Stope Productivity Improvement through Application of Cut-and-Fill Mining Method Variant at Bogala Graphite Mines, Sri Lanka

Abeykoon AGTBB, Lanka KASS, Ovitigala IR, Wijerathna KS, *Hemalal PVA and Dharmaratne PGR

Department of Earth Resources Engineering, University of Moratuwa
*Corresponding author – hpanagoda54@gmail.com

Abstract: Vein graphite mining is more often carried out by underground mining in Sri Lanka due to its mode of occurrence. Bogala underground mine is one of the major graphite mines in the country, where overhand cut-and-fill mining method is used for the extraction of graphite since the ore bodies are steeply dipping, with considerable vertical extent and clear and stable ore boundaries. According to the standard practices at the mine, ectraction is carried out at the stope by blasting of both rock and graphite vein in the exposed face, followed by hand sorting to collect graphite. Blasting the host rock and veins are carried out separately. Waste rock generated is used to fill the lower bench. Simultaneously, stope support is carried out and the working platform prepared. In this practice one cycle extends for four shifts and the research was launched with the objective of improving stope productivity by reducing the cycle time. In the proposed methodology, blasting of the face (graphite vein and rock) was carried out simultaneously resulting in the reduction of cycle time to two shifts. Therefore, in the research carried out, with the proposed alternative stope technique followed by froth flotation relevant performance indicators or parameters of productivity, cost and safety were analysed.

Keywords: Blasting, Cost, Cycle Time, Froth Flotation.

1. Introduction

The three basic principles on which a mining method is selected are safety, efficiency (maximum extraction) and economy (lowest cost/ maximum profit), where two and three are conflicting [1].

In Bogala underground mine, the mining method applied is Cut-and-Fill stoping, which is an artificially supported method. Since ore bodies are steeply dipping (greater than the angle of repose of the broken ore) and having considerable vertical extent and weak walls, in Bogala underground mine, Cut-and-Fill stoping method has proven itself the most appropriate mining method. Cut-and-fill stoping mining method is a highly selective supported mining method. There are mainly two types of cut-and-fill mining methods, namely, Overhand Cut-and-Fill and Underhand Cut-and- Fill mining. Out of this, Overhand Cut-and-Fill method is used in Bogala Underground mine, in which, mining of a block or a panel begins at the bottom of the ore body and progresses upward. During mining, the back of the excavation is temporarily supported using rock bolts, anchors and timber supports before the stope is back filled to form the floor of the next level of development [2].

There are a number of significant advantages with cut-and-fill mining method, such as minimizing ground movement, preventing subsidence with footwall and hanging wall supported by filling material. Hence the working is stable, waste material can be used as filling material and less possibility of dilution [1]. Generally, in a cut-and-fill mining, ramps or inclined tunnels are excavated to connect the surface to the underground ore body. Drifts are excavated to access the ore, and chute raises are excavated to provide the easy removal of ore from the mine. Drilling is the first stage in removing slices or ore using a mounted pneumatic or rotary percussion drill. The secondary stage involves blasting the ore to further break it up. Blasting is typically carried out using a combination of ammonium nitrate and fuel oil (ANFO), slurries and/or and emulsions. In some circumstances, a mechanism for secondary breakage of the ore is necessary and the drill-and-blast method, mud-capping, or impact hammers are used to accomplish this. It is common to remove horizontal slices of ore that span the entire width and length of the stope. Once a slice of ore has been completely mined from the stope, the empty space left behind is backfilled [3 and 4]. Sometimes ore waste is mixed with other materials such as sand, cement, waste rock, or dewatered mill tailings, a low-grade ore that has been rejected for processing to make the backfill. Backfill provides a working floor for miners and equipment as the mining progresses and also supports the stope walls.

Currently, the stopping cycle practiced in Bogala underground mine can be described as follows: drill both rock and graphite and blast the graphite vein, sort and collect the graphite and blast the rock, mucking and fill the lower level with barren rock, place anchors and timber posts and prepare roof and working flat form. Usually this process takes four days on average to complete one cycle [5]. After the stopping process, collected graphite is sent to the processing plant. Major upgrading of carbon percentage is carried out in the froth floatation process.

The intention of the proposed method is to modify existing mining method by applying a variant to the existing overhand cut-and-fill method in combination with froth floatation and by applying which, it is envisaged that the production rate and efficiency are increased and the amount of man hours required reduced in the overall process of graphite production. As a result of the modification proposed on the existing mining method, graphite processing activities will also be drastically changed.

2. Methodology

2.1 Identification of a suitable stope

Since the major objective of the research project is to compare the outcomes between existing and proposed method with a view to increase stoping productivity with intact dilution and recovery levels, it is of prime importance to identify, a stope to conduct the project. The essential requirements of the expected stope were to have lesser vein width variations throughout the mining process.

2.2 Collection of data corresponding to existing mining methodology

Data were collected on the current mining method. In the existing method, following activities were employed sequentially: drilling and blasting of the graphite vein, manual sorting and loading of blasted graphite, drilling and blasting the rock followed by mucking and refilling the lower bench along with fixing. This includes the collection of data on cycle time for drilling, charging, blasting, extraction of the ore, haulage, refilling with barren rock, supporting and processing of graphite, explosive usage, advance of the stope per cycle, quantity of ore haulage to surface, ore dilution before processing, man power input required for producing the final product, quantity of barren rock required for back-filling, support techniques applied, details regarding safety etc. Corresponding cost factors of the above parameters will also be identified along with unit costs of each parameter. Since data are collected for the existing methodology, most of the cost factors were obtained from company database, while only the remaining essential cost factors were determined during this period. Therefore accuracy of data was expected to be improved in this phase, with previously obtained data on stoping at that particular production unit of Bogala Graphite Lanka PLC.

2.3 Cost and cycle time analysis for existing mining methodology

Based on the unit cost values, total cost for the graphite extraction and upgrading process were calculated for conventional method applied in Bogala underground mines along with the amount of graphite production, time taken for the process and man hours involved.

2.4 Establishment of proposed mining method

Proposed cut-and-fill variant was developed at this stage in order to improve stope productivity. In the proposed method, rock and the graphite vein is blasted at once and the ore (a mix of graphite and rock) is transported and stockpiles prepared in order to conduct further upgrading by flotation. Therefore, in the proposed method following steps were employed: Drilling and blasting of face (graphite vein and rock simultaneously), scaling, mucking and fixing the stope and collecting the mix and sending to the stockpile.

2.5 Collection of data corresponding to proposed mining methodology

Data were collected on cycle time for drilling, charging, blasting, extraction of ore, haulage, refilling barren rock, supporting and processing of graphite, applied blasting methodology, amount of explosives, advance of the stope per cycle, quantity of ore haulage to surface, dilution of ore before processing, number of man hours required for producing final product, quantity of barren rock required for back filling, supporting methodology applied, details regarding safety etc.

2.6 Cost and cycle time analysis for proposed mining methodology

Analysis of the data obtained for the proposed mining method was conducted, where costs and cycle times were analysed. Therefore, corresponding cost factors of the above parameters were identified along with unit costs of each parameter. Still it is not expected to have significant variations in unit costs in materials and power for 1 m advance in stoping and material and maintenance cost in froth floatation process for 1 ton of output.

2.7 Analysis on stope productivity improvement

By comparing analyzed data for both existing and proposed methodologies, stope productivity improvement of proposed method was determined, in terms of cost, time efficiency and safety.

3. Results

Table 1 : General Parameters

Parameter	Existing	Proposed
Number of shifts	36	78
Number of cycles	9	39
Number of man-shifts	110	242
Number of man shifts per cycle	12.22	6.21
Advance	9.6 m	47.97 m
Advance per cycle	1.067 m	1.23 m
Average vein thickness	27.4 cm	61.78 cm
Extracted volume	43.58 m^3	164.89 m^3

3.1 Cycle time

Cycle times for both existing and proposed methods were analyzed to compare between efficiency of methods.

Table 2 : Cycle times of the existing method

Parameter	Time Taken (Minutes)
One cycle	1560
Drilling graphite vein	47
Charging graphite vein	42
Mucking blasted graphite	264
Drilling rock	58
Charging rock	51
Mucking rock and back filling	157
Fixing and supporting	92
Idling	849

Table 3 : Cycle times of the proposed method

Parameter	Time Taken (Minutes)
One cycle	780
Drilling graphite vein and rock	109
Charging graphite vein and rock	101
Mucking	289
Fixing and supporting	93
Idling	188

3.2 Grade of Ore

Table 4 : Grade of Ore

Parameter	Existing	Proposed
Grade of Ore before upgrading	83.73 %	82.49%
Grade of Ore after upgrading	98.90%	98.60%

3.3 Costs

Table 5 : Costs

Cost	Existing (LKR)	Proposed (LKR)
Stoping	72436.00	54972.61
Froth Flotation	12550.00	12914.00

4. Conclusions and Recommendations

Prime objective of this research project is to improve the stope productivity using cut-and-fill mining method variant in Bogala underground mines. The major change in stope activity was drilling and blasting of the graphite vein and the country rock simultaneously. This resulted in cycle time reduction by half. However, this resulted in higher dilution and greater haulage quantity to the surface, which requires higher degree of upgrading.

For this purpose, work place No. 6 (underground) was selected since it was expected to have uniform vein thickness based on exploration data and empirical knowledge. In this experimental stope, conventional mining method was applied for a period of nearly one month and the proposed method for nearly two months. At the time of the commencement of the conventional method, the average vein thickness was 27.4 cm, which falls in the normal range of vein thicknesses in Bogala mines. However, in the course of the application of the proposed method, the vein thickness of the experimental stope increased abruptly and significantly, to a value of about 61.8 cm, where the vein covered almost half of the stopes exposed face. Because of this reason, the expected dilution was reduced and the grade of ore before upgrading turned out to be equal to that obtained with the conventional method. Therefore, even in this step manual sorting was employed, since effectiveness of the manual sorting process is enhanced by lower dilution.

During analysis, it was expected to separate some amount of barren rock from graphite ore at the stope from visual identification. But due to lower dilution, back filling process could be done at the stope with visually separated barren rock material itself and hence there was no additional requirement for bringing back filling material from the surface.

Under the predicted conditions it was expected to have higher upgrading through froth flotation, but this significantly increased vein width resulted in a graphite content equal to that of the usual upgrading process. Even though with analysis it was expected to have higher cost for froth floatation, obtained cost is almost similar to the usual processing cost. Hence, determination of increased upgrading costs, power requirements, need of enhanced froth flotation process could not be determined.

In the stoping process it was expected to have lower cost for 1 m advance, due to reduced labour cost as a result of halved cycle time. The values obtained from the research reflects that expected result since there is a cost reduction of LKR 17463 for 1 m advance.

Also according to analysed data, worker idling for one cycle of stoping has reduced significantly with the application of the proposed method; One obvious reason was the reduction of the number of shifts. However, it also resulted in increased productivity in the stoping process.

With the obtained results it can be concluded that the proposed method is effective, efficient and profitable when compared with the conventional method for vein thickness of 61 cm or above.

Because of the unexpected increment of graphite vein thickness, it can only be concluded that the proposed method is profitable and productive only for vein thickness equal or above 61 cm. Therefore, further studies on other vein thicknesses are recommended.

Results may vary on the type of geology and vein parameters; hence the results cannot be utilized as universal model for graphite mining.

Segregation can be incorporated to the process to reduce the upgrading required through froth floatation.

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References

[1] Dharmaratne, P. G. R., Hemalal, P. V. A, and Hettiwatte, M. C., (2013) Evaluation of Overhand Cut-and-Fill Mining Method used in Bogala Graphite Mines, Sri Lanka, 19th ERU Research Symposium, November 26, 2013, The University of Moratuwa, Sri Lanka : 53-58.

[2] Hemalal, P. V. A., (1992) Critical Evaluation of the Overhand Cut-and-Fill mining method with special; reference to Bogala Graphite mines Sri Lanka, Journal of the Institution of Engineers, Sri Lanka, 20(1).

[3] Hustrulid, W. A. and Bullock, R. L., (1982) Underground Mining Methods, Engineering Fundamental and International Case Studies, 1st ed., pp. 287-355.

[4] Naghadehi, M. Z., Mikaeil, R. and Ataei, M. (2009) The application of fuzzy analytic hierarchy process (FAHP) approach to selection of optimum underground mining method for Jajarm Bauxite Mine, Iran. Expert Systems with Applications : 8218-8226.

[5] Welideniya, H. S. and Ekanayake, K., (2012) Challenges Faced by Narrow Vein Graphite Mining and Influence of Graphite Infill on Wall Stability, Proceedings of Narrow Vein Mining Conference 2012, Perth, Western Australia, March 2012 : 71-75.