Waste Management in Underground Metalliferous Mines

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Abstract:
This paper deals with Waste management is the systematic assessment of potential hazard, disposal and proper utilization of mining waste in the mining industries. In the mining industry, every stage of the operations generated waste and required to handle properly. The type of waste generated from the mining industries is solid, liquid and gases waste. The use of backfill in underground mining is increasing due to the need for systematic filling of mine openings. Backfilling is that material that is utilized in void opening in underground mines for better safety in mines. It prevents fire, explosion and improves mine ventilation to increase the stability of the rock, subsidence effects at the surface and economical-environmental factors. The systematic selection, application and placement of backfilling in mines are multi processes. Backfilling is a paste, hydraulic and CRF and combination of wastes.

Keywords: Mining, underground mine, Metalliferous, Ore, Waste Management, Backfilling, Subsidence, Beneficiation, Waste rock, environment, CRF method, Rock Stability.

I. INTRODUCTION

OBJECTIVES:
1. To study the waste disposal and management practices in metal mine
2. Environmental impact of mining waste.
3. Mining waste disposal techniques.
4. To study the waste disposal and management practices in Kayad Lead-Zinc mines.
5. To determine suitability of mine waste for backfilling process.
6. Other waste management techniques.

APPROACH

INTRODUCTION &NEED OF THE STUDY
Underground mining activities lead to surface impacts on the surface ground caused by subsidence Movements and further deep mining require to backfill the void area. The mining method is the component of subsidence that influences its environmental impact. The following techniques are used in the underground mining excavation for the subsidence control and utilization waste as a backfilling in the mines.

1. Long wall mining
2. Sub-level caving
3. Room-and-pillar mining
4. Block caving
5. Stope mining

Field studies have been carried out on waste management in different industries like open cast and Under Ground Lead - Zinc Mines, open cast mines Rampura-Agucha as well as an underground Metal mines Kayad mines Ajmer Hindustan Zinc Limited. In underground different types of waste generated so waste management techniques also different. The solid waste generated can be raw material for process. Water and soil samples analysis of mine carried out to ascertain impact of waste generation. Mines pay less attention on the waste management as they are much concern with their production of Ore /Metal. Waste management scenario in the mines industries can be improved by following best practices.

II. IMPORTANCE OF BACKFILLING IN UNDERGROUND MINES
Underground mining activities lead to surface impacts on the ground caused by subsidence movements. The mining method is the component of subsidence that influences its environmental impact.

The following mining techniques produce associated surface subsidence:-
1. Longwall mining
2. Sub-level caving
3. Room-and-pillar mining
4. Block caving
5. Stope mining
Cross-section of subsidence trough
The resultant surface impact is a large shallow depression in the ground, which is usually circular / elliptical in shape, depending primarily on the geometry of the Mine workings and the geological conditions of the mines.

Four types of measures may control subsidence in the mines surface area damage:
1. Alteration in mining techniques.
2. Post-mining stabilization.
3. Architectural and structural design.
4. Comprehensive planning.

The proper planning is done by the managing the waste it would be beneficial for environmental balance. Efforts must be made to minimize waste generation, proper disposal and new waste management techniques need to adopt. The type of waste generated from the mining industries is solid, liquid and gases waste. The use of backfill in underground mining is increasing due to need for systematic filling of mine openings. Backfilling is that material that is utilized in void opening in underground mines for better safety in mines. Importance of backfilling to prevent fire, explosion and improve mine ventilation, increase stability of the rock, subsidence effects at surface and economical-environmental factors.

Figure 1. Systematic selection and application of backfill flow sheet
The Backfilling in underground mines will have following importance:

1. To improve ground stability and reduce ore dilution.
2. To reduce surface mining waste disposal; this in turn reduces and even eliminates some problems, such as tailing dam failure or acid mine drainage (AMD), associated with mining waste management.
3. To ensure a safe and economical backfill design, the strength of the backfill must be high enough to allow it to remain stable during the exploitation of adjacent stopes, at the very least.
4. To decrease surface and ground water contamination, soil erosion and sedimentation.
5. To protect from subsidence, fire and explosion etc.

**DESIGN OF CRF SYSTEM FOR BACKFILLING OF BLAST HOLE STOPES AT KAYAD LEAD- ZINC MINES**

**INTRODUCTION:-**

To design a cemented rock fill (CRF) system for backfilling of the underground blast hole stopes, extensive laboratory studies have been carried out at CSIR-CIMFR (Council of Scientific and Industrial Research-Central Institute of Mining and Fuel Research) to determine various physio-mechanical properties of Kayad Mine rock.

The laboratory studies under the project have been undertaken with the following scope of work:

1. Determination of strength properties of Kayad Rock and Rampur Agucha Rock with various combinations of fines and analysis of backfill stability.
2. Recommendation on curing time for various cements: rock proportion as well as suggestion on quick setting additive.
3. Determination of optimum proportion of cement and rock in the CRF.
4. Recommendation on procedure for preparing and filling of CRF and monitoring of filled stopes.
5. Design of suitable barricade.

**CHARACTERSTICS OF CRF:-**

- In the majority of the operations, 10 mm – 300 mm sized rock fill aggregate is mixed with cement slurry, usually 5 to 6% by weight of aggregate at a pulp density of 50-60%.
- An advantage of a CRF as compared with hydraulic fill system is the higher filling rate at lower cost.
- CRF filling needs to be quality controlled as it is batch mix dependant. Its system needs to be established properly for smooth operation and achieving optimum rate of filling.
- It is a cyclic operation and comparatively slow its safety features are far better than other hydro fill operations.
- One major advantage is that it requires minimal water and hence very much acceptable in water scarce area.
- Uniaxial Compressive Strength (UCS)

**DESIGN FOR STRENGTH REQUIREMENT OF ROCK FILL**

One of several purposes of back filling stopes before recovering adjacent pillars is to provide over-all ground support.

Sufficient back fill strength is required especially in long hole/ blast stopes to maintain a free standing height of fill in the primary stope while ore in the secondary stope is extracted.

The maximum free standing vertical height of the fill wall is a function of the fill properties, such as, cohesion and the internal angle of friction and also on the fill geometry, such as, the span and width of the fill block.

Analytical approximation as shown by eqn. as derived by Caceres (2005) for cemented rock fill relating the stope geometry and various fill properties with the strength requirement $Q_u$.

$$Q_u=\frac{\gamma L^2 K \tan(\phi)}{2} \times \sin^2(\beta) \times \left(1 - (-2KZ\tan\phi L \times \sin 2\beta)\right)$$

Where:

- $L=$ Span of the stope
- $Z=$ Height of rockfill
- $K=$ Coefficient of lateral earth pressure ~ 1.4sin2( $\phi$) - 2sin( $\phi$) + 1
- $\gamma=$ Rockfill’s unit weight
- $\phi=$ Rockfill’s friction angle
- $\beta=$ Stope dip angle
The design uniaxial compressive strengths $Q_{dof}$ of the fills are provided assuming a factor of safety of 2.0.

For blast hole stopes of Kayad Mine, the strength requirements have been determined using the above equations, considering:

- Rock fill's friction angle ($\phi$) = 34°,
- Stope dip angle ($\beta$) = 70°,
- Rock fill's unit weight ($Y$) = 19.62 KN/m$^3$,
- Stope backfill height ($H$) = 25m
- Length varying between 5 to 20m

Table 1. Design strength of CRF required for different fill dimension

<table>
<thead>
<tr>
<th>Weight (m)</th>
<th>Length (m)</th>
<th>Rock fill unit weight (KN/m$^3$)</th>
<th>Rockfill's friction angle</th>
<th>Stope dip angle</th>
<th>uniaxial compressive strengths $Q_d$ (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>25</td>
<td>5</td>
<td>13.62</td>
<td>34</td>
<td>70</td>
<td>367</td>
</tr>
<tr>
<td>25</td>
<td>6</td>
<td>13.62</td>
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<td>25</td>
<td>9</td>
<td>13.62</td>
<td>34</td>
<td>70</td>
<td>537</td>
</tr>
<tr>
<td>25</td>
<td>10</td>
<td>13.62</td>
<td>34</td>
<td>70</td>
<td>567</td>
</tr>
<tr>
<td>25</td>
<td>11</td>
<td>13.62</td>
<td>34</td>
<td>70</td>
<td>593</td>
</tr>
<tr>
<td>25</td>
<td>13</td>
<td>13.62</td>
<td>34</td>
<td>70</td>
<td>638</td>
</tr>
<tr>
<td>25</td>
<td>14</td>
<td>13.62</td>
<td>34</td>
<td>70</td>
<td>656</td>
</tr>
<tr>
<td>25</td>
<td>15</td>
<td>13.62</td>
<td>34</td>
<td>70</td>
<td>684</td>
</tr>
<tr>
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<td>16</td>
<td>13.62</td>
<td>34</td>
<td>70</td>
<td>712</td>
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<tr>
<td>25</td>
<td>18</td>
<td>13.62</td>
<td>34</td>
<td>70</td>
<td>734</td>
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<tr>
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<td>20</td>
<td>13.62</td>
<td>34</td>
<td>70</td>
<td>734</td>
</tr>
</tbody>
</table>

In order to obtain a fill of the designed strength, uniaxial compressive strength of backfill was determined by preparing and testing of 300x300x300 mm cubical moulds. The moulds were prepared by mixing the required quantity of Kayad and Rampur Agucha mines' waste rock, ordinary Portland cement (OPC-43 Grade) / Low cost binder (developed at CSIR-CIMFR) and water. Rock samples below 100mm were taken for preparing the moulds. Fill testing was carried out of samples in a 100T Vertical Compression Testing Machine.
OPTIMISATION OF FINES CONTENT

1. To optimize the fines content, three moulds of mix corresponding to 10, 15 and 25% fines concentration were prepared each for Kayad as well as Rampur Agucha mines with cement slurry, 5% by weight of aggregate at a pulp density of 60% w/w. The moulds were capped with thick cement paste and covered with wet jute bugs for 7 days of curing.

2. The variation in uniaxial compressive strength with different fines content is given in Table.

Table 3. Variation of UCS of CRF samples with fines content

<table>
<thead>
<tr>
<th>Mould No.</th>
<th>Name of the mine</th>
<th>% fines</th>
<th>UCS (Kpa)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Kayad</td>
<td>10</td>
<td>598</td>
</tr>
<tr>
<td>2</td>
<td>Kayad</td>
<td>15</td>
<td>1329</td>
</tr>
<tr>
<td>3</td>
<td>Kayad</td>
<td>25</td>
<td>485</td>
</tr>
<tr>
<td>4</td>
<td>Rampura Agucha</td>
<td>10</td>
<td>630</td>
</tr>
<tr>
<td>5</td>
<td>Rampura Agucha</td>
<td>15</td>
<td>1151</td>
</tr>
<tr>
<td>6</td>
<td>Rampura Agucha</td>
<td>25</td>
<td>389</td>
</tr>
</tbody>
</table>

The results indicate that around 15% fines (less than 10mm) would be an optimum amount in the fill mix to obtain maximum strength of the CRF.
BINDER ALTERNATIVES

1. A chemical additive developed at CSIR-CIMFR was also used as a low cost binder alternative and two moulds were prepared having the composition of 15 and 25% fines and 5% chemical additive. The moulds were tested after 7 days curing. The strength obtained are compared with the strength of moulds prepared with OPC.

2. The results indicate almost similar performance of the chemical additives to that of OPC. It has been estimated that the cost of the chemical additive is about 50% of OPC. Hence, replacement of OPC with the chemical additive will considerably reduce the cost of filling.

<table>
<thead>
<tr>
<th>Mould No.</th>
<th>Name of the mine</th>
<th>Cement content (%)</th>
<th>UCS after 7 days (Kpa)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Kayad</td>
<td>3</td>
<td>381</td>
</tr>
<tr>
<td>2</td>
<td>Kayad</td>
<td>5</td>
<td>1529</td>
</tr>
<tr>
<td>3</td>
<td>Kayad</td>
<td>7</td>
<td>1449</td>
</tr>
<tr>
<td>4</td>
<td>Rampur Agucha</td>
<td>3</td>
<td>405</td>
</tr>
<tr>
<td>5</td>
<td>Rampur Agucha</td>
<td>5</td>
<td>1151</td>
</tr>
<tr>
<td>6</td>
<td>Rampur Agucha</td>
<td>7</td>
<td>1385</td>
</tr>
</tbody>
</table>

Table.4. Variation of UCS of CRF Samples:

Table.5. Comparison of strength of CRF between OPC & Chemical Additive

<table>
<thead>
<tr>
<th>Mould No.</th>
<th>Particular</th>
<th>% fines</th>
<th>UCS (kpa)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Chemical Additive (Polyethyleneoxide and Aluminum-chloride)</td>
<td>15</td>
<td>1025</td>
</tr>
<tr>
<td>2</td>
<td>Chemical Additive (Polyethyleneoxide and Aluminum-chloride)</td>
<td>25</td>
<td>534</td>
</tr>
<tr>
<td>3</td>
<td>OPC</td>
<td>15</td>
<td>1329</td>
</tr>
<tr>
<td>4</td>
<td>OPC</td>
<td>25</td>
<td>485</td>
</tr>
</tbody>
</table>

FILL STRENGTH REQUIREMENTS

1. The results of 7 days’ tested strength were compared with the designed strength of backfill for free standing wall.
2. It can be seen that for blasthole stopes at Kayad Mine of 25 m height, the design strength for free standing wall of 10 and 20m block spans are 567 and 734 kPa respectively.

3. The results of strength tests of CRF show that 5% cement will be sufficient to achieve this design strength. However, the mix should contain about 15% of fines (below 10mm) which will maximize the backfill strength and the backfilled CRF should be allowed to cure for at least 7 days before the wall can be exposed.

Figure.8. CRF Plant at Kayad Lead-Zinc Mines
Reason for selection of this project:
- To fill the void at higher rate.

System Improvements Initiatives:
- Slurry transportation system was designed by third party.
- Based on study Installation and commissioning of slurry transportation system was done up to 200mRL at both level.

Benefits achieved through above initiative:
- Higher backfilling rate achieved.
- Implementation of this system helps to meet the BP targets.
- Saving in cost.
- Reduced traffic conjunction.

Reason for selection of this project:
- To maximise Availability of waste.
- To reduce the time requires transporting waste from DSP to Mixing site.
- Direct transportation of Slurry in to the open stope to avoid LHD Damage.

System Improvements Initiatives:
- Waste pass developed from 250mRL to 200mRL.
- Slurry line extension up to open stope edge.

Benefits achieved through above initiative:
- Higher backfilling rate achieved.
- Sufficient amount of waste is available at nearest location.
- LHD availability and reliability improved.

FILL BARRICADE:
- After completion of one stoping panel, the extraction brow is barricaded and prepared for CRF filling from upper level.
- The barricades for CRF filling is mainly required to arrest the fill right at the brow, and prevent flying rock hazard, and retain the wall in the brow till it is consolidated.
- Unlike hydraulic fill the barricade does not have to take any hydrostatic head. It is recommended to use waste muck pile, heaped up to the roof with LHD bucket or other improvised muck pillars.
- The gap in the roof is to be blocked with help of suitable wire mesh (25mm sq. wire mesh) tightly fixed to the roof and side walls with the help of rock bolts/eye bolts, and to be installed in-bye of the muck pile.
- It may be noted that after completion of filling and sufficient curing of say 7 days the waste muck pile from the brow should be removed before the first blast of the next stope to avoid any dilution and create space for blasted rock.

CRF/BERM QUALITY CHECK

1. Berm 200, N410 stopes FW side. Size 1.5m height, 4.5m width and 2m thick.

2. Berm 200, N455 stopes FW side. Size 1m height, 4.5m wide and 1.5m thick.
Figure.11. Visual observation 3 days = soft, 7 days = slightly hard, 14 days = hard, 28 days = hard. LHD hitting was required to break the berm.

Figure.12. N 425: Crf Intact Even After Shoulder Deterioration
Berm S 350 stope HW side, dated 22.12.18
CRF PLACEMENT IN STOPE VOIDS
1. The method of mining is blast hole stoping with continuous sequencing, retreating from far end and advancing bottom to top in stepped manner in each mining block.
2. This enables opening of one stoping panel at each strike end at one level and subsequently provide additional stopes in upper level with sufficient advance of the lower level stopes. Each stope panel has a strike length of 25m with level interval of 25m, and ore body width varying from 5m to 12m (average 8m). 
3. During CRF pouring by LPDT/LHD from upper levels, care to be taken to have Stop Logs, sufficiently strong, near the edge of the stope to prevent loader from entering the stope void.
4. The initial pours will fill the brow quite strongly due to the free fall and compaction.
5. There may be some amount of segregation of heavier/larger size particles away to opposite side, due to the angle of repose which may vary from 35 to 50o, but the placement of the finer fragments against the adjacent stope wall, will ensure stable fill wall during next stope excavation.
6. It is suggested to do CRF filling at least till the 80% of the stope void is filled and then the rest of the void may be filled with dry waste rock to optimize cement consumption.
INSTRUMENTATION FOR BACKFILL MONITORING

- The initial two to three consecutive stopes should be instrumented with MPB Ex in hang wall.
- The wall movements should be studied and effectiveness of the CRF should be assessed. Upper level instrumentation is also suggested for long term mine stability studies.
- The details of instrumentation shall be given once the ore body, stoping block and stoping panels and their sequence are identified.

II. CONCLUSIONS AND RECOMMENDATIONS

The study revealed the following:
1. For the blast hole stopes at Kayad Mine of 25 m height, the strength required for free standing wall of 10 and 20m block spans have been found to be 567 and 734 kPa respectively.
2. A rock fill consisting of 15% fines (-10mm), 80% coarser fractions (-100mm) and 5% cement (OPC-43 grade) at a pulp density of 60% w/w has been found to be the optimum composition for filling the blast hole stopes of Kayad Mine. However, the fill should be allowed to cure for at least 7 days before the fill wall can be exposed.
3. Advantages of a CRF as compared with hydraulic fill system is the higher filling rate at lower cost.
4. It has higher compressive strength, cohesion, friction angle, modulus of elasticity with lower binder content.
5. There is no drainage problem and it is a continuous filling system.
6. A surface silo of capacity 150 to 200T will be required for storage of cement
7. Approximately 70-80 m3 water will be required per day for various fill operations.
8. It is suggested to do CRF filling at least till the 80% of the stope void is filled and then the rest of the void may be filled with dry waste rock to optimize cement consumption.
9. The initial two to three consecutive stopes should be instrumented with MPBEx in hang wall. The wall movements should be studied and effectiveness of the CRF should be assessed.

III. RESULTS AND DISCUSSION

Mining wastes is generated during the process of extraction, beneficiation and processing of minerals. Extraction is the first phase that consists of the initial removal of ore from the earth. This is normally done by the process of blasting, which results in generation of large volume of waste (soil, debris and other material). This is useless for the industry and is normally just stored in big piles within the mine lease area, and sometimes, on public land. The bigger the scale of the mine, greater is the quantum of waste generated. Opencast mines are therefore more pollution intensive as they generate much greater is the quantum of waste generated compared to the underground mines. Open-pit mines produce 8 to 10 times as much waste as underground mines. So mining waste we can as a backfilling material.

IV. REFERENCES

[5]. Design of cemented rock fill system for back filling of blast hole stopes at kayad mines
[12]. Environmental waste management in non-ferrous metallurgical industries.


