DINESH KUMAR
PRIYDARSHI HEM
AMAN KUMAR
RAVINDRA KUMAR GUPTA
and
U. K. SINGH

Design of underhand cut and fill method for extraction of friable chromite ore left in open pit benches

In Sukinda valley at Kaliapani, Dist Jajpur, Odisha, high grade chromite ore is blocked in barrier pillars between opencast mines of different mining companies. The blocked ore is friable and weak in nature. A underhand cut and fill (UCF) method using cemented rock fill (CRF) is described in detail in this paper. This addresses the design of the mining method, design, preparation, transport and placement of CRF in stope. An economic analysis shows that this venture is profitable.

Keywords: *Chromite ore, friable and weak, underhand cut and fill (UCF), cemented rock fill (CRF), economic analysis.*

Introduction

In Sukinda valley at Kaliapani, Dist Jajpur, Odisha, the chromite ore is being extracted by open pit methods. Several open pit mines are being operated on strike of the ore body by various mining companies. This practice has blocked the chromite ore in barrier pillars between the open pit mines. For example, a huge block of chromite ores has been left in the barrier pillars between 'Jindal Stainless Limited (JSL) and ISPAT' and between 'JSL and Tata Steel'. The average grade of the blocked ore in the barrier pillar between 'JSL and ISPAT' is about 30% and is currently infeasible to be mined economically. But, the blocked ore between 'JSL and Tata Steel' has chromite of grade +44% and brings a huge opportunity to mine this ore. A photograph in Fig 1 shows blocked ore in the barrier pillar after open pit mining by Jindal Chromite Mine of JSPL.

Theoretically, it is observed that underhand cut and fill (UCF) mining method can be a feasible method to mine the blocked chromite ores in the barrier pillar between Jindal chromite mines and Tata Steel chromite mines. This paper focuses on the mining method, design and stability and analysis of the overall economy using UCF mining of the blocked ore in the open pit barrier pillar.

Messrs. Dinesh Kumar, PhD Scholar and JRF, Priydarshi Hem, B. Tech (Mining Engineering), Aman Kumar, B. Tech (Mining Engineering), Ravindra Kumar Gupta, B. Tech, (Mining Engineering), and U. K. Singh, Professor, Dept of Mining Engineering, IIT/ISM, Dhanbad.

Fig.1 A photograph of open pit mines of Jindal Stainless Steel showing friable chromite Band-I left in barriers between open pit of Tata Steel on the right side and Balasore Ispat on left side. (Courtesy, Jindal Chromite Mine, Kaliapani, Jajpur, Odisha)

Geotechnical details of ore body and host rock

The stratigraphic sequence of different litho units as established in the lease area from field observations at adjoining mine workings in Tata Steel leasehold area as well as OMC's South Kaliapani and other areas coupled with the drillhole data of GSI are as below:

Surface, 0, m
Laterite soil (chromiferous laterite at places)
Dolerite
Pyroxynite
Serpentinite
Limonite
Chrome ore
Sandy soil with quartzite
Quartzite
80 m

The chromiferous dark brown coloured laterite occurs as a capping over a major part of the mining leasehold followed by a thin layer of topsoil. The thickness of the topsoil horizon varies between 10 to 25 cm with an average thickness of 15 cm in the area while the laterites/lateritic soil is observed up to 3 m depth.

The friable chromite bands in Sukinda valley, Odisha are having 25 to 30m width with 70° to 80° dip towards north. The average grade of Cr_2O_3 is 46%-48% except in the contact zone (3m each side- north and south of the chromite band) where the average grade is +30% in the friable ore quarry. Due to alteration and lateritisation of ultrabasic rocks, the nickeliferous limonites have been formed mostly along the hanging wall side of the Northern and Central band (Band I and II).

Three chrome ore bands are reported to exist in the present lease area as established from the field observations and from drillhole data of GSI. The following chromite bearing bands are located within the mining lease area:

(i) Band I : Northern brownish friable chrome ore band
(ii) Band II : Middle brownish friable chrome ore band
(iii) Band VI : Southern grey lumpy band

The Band - I the brownish ore band is known as Northern friable chrome ore. Chromite of this band is brownish in colour, fine to coarse grained and friable/powdery in nature. The grade of the ore band varies from 30 to 45% Cr_2O_3 and is averaged to be 36% Cr_2O_3. It is the thickest band having an average width of about 30m as observed from the drillhole data. This band strikes in ENE-WSW direction with steep dip of 70°-75° towards N-NNW. The hanging wall consists of the nickeliferous limonites and serpentinite. The ore body and the hanging wall are both weak and friable is shown in Fig.2. A series of shear tests of the sample collected from one of the mines is given in Table 1.

The milky white coloured massive quartzites are exposed on the southern part of the area along the Mahagiri range. The quartzite is characterized by fine to medium grained mosaic texture. The band - IV, the grey lumpy ore is associated with this quartzite rock. At present this band is mined by open pit method.

(a)

(b)

Fig.2 Friable chromite ore body dark brown in colour on the left side and hanging wall rocks on the right. Hanging wall contact (a) non weathered and (b) weathered serpentinite rock. (Courtesy, Jindal Chromite Mine, Kaliapani, Jajpur, Orissa)

Selection of uunderhand cut and fill method using cemented rock fill

The ore body and the host rocks are weak and fragile. Therefore, it is difficult to have a stable stope back. As per the present mining situation and the geological properties of both ore body and host rock, an “underhand cut and fill”, called UCF, mining method has been found to be the most suitable one. It is a method of extracting a block of ore by mining of successive slices, working from top down. After a slice of ore is completely mined out, the void is filled with cemented fill material. The mining is then resumed immediately below the competent roof of the cemented fill.

The UCF method of mining is applicable for a weak and fragile ore body which cannot be mined by conventional overhand cut and fill and open stoping methods. It is because roof and sides of an excavation in weak rock are not self supporting which is a prerequisite for the open stoping and overhand cut and fill methods of mining.

This method is widely used in (a) extraction of high grade weak and fragile ore, (b) extraction of an ore body at higher depths which is not suitable for mining by overhand cut and fill method or open stope methods, and (c) extraction of highly stressed horizontal and vertical pillars left in filled stopes. The main consideration in UCF mining is that we work under a stable roof made of engineered cemented fill which is stable than that of the ore body. The higher cost of filling due to cement used in the fill has to be paid by high value of the ore.

The drift and fill is a common method of extraction of a slice of ore in underhand cut and fill method using cemented rock fill, called CRF, as shown in Fig. 3. The CRF is a low cement concrete consisting of aggregates larger than the conventional concrete. In this method, a drift is driven under an artificial roof made of engineered material, the CRF, to the end of a stope. Subsequently, the drift is filled with the CRF. Leaving a solid barrier of the ore another drift parallel to the previous one is driven to the end of the stope and filled. This cycle is repeated until full width of the ore body is extracted in the slice. Finally, the ore left in the slice are extracted and filled with CRF. The next slice is extracted underneath CRF roof of the previous slice. There are variants of this method. They are:

(a) Variant-1: The drift in the lower slice is parallel to the upper ones but staggered (Fig. 3a), and

(b) Variant-2: The drift in the lower slice is driven at an angle to the upper ones (Fig. 3b).

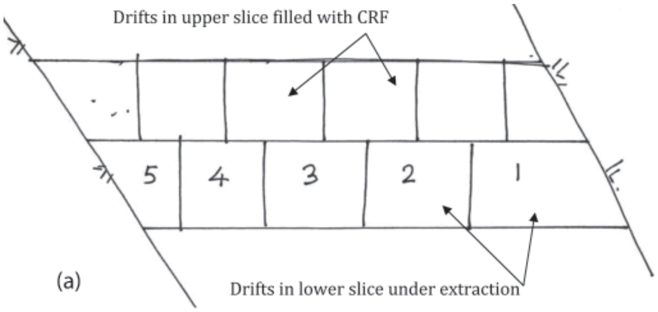

Fig.3a X-section showing drift in the slice parallel to the upper ones but staggered

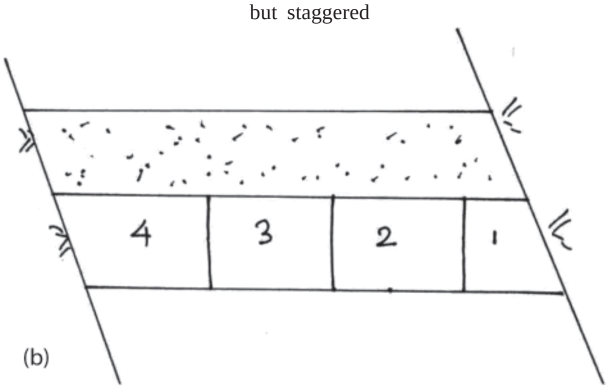

Fig.3b X-section showing drift in the slice at angles to the upper ones

The above variants are practiced to deal with the cold joint formed between the CRF placed in two adjacent drifts. This practice ensures that a CRF of the upper slice does not slide down in the lower drift.

The design parameters of the underhand cut and fill method using CRF are:

1. Span and thickness the CRF,
2. Span and layout of the drift beneath the CRF,
3. CRF strength, maximum size of aggregates, type of binder and its quantity,
4. Methods of preparation, transportation and placement of CRF in stope, and
5. Gap between the CRF placed in a drift and roof.

These design parameters practiced in various mines are compiled in Table 1.

In view of the above, the underhand cut and fill (UCF) method with cemented rock fill (CRF) is one of the suitable methods of underground mining of the friable chromite ore for following reasons:

1. The chromite is a high value ore.
2. Ore body and walls are not self supporting and they are very weak and friable. The shear strengths are very low (Table 2).
3. Filling material selected is CRF to be placed in the stope by a LHD. Hydraulic cemented fill is not suitable as shear strength of the ore body and the hanging and foot walls decrease in presence of water (Table 2). The quartzite overburden rocks removed for mining of the lumpy ore can be used as coarse aggregate in CRF after crushing and sizing.

Design of UCF

The ore body geometry and a typical open pit geometry are given as follows:

- Orebody: friable band having 25 to 30m width with 70° to 80° dip.
- Open pit::
  - Bench height = 6.5m to 7.8m
  - Bench width = 12m
  - Lowest workable level = 57m RL, RL of surface = 133.76m
  - Overall pit slope = 30 degree

A cross section X-X is shown in Fig. 4 across benches 1, 2, 3 and 4. The upper two benches are left un-mined due to poor grade of the ore. The extraction of ore from bench 3 is shown schematically. Before starting operation on bench 3, all walls of the benches are secured by wire mesh, shotcrete and rock bolts in the mining area. The bench 3 is shown mined in two slices of 3.5 m high each.

Extraction of slice 1 of bench 3 (Fig.4)

1. A ramp from top of the bench 3 is driven down to the floor of the slice 1 and its open part is stripped for making a room for driving drifts in the slice.
2. A 2 to 3 m wide drift, I-A, is driven following the hanging wall as shown on plan Y-Y, along slice-1 (Fig. 4). This drift and subsequent drifts to be driven under the chromite ore have to be heavily supported by wire mesh, shotcrete and rock bolts. If requires their widths are also reduced for ensuring stability of the drift.

Table 1: Design parameters of underhand cut and fill (UCF) methods with cemented rock fill (CRF), practiced in mines.

	Name of the mine and country, ore	Span and height of the drift under CRF (m)	Layout of drift under CRF	Max. size of aggregates and binding material	CRF compressive strength (MPa)	Transportation and placement methods	Cold joints	Support of ribs	Others	Reference
1	Turquoise ridge joint venture underground mine, Nevada, USA (gold ore)	Span: 3.7-6 m (max 9 m) Height: 3.7-4.6 m	Staggered, parallel to the upper drift	Crushed waste rock -2", binder 7.8%, (C 5% + F 1.95%)	Target 4 MPa, Av > 8 MPa (28 days)	Batched and mixed at surface, dumped down in transfer raises to level, hauled to stope and jammed by a LHD	Vertical cold joints as strong as fill. Inclined joint weak	Swellex Rock bolt and wire mesh		Sandback, et.al. (2012) and Terasik, et.al. (2003)
2.	Underhand cut and fill mining at Murray Mine, Jerrit Canyon Joint Venture, Nevada, USA (gold ore)	Span: 6.3-10.5 m, Height: 4.5 m, Benching on floor: 4.5m	Parallel staggered: Adjacent drift started within 24 hours without leaving a pillar	Lime stone aggregate, Binder: 6.5%, (C-5.2% and F-1.3%)	Av. 5 MPa (1.4 to 13.1 MPa	Haulage truck dumps mix at the face and jammed by LHD	Instability below cold joint. All inclined fill surfaces excavated in vertical prior to filling			Brechtel et.al. (1999, 2001)
3.	The Carlin underground mine, Nevada, USA (gold ore)	Span: 4.2 m, Height: 4.6 m	X-cuts oriented at 45º from drift axis. Drift offset or at an angle	Aggregate: 2" crushed diorite W:C = 0.8-1.2	Target 5 MPa	Surface back fill plant. Transported by gravity. Conveyer dumps in to stope, jammed by LHD				Sobering (2001)
4.	Barrick Bulfrog Mine, Nevada, USA (gold ore) Mine closed		Parallel drifts, after filling, another parallel drift started	Aggregate 6" and 3" Cement: 3-7%	Designed: 4.5 MPa, in place-3.5 MPa	Batching plant at the pit bottom Cement water slurry sprayed at -6" aggregate in a haul truck. The aggregate -3" mixed in drum mixture with cement and water. The mix discharged in a haul truck				Kump, el. al. (2001)
5.	SMJ's Jouac Mine, France (Uranium) Mine closed		Perpendicular to the upper ones. Partly filled	Waste rock aggregates	12-15 MPa	Mixed at the surface and pumped to the drift for filling and jammed by LHD				

TABLE 2: SHEAR TEST RESULTS OF FRIABLE CHROME ORE AND THE HANGING WALL NICKELIFEROUS LIMONITES AND SERPENTINITE.

	Rock type	In-situ sample		Water drained sample	
		Cohesion, MPa	Angle of friction, degrees	Cohesion, MPa	Angle of friction, degrees
1	Friable chromite band -I	0.37	15	0.49	12
2	Serpentinite	0.30	19	0.13	11
3.	Nickeliferous limonites	0.24	23	0.29	07

3. After completion of the drift I-A up to the boundary of the mine, CRF is brought by a LHD and dumped at the end of the drive. Another, LHD fitted with a ramming plate, pushes the CRF so that the drift is filled up to top. The filling of the drift ends at line AB.
4. Another drift, I-B or I-C parallel to the I-A is driven and filled with CRF. The driving and filling is repeated until complete slice is extracted.

Extraction of slice 2 of bench 3 (Fig.4)

The CRF in slice 1 forms a competent roof for extraction of the lower slice 2. This is extracted in following manner:

(1) From top of the bench 4, 4 to 5 m wide drift is driven in the bench following the hanging wall under CRF roof of the slice 1.

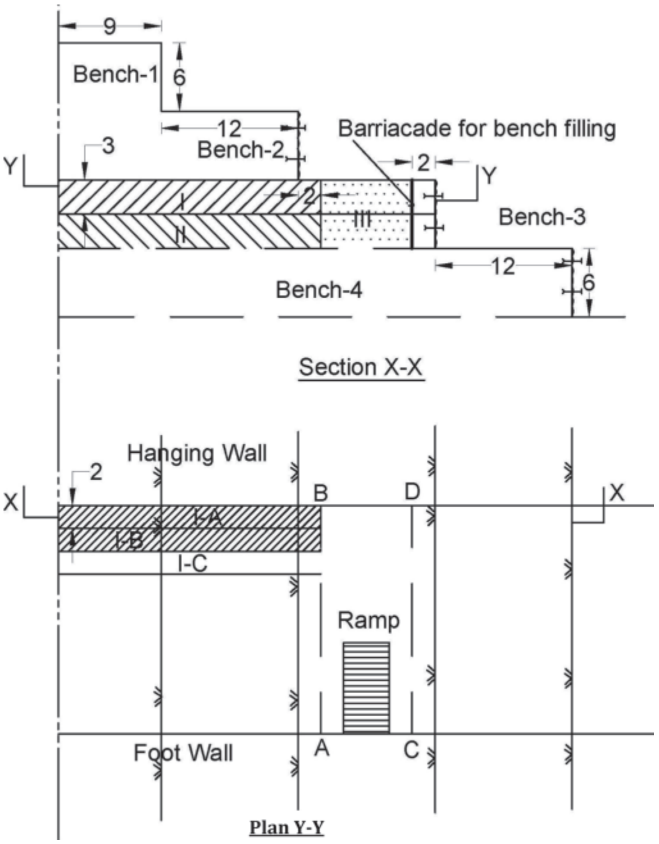

Fig.4 Plan and section of the benches showing method of UCF with CRF

(2) The drive is filled up to line AB as shown in Fig. 4. Similar to slice 1, subsequent drifts are driven and filled for extraction of slice 2.

(3) In this way the bench 3 is partly filled with CRF up to line AB.

(4) The remaining part of the open bench ACDB is filled with CRF up to full height of the bench 3.

After completion of extraction of slices 1 and 2 of bench 3, the ore gets replaced by the competent CRF. The extraction of bench 4 and subsequent lower benches are performed in similar way as that of the bench 3 under competent roof of the CRF.

The ore, mined in benches, are loaded by a LHD and discharged onto a chain conveyor. The chain conveyor discharges the ore into a dumper waiting at the pit bottom. The schematic ore transportation system is shown in Fig.5.

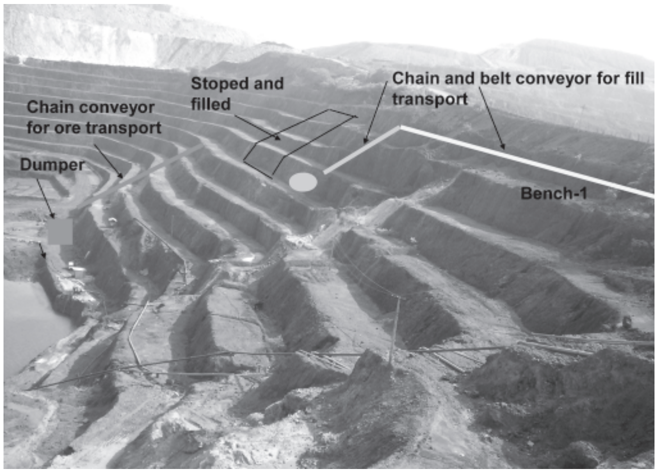

Fig.5 Schematic layout of transport of fill materials to an open pit bench and of extracted ore from at the bench to the bottom of the open pit

Preparation and transport of filling material to the UCF stope

The filling material for CRF consists of:

1. Coarse aggregate: -150 mm size to be prepared by crushing of the quartzite over burden rock produced from the adjacent pit of lumpy chromite ore,
2. River sand,
3. Bottom ash from power plant, and
4. Cement and fly ash.

A consistent mix is prepared by mixing a designed proportion of coarse aggregates, sand, fly ash and cement. A suitable mix can be designed by the procedure explained by Dinesh (2014). The CRF containing 6% cement by weight has following properties (Dinesh, 2014):

- Uniaxial compressive strength : 5 MPa,
- Tensile strength : 0.95 MPa, and
- Young's Modulus of elasticity : 9 GPa

One can easily achieve 4 to 6 m stable span under 3 - 3.5 m thick designed CRF with the above properties (Dinesh, 2014). The procedure for CRF preparation, transport and filling are as follows:

1. A semi-wet, filling mix will be prepared at the pit top in a concrete preparation plant so that the mix does not stick to the conveyor system.
2. The prepared fill material will be taken to the top bench by a belt conveyor (Fig. 5)
3. Further, it will be taken to the stoping benches through a chain conveyor
4. The chain conveyor will discharge the material on top of the bench.
5. Stope filling operation
   a. A LHD will load the fill material and take to the drift.
   b. If required water may be sprinkled to make the mix workable so that a LHD fitted with ramming plate pushes the CRF to fill the drift up to top. All efforts are made to push the CRF tight to the roof.

Equipment and machines

(a) A CRF mixing plant of capacity, $16m^3$/hr is required for proper mixing of filling material in order to form a quality CRF.

(b) A belt conveyor of capacity 40 m^3/hr for transportation of CRF from the plant to the chain conveyor.

(c) Two chain conveyors 40 m^3/hr

- For transportation of ore from working bench to the pit bottom, and
- Transportation of filling material from pit top to the working bench.

(d) Two load haul dumping (LHD) machines: 3.6 t hauling capacity

- For loading and hauling of ore from the working face to the hopper of chain conveyor, and
- For transportation of filling material in to the stope for filling.

Discussions

The friable chromite ore which is blocked in the open pit can be efficiently and economically extracted by UCF using CRF from the existing benches. There are following benefits of the methods:

(a) the blocked ore is economically extracted,

(b) the barrier pillars remain in operation by both the mines, and

(c) open pit activities are not disturbed.

Before commencement of extraction of the ore from the benches, their walls are reinforced with wire mesh, shotcrete and bolts,

Over a period of 10 years, the present value of investment (PVIN) in 2011 was Rs.353 lakhs for a production of 250t chromite ore per day. At a sailing price of Rs.4000 per tonne friable chromite ore, in 2011, the PVOUT was Rs.1577 lakhs. Thus, NPV, net value of the project in 2011 was Rs.1224 lakhs.

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