, 38, and 32 weight percent in the three fractions respectively at grades of 18.99, 20.89 and 22.79%

Table 4. Metallurgical balance on tabling of chromite at feed sizes 100 percent passing.

	1.4 mm			1.0 mm			0.7 mm1			0.5 mm			0.35 mm		
Products	Weight (%)	Assay Cr_2O_3 (%)	Cr_2O_3 Distri-bution (%)	Weight (%)	Assay Cr_2O_3 (%)	Cr_2O_3 Distri-bution (%)	Weight (%)	Assay Cr_2O_3 (%)	Cr_2O_3 Distri-bution (%)	Weight (%)	Assay Cr_2O_3 (%)	Cr_2O_3 Distri-bution (%)	Weight (%)	Assay Cr_2O_3 (%)	Cr_2O_3 Distri-bution (%)
Concentrate	70	44.3	82.40	65	46.3	81.65	66.0	50.65	84.60	63	48.80	81.43	47.5	50.65	67.30
Tailing	22	22.8	13.33	26	18.99	13.40	23.5	19.00	11.30	25	17.73	11.74	30.5	22.80	19.50
Fines	8	20.3	4.31	9	20.30	4.95	10.5	15.38	4.10	12	21.53	6.84	22.0	21.53	13.20
Calculated heads	100	(37.65)	100.04	100	(36.86)	100.00	100.00	(39.51)	100	100	(17.75)	100.01	100.0	(35.75)	100.00

Table 5. Metallurgical balance of combined 1.4 mm ore and tailing processed on table.

Product	Weight (%)	Assay Cr_2O_3 (%)	Cr_2O_3 distribution (%)
Concentration (C2)	9.08	42.77	10.32
Tail (T2)	12.92	8.76	3.01
Concentration (C1)	70.00	44.30	82.40
Tail (T1)	(22.00)	(22.80)	(13.30)
Fines	8.00	20.30	4.30
Calculated heads	100.00	(37.65)	100.00

Table 6. Metallurgical balance of combined 1.0 mm ore and reprocessed tailings.

Products	Weight (%)	Assay Cr_2O_3 (%)	Cr_2O_3 distribution (%)
Concentration (C2)	7.97	42.51	9.20
Tail (T2)	18.03	8.59	4.20
Concentration (C1)	65.00	46.30	81.65
Tail (T1)	(26.00)	(18.99)	(13.40
Fines	9.00	20.30	4.95
Calculated heads	100.00	(36.86)	100.00

Cr_2O_3. Improvement in recovery could be achieved by processing these tailings after regrinding. Regrinding of -0.7 + 0.35 and -0.35 + 0.25 mm tailings may be expected to yield fines that will end up in the slimes fraction. It, therefore, does not appear reasonable to regrind and reprocess these tailings because already we are encountered with a loss of values amounting to 12.7% in the minus 0.25 mm fraction.

Processing of the ore on a spiral. Before using the Humphreys spiral for processing the ore, experiments were carried out to optimise the processing parameters such as dry feed rate, percent solids, and pulp flow rate. The optimum conditions as determined are reported as under.

Optimum parameters for spiral concentration	
Dry feed rate	1.25 t/hr
Percent solids	18
Pulp flow rate	100 litres/min.

Processing of minus 1.4, 1.0, 0.7 and 0.5 mm feed. The feed material as prepared earlier (Fig. 1), i.e. 100 percent passing 1.4, 1.0, 0.7, 0.5 mm, was processed on the spiral concentrator in 10 kg batches under the optimum conditions reported above.

The concentrates assaying 41.8, 45.0, 46.85 and 44.33% Cr_2O_3 were obtained representing 76, 78.5, 79.85

Table 7. Metallurgical balance of the tabling of closed size fractions.

	-0.7 +0.35 mm			– 0.35 ± 0.25 mm			– 0.25 mm		
Products	Weight (%)	Assay Cr_2O_3 (%)	Cr_2O_3 distribution (%)	Weight (%)	Assay Cr_2O_3 (%)	Cr_2O_3 distribution (%)	Weight (%)	Assay Cr_2O_3 (%)	Cr_2O_3 distribution (%)
Concentrate	60	44.32	77.8	62	45.60	78.07	44	50.02	65.6
Tail	40	18.90	22.2	38	20.89	21.93	32	22.79	21.7
Slimes	–	–	–	–	–	–	24	17.73	12.7
Calculated heads	100	(34.18)	100.0	100	(36.21)	100.00	100	(35.56)	100.0

Table 8. Metallurgical balance on the spiralling of chromite ore of feed size 100 per cent passing.

Products	1.4 mm			1.0 mm			0.7 mm			0.5 mm		
	Weight (%)	Assay Cr_2O_3 (%)	Cr_2O_3 distribution (%)	Weight (%)	Assay Cr_2O_3 (%)	Cr_2O_3 distribution (%)	Weight (%)	Assay Cr_2O_3 (%)	Cr_2O_3 distribution (%)	Weight (%)	Assay Cr_2O_3 (%)	Cr_2O_3 distribution (%)
Concentrate	72.5	41.80	76	64.28	45.00	78.5	64.7	46.85	79.85	79	44.33	78.2
Tail	25.0	36.73	23	24.72	24.44	16.4	24.8	26.40	17.25	25	29.13	19.2
Fines	2.5	15.00	1	11.00	17.10	5.1	10.5	10.50	2.90	8	12.75	2.6
Calculated heads	100.00	(39.85)	100	100.00	(36.85)	100.00	100.00	(37.96)	100.00	100	(37.96)	100.00

and 78.2% recoveries. The result of these tests have been pented in the form of metallurgical balance chart. (Table 8).

It may be seen from this Table that both the grades and the recoveries obtained are comparatively low with respect to the results obtained by processing the same size of the ore on the Wilfley table.

DISCUSSION AND CONCLUSION

The results of the test work have pointed out the possibility of producing chromite concentrates with grades acceptable to the consuming industry by processing the low grade Muslimbagh chromite ore by gravity based methods.

The chromite concentrates find use in the manufacture of ferrochrome where the Cr_2O_3 content should be 48 percent with a Cr:Fe ratio of 3:1. In the refractory industry the concentrate should contain 31-33% Cr_2O_3 alongwith 26 percent Al_2O_3 and small quantities of Fe_2O_3. In the chemical industry, the percentage of SiO_2 is important. It should not normally be more than 8% but lesser percentages are recommended. The Cr_2O_3 content should be 45% minimum.

Better grades and recoveries have been obtained by processing the ore on a Wilfley table than on a spiral concentrator.

A grade of 50.65% Cr_2O_3 with a recovery of 84.60% has been obtained by using the Wilfley table on a feed material 100% passing 0.7 mm.

The processing of feed material 100% passing 1.4 and 1.0 mm has resulted in concentrates assaying 44.3 and 46.3% Cr_2O_3 at recoveries of 82.4 and 81.3% as compared to feed materials 100 percent passing 0.7 and 0.5 mm giving concentrates assaying 50.65 and 48.8% Cr_2O_3 at recoveries of 84.60 and 81.43%. The lower grade and recovery in the coarser sizes may be explained to be due to the fact that the feed sizes of 1.4 and 1.0 mm contain only 51.4% material passing 350 microns (mesh of liberation), as may be seen from the size distribution table 2, as compared to 77-80% material passing 350 microns for feed sizes of 0.7 and 0.5 mm.

In the case of the feed material 100% passing 0.35 mm, although the grade of the concentrate is high (50.65%) the recovery is significantly low, i.e. 67.3%. This low recovery may be attributed to the loss of chromite in the fines during tabling operation (22.0 wt. % at a grade of 21.53% Cr_2O_3) as is evident from Table 4.

The regrinding and retabling of tailings obtained during the processing of coarser size material (1.4 and 1.0 mm) has resulted in the production of concentrates assaying 42.8 and 42.51% Cr_2O_3 with recoveries of 81.17 and 63.69% respectively. On combining these results with the processing of the 1.4 and 1.0 mm ore, an average grade of 44.12 and 45.88% Cr_2O_3 representing 92.72 and 90.85% recoveries would be obtained. This significantly high recovery coupled with a reasonable grade suggests the possibility of processing the ore at coarser sizes.

Although the gravity processing of the close size fractions has resulted in comparable grades of the concentrates the recoveries are low. It may be seen from the metallurgical balance Table 7, that 40, 38 and 32 weight percent of the material assaying 18.99, 20.89 and 22.79% Cr_2O_3 is reporting into the tailings respectively. In addition, 24 weight percent of material assaying 17.73% Cr_2O_3 reports into the fines fraction in the case of minus 0.25 mm feed.

The recovery may be possibly be increased by regrinding and reprocessing of the tailings (40, 38, 32 wt. percent) but there is every likelihood of loosing the liberated chromite into the fines fraction as is evident from the results obtained by the processing of the ore at 100 percent passing 0.35 mm (c.f. Table 4) and the 0.25 mm fractions (c.f. Table 7).

The chemical analyses (Table 9) of the concentrates obtained from the treatment of 100 percent passing 0.7 mm

Table 9. Chemical analysis of concentrate.

Constituents	1.4 mm (%)	1.00 mm (%)	0.70 mm (%)
Cr_2O_3	44.35	45.88	50.68
Fe_2O_3	14.73	15.37	16.88
Al_2O_3	11.28	10.55	9.85
SiO_2	8.00	7.80	6.50
MgO	17.75	17.45	12.70
L/I	3.80	2.85	3.40
Fe/Cr	1:3	1:2.99	1:3

ore (50.65% Cr_2O_3 and 84.59% recovery) and 100 passing 1.4 and 1.0 mm ores with subsequent treatment of the tailings (44.12% Cr_2O_3 at a recovery of 92.72% and 45.88% Cr_2O_3 at a recovery of 90.85%) indicates the possibility of the production of chromite concentrates having different Cr_2O_3 contents at fairly high recoveries for use in different consuming industries. On the basis of these test results a tentative flowsheet may be suggested as in Fig. 2.

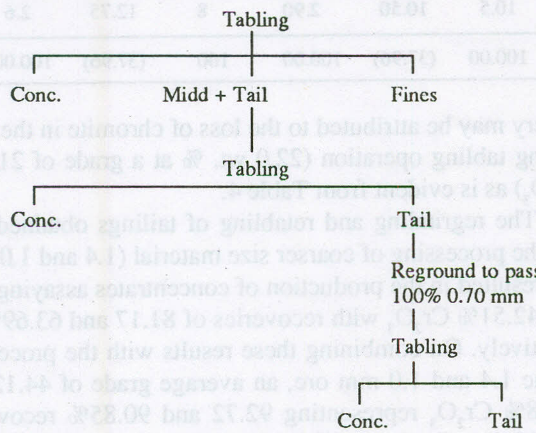

Fig. 2. Flowsheet for the processing of chromite ore. (Feed 100% passing 1.40, 1.00 and 0.7 mm)

It has been observed during the studies that the loss of chromite into the fines fraction increases progressively. These fines (material less than 0.25 mm) have been found to be difficult to treat on the conventional gravity processing equipment. Methods like flotation, high intensity magnetic separation and electrostatic separation may be used for the recovery of fine chromite. In addition, the use of a cross belt separator may be helpful. In the present case, however, it is concluded that processing may be carried out at coarser sizes of 1.4 or 1.0 mm followed by regrinding of the tails and tabling. Processing of material 100% passing 0.7 mm is the other alternative which gives better grade at a slightly lower recovery.

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