Pakistan J. Sci. Ind. Res., Vol. 29, No. 1, February 1986

BENEFICIATION OF MALAKAND GRAPHITE ORE

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(Recieved September 1, 1983 - revised October 16, 1985)

Malakand graphite, containing 18–20% of graphitic carbon, has been upgraded to a foundry grade concentrate having over 85% carbon content. The flotation process, used in the study, has been discussed in detail with special emphasis on the grind size and of the feed, solid-liquid ratio of the pulp and the reagent combinations. The final product, obtained at optimum recovery, was tested at various local foundries and was found to be satisfactory.

INTRODUCTION

Graphite occurs in sizeable deposits near Dargai in Malakand District and around Kel[1] in Azad Kashmir. Small showings have also been reported in Swat, Hazara and Khyber Agency[2]. The graphite reserves of Malakand are of significant importance due to their size and location. These deposits have been estimated at 3 million tonnes as proved and 13 million tonnes as inferred[3].

The graphite deposits in Malakand are spread over an extensive area covering occurrences at Dargai, Usman-Khel, Haspur, Agra and Rang Dheri. Graphite occurs in the garnet grade metamorphic schists of pelitic-psammitic nature. It is found in the form of sheets, lenses and streaks in the Malakand metamorphic complex[4]. It also occurs as independent grains as well as intergrowths and inclusions in other minerals, especially muscovite. Other gangue minerals, present in lesser amount, are iron oxides, clay, albite, boehmite, andalusite.

No efforts have so far been made to exploit these deposits for local consumption. Presently, all graphite requirement, mostly needed for the foundries and to some extent required for manufacturing pencils and crucibles, is met through imports. Keeping in view the annual demand of about 4000 tonnes[5] and the anticipated requirement of the future, it has been realized to work on the indigenous deposits. The present study, therefore, is an attempt to evaluate the graphite ore of Malakand for the production of foundry grade graphite concentrate.

EXPERIMENTAL

Chemical Analysis of the Ore. A representative sample, taken from a bulk ore sample, was subjected to chemical analysis. Its important chemical constituents are reported in Table 1.

Table 1. Chemical Assay of Graphite Ore

Constituent	Percent
Moisture	3.05
Graphite carbon	18.78
Amorphous carbon	0.93
SiO_2	54.34
Fe_2O_3	6.13
Al_2O_3	11.54
Na_2O & K_2O	2.25
MgO	2.18
Total	99.20

Sample Preparation for Test Work. About 8 tonnes of the ore, composed of trench samples from Agra, Rang Dheri, Silai Patti and Haspur, representing almost all the feasible ore reserves of Malakand, was recieved for the investigation from Messrs Malakand Mines Limited, Peshawar.

This bulk sample was crushed through a jaw crusher (set at 19 mm opening) and subsequently through a roll crusher which operated in closed circuit with a five mesh screen (3.34 mm). The crushed material was split by the standard sampling procedure into 2 kg and 1 kg batches.

The minus five mesh ore batches were ground in a 305 x 127 mm ball mill for flotation tests. Size analyses of the ball mill feed and ball mill product are given in Table 2.

Floatation Tests. The ground pulp (50% solids) was diluted to the desired limit and fed to a Denver D-12 floatation machine. Commercial kerosine oil[6], used as collector, was added to the grinding mill and floatation was carried out with the addition of the frother (pine oil)[7]. Soda ash was used for the adjustment of pH whereever

Table 2. Size analysis of ball mill feed and product

Mesh size (BSS)	Cumulative wt. % Passing	
	Ball mill feed	Ball mill product
-5	100.0	–
-5+12	67.5	–
-12+25	50.0	–
-25+36	39.0	–
-36+85	26.5	–
-85+120	23.5	–
-120+150	22.0	–
-150+200	15.5	100.00
-200+240	11.0	98.4
-240+300	5.5	60.9
-300	5.5	41.1

necessary and in some experiments sodium silicate[8] was used to depress the silicate gangue minerals.

A number of laboratory floatation tests were carried out to optimise grind size of the ore, solid-liquid ratio of the floatation pulp, and the quantities of the floatation reagents for the maximum recovery of graphite in the concentrate.

Optimization of Floatation Parameters: (a) Grind size. Six floatation tests were carried out. In each test 1 kg ore was ground with 4 ml of kerosine oil. The grinding time was 30, 60, 90, 120, 150 and 180 min. The ground ore pulp, containing 20% solids, was subjected to flotation. These time periods respectively produced 90, 98.4, 99.4, 100, 100 and 100% minus 200 mesh products. The floatation concentrates and tailings were analysed for their grades and recoveries. The results have been presented in Fig. 1.

(b) Pulp Dilution: For the determination of an optimum pulp dilution, five tests were carried out. Keeping the quantity of reagents and the grind-size of the feed constant, the degree of dilution was varied. The results have been presented in Fig. 2.

(c) Collector: After optimizing the grind-size, obtained on grinding the ore for an hr. (98.4% passing 200 mesh) and 20:80 as the solid:liquid ratio, the effect of the various quantities of kerosine oil was studied in a set of experiments. The results have been shown in Fig. 3.

Other collectors such as paraffin liquid, fuel oil and mobil oil were also tried but on qualitative basis. Similarly, frother addition was also controlled on qualitative basis and 0.1 to 0.2 ml/kg was found to be adequate to give a proper forth; sodium silicate did not show any significant effect on the quality of the concentrate, so its addition was not optimized. pH variations also did not improve the recovery or grade of the concentrate, so no effort was made to study its effect.

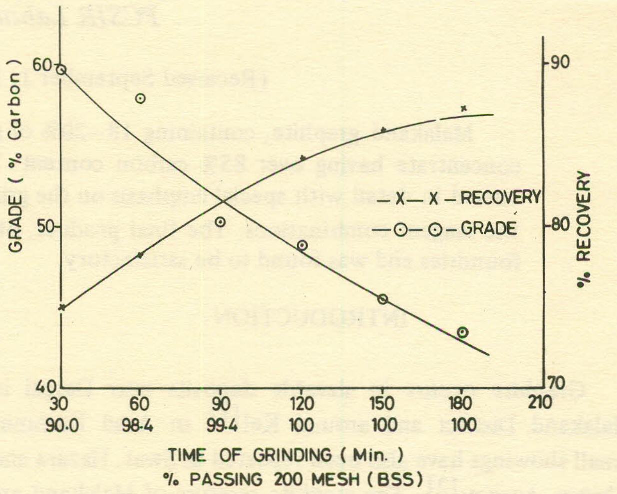

Fig. 1. Effect of grind size of the feed on the recovery of graphite (kerosine oil = 4 ml/kg of ore; solid in the pulp = 20%).

TESTS UNDER OPTIMUM FLOATATION CONDITIONS

Production of Rougher Concentrate. Rougher floatation tests were carried out with a feed, 98.4% of which passed through 200 mesh. The pulp, containing 20% solids, was floated with the addition of 12 ml kersoine oil and 0.1–0.2 ml pine oil per kg of the ore. Tests were performed at neutral pH. Sodium silicate, weighing 1 g/kg, was added as silicate depressant.

Cleaning of Rougher Concentrate. Microscopic examination of the rougher concentrate indicated some middling grains as well as gangue particles having graphite inclusions. It was found very difficult to determine the extent of grinding required for the complete liberation of the graphite grains. So the concentrate was reground at certain intervals of time till it produced the desired product.

For the first set of tests, the rougher concentrate was once cleaned (at 15% solids) and then reground for 15, 30, 45 and 60 min. separately. The reground concentrate was floated (at 10% solids) to produce the final concentrate. The results are presented in Table 3.

In the second set of experiments, the rougher concentrate was first ground for 15, 30, 45 and 60 min. separately and then subjected to cleaning and recleaning under similar conditions as mentioned above. The results are shown in Table 4.

Table 3. Effect of regrinding of cleaner concentrate on the grade and recovery

Floatation products	15 min wt. %	15 min Grade % C	15 min Recovery %	30 min wt. %	30 min Grade % C	30 min Recovery %	45 min wt. %	45 min Grade % C	45 min Recovery %	60 min wt. %	60 min Grade % C	60 min Recovery %
II cleaner conc.	2.7	82.36	12.07	3.51	85.48	15.78	5.01	86.30	23.05	6.21	86.52	28.67
II cleaner tail	10.31	69.72	39.03	9.63	67.48	34.17	7.92	68.50	28.92	6.81	67.12	24.39
I cleaner conc.	(13.01)	(72.34)	(51.10)	(13.14)	(72.29)	(49.95)	(12.93)	(75.40)	(51.92)	(13.02)	(76.37)	(53.06)
I cleaner tail	19.02	37.7	38.93	18.86	41.10	40.76	19.04	38.04	38.61	19.02	37.32	37.86
Rougher conc.	(32.03)	(51.77)	(90.03)	(32.00)	(53.90)	(90.71)	(31.97)	(53.15)	(90.58)	(32.04)	(53.19)	(90.92)
Rougher tail	67.97	2.7	9.96	68.00	2.60	9.29	68.03	2.60	9.42	67.96	2.5	9.07
Heads	(100.00)	(18.42)	(99.99)	(100.00)	(19.02)	(100.00)	(100.00)	(18.76)	(100.00)	(100.00)	(18.74)	(99.99)

Table 4. Effect of regrinding of rougher concentrate on the grade and recovery

Floatation products	15 min wt. %	15 min Grade % C	15 min Recovery %	30 min wt. %	30 min Grade % C	30 min Recovery %	45 min wt. %	45 min Grade % C	45 min Recovery %	60 min wt. %	60 min Grade % C	60 min Recovery %
II cleaner conc.	7.80	82.72	34.50	9.73	86.12	45.32	15.43	85.66	70.34	17.62	87.22	81.50
II cleaner tail	4.20	50.12	11.26	2.90	45.38	7.12	2.30	44.26	5.42	3.22	16.63	2.84
I cleaner conc.	(12.00)	(71.13)	(45.76)	(12.63)	(76.76)	(52.44)	(17.73)	(80.29)	(75.76)	(20.84)	(76.33)	(84.34)
I cleaner tail	19.50	43.94	45.82	19.06	37.18	38.32	14.23	20.54	15.55	11.02	11.96	6.99
Rougher conc.	(31.50)	(55.19)	(91.58)	(31.69)	(52.96)	(90.76)	(31.96)	(53.69)	(91.31)	(31.86)	(54.07)	(91.33)
Rougher tail	68.50	2.30	8.43	(68.31)	2.50	9.24	68.04	2.40	8.69	68.14	2.4	8.67
Heads	(100.00)	((18.70)	(100.01)	(100.00)	(18.49)	(100.00)	(100.00)	(18.79)	100.00	(100.00)	(18.86)	(100.00)

DISCUSSION

Graphite was observed in test samples as independent grains and also as intergrowths and inclusions in other minerals specially muscovite. Flakes were smaller (less than 0.1mm) than in the usual flaky ores. The graphite was very finely distributed in the micaceous schist.

Our investigation shows that the recovery increases with the increase in grind size of the floatation feed while the grade drops (Fig. 1). No substantial increase in recovery is observed when the ore is ground beyond an hour. This indicates that on more fine grinding, the grade falls due to gangue fines which float with the concentrate. The recovery, however, improves but with least economic benefit. One hour's grinding therefore, was considered to be an optimum for the rougher floatation.

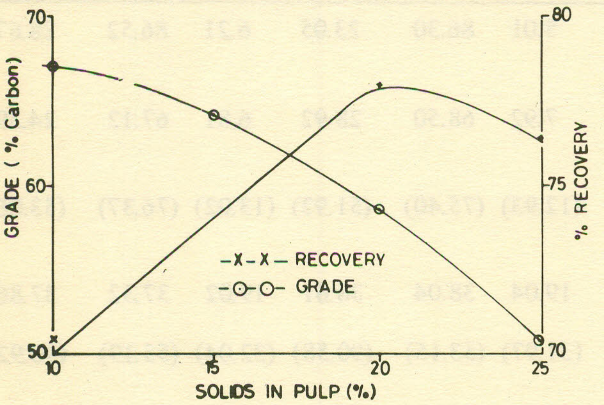

Fig. 2. Effect of percent solids in flolation pulp on the recovery of graphite (Grinding time = 1 hr or 98.4% passing 200 mesh; kerosine oil = 4 ml/kg of ore).

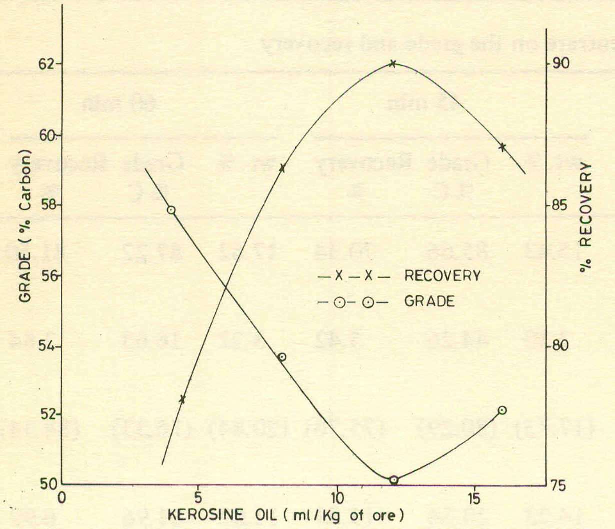

Fig. 3. Effect of the quantity of kerosine oil on the recovery of graphite (Grinding time = 1 hr or 98.4% passing 200 mesh; solids in pulp = 20%).

The results, as shown in Fig. 2, indicate that 20 percent solids in the floatation pulp produce better recovery. It may be concluded, therefore, that the graphite and tailing grains have more freedom of movement in dilute pulps facilitating floatation of graphite with least contamination and, therefore, the grade has improved with dilution. At the same time as the percentage of solids in the pulp increases, the recovery also increases upto a limiting value of 20% solids, after which a gradual decrease in recovery is noticed.

The grade and recovery curves in Fig. 3 indicate around 90% recovery on addition of 12 ml of kerosine oil per kg of the ore treated. This quantity of the collector seems to be sufficient to give an effective coating to graphite ~~grains for~~ floatation. The lesser amounts of collector and those exceeding this limit show low recoveries but higher grades. Higher quantities of collector adversely affect the froth formation resulting in a scum which is greasy in nature. Such information presumably hinders the proper action of the frother and thereby decreases the recovery. No substantial difference was noticed in grade while varying the quantity of the collector.

The results as shown in Table 3 indicate a little improvement in the grade with an increase in the regrinding time but the recovery was extremely low. This showed that only free graphite grains came up in the concentrate which, on regrinding and subsequent floatation did not exhibit any significant improvement in the grade. The cleaner tailings mainly contained the composite particles which carried a significant quantity of graphite and resulted in poor recovery.

It may be seen (Table 4) that the grade of concentrate was almost the same as in Table 3 but the recovery increased considerably. On grinding of the rougher concentrate for an hr. a grade of 87.2% carbon with a recovery factor of 81.50% was achieved. It was concluded that the rougher concentrate containing unliberated graphite grains should be reground prior to its cleaning and recleaning.

EVALUATION OF THE FINAL PRODUCT

The final product, produced on grinding of the rougher concentrate for an hr. and on two subsequent cleanings, had the following chemical composition Table 5.

Table 5. Chemical composition of the final concentrate

Constituent	Percentage
Graphite carbon	87.22
SiO_2	7.62
Al_2O_3	1.95
Fe_2O_3	1.65
Na_2O & K_2O	0.40
MgO	0.74

The average size analysis of the final concentrate was as below: Table 6.

Table 6. Size analysis of the final concentrate

Mesh Size (BSS)	% Passing
150	100.0
200	100.0
240	98.7
300	84.3

The concentrate was sent to six local foundries to check up its suitability as mould facing. According to the reports, the concentrate behaved satisfactorily and in a way which was similar to the imported graphite available in the market for foundry use.

CONCLUSION

The Malakand graphite, containing 19% graphitic carbon and micaceous in nature, was found amenable to flotation. For its beneficiation the ore was crushed to 3.34 mm (5 mesh BSS) and fed to a ball mill for grinding in the presence of 12 ml kerosine oil. This ground material was floated at neutral pH with 20% solids in the pulp and 0.1–0.2 ml of pine oil per kg of the ore treated. The rougher concentrate so produced was reground to 65–60 microns (250 mesh) and cleaned twice at 15 and 10% solids respectively.

Based on these investigations it is concluded that 90% of the graphite contained in the original ore is recoverable. The final concentrate produced contains 87% carbon and this grade is suitable for foundry use.

Acknowledgement. The authors gratefully acknowledge the assistance provided by Messrs. M. Sadiq Naeem and Ziaullah in carrying out the experimental work for this study.

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