Substantiation of chamber parameters under combined open-cast and underground mining of graphite ore deposits

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ABSTRACT: The move from open-cast to combined mining method of developing Zavalyevsky deposit of graphite is considered in the paper. The selection of chamber dimension satisfying conditions of long-term stability is one of the questions for scientific substantiation of the move to combined mining method of deposit development.
With this purpose physical and mechanical properties of graphite and enclosing rocks are determined. Stress and strain condition of rocks around the chambers using the method of finite elements is studied.

1 INTRODUCTION

The main consumers of graphite are enterprises of metallurgical, electrical engineering, mechanical engineering, aircraft and other branches of industry. One of the most important raw material base supplying graphite is Zavalyevsky deposit of graphite (Ukraine).

Nowadays the development of deposit is carried out by the open-cast method. The Southern-Eastern part of the deposit is worked-out. The depth of the quarry is 100 m and it is very close to its boundaries.

A great part of commercial reserves is within the pillars under the bed of the Yuzhny Bug river, dressing mill and the village. While deepening a quarry it's boundaries should be moved. Besides, it is necessary to move aside dressing mill and the bed of the Yuzhny Bug river. For further open-cast mining operations it is required to construct a dam and offtake bed channel, relocate dressing mill and amortize the land of 400 ha. Total cost of underground mining of graphite is muck higher then it was expected. Therefore, it is required to work-out the deposit by combined mining method, e.i. to carry out further development of the quarry up to the level of 19 m. For further deepening reserves of graphite ores are worked-out in designed contour of Southern-Eastern quarry without wall cutback. After that the transition to underground mining with dressing mill reconstruction is performed. It's capacity is up to 62,0 thousand ton of graphite per year. At the same time the thickest and the richest ore bodies of the Northern part of Zavalyevsky deposit are worked-out.

Taking into account the demands as for Earth surface protection, steep dip of ore body, available information concerning mechanical properties of ore and enclosing rock, attempts to avoid significant losses and delution under the safe condition of stoping, it is recommended to apply level and chamber mining method. In this case ore is broken by deep boreholes and subsequent filling of worked-out area is carried out by consolidating stowing.

At the same time three chambers are worked-out. Chamber stowing is carried out after finishing extraction. There are three stages of filling worked-out chambers by consolidated stowing:

- filling chamber bottom with the mixture of higher content of binding substance with the aim to obtain hardened stowing on the level of the dam;
- filling chamber from the bottom till the top stopping on the level of the dam;
- additional chamber stowing with higher content of binding substance.

Applying chamber method of mining determines the necessity of substantiating chamber and pillar dimension meeting the requirements of long-term strength. For this purpose it is required to carry out the study of physical and mechanical properties of graphite and enclosing rock.

2 DETERMINING PHYSICAL AND MECHANICAL PROPERTIES OF GRAPHITE AND ENCLOSING ROCK

Study concerning determination of breaking stress under one-axle compression and on tension was carried out on regular form samples according to the standard methodic (Baron L.E., Loguntsov V.M. & Nozin E.Z., 1962).

According to this methodic cylindrical form samples with the diameter and height ratio equal one were used during the study. Diameter of the samples was from 50 till 51 mm for graphite and from 57 till 58 mm for enclosing rock. Sample processing was carried out in such a way that fluctuation from the end parallelism was not more than 0,05 mm, from end perpendicularity to the cylinder element was also 0,05 mm. Tests were performed on the press PG-100A.Ball centering device was used for strict load centering. Loading was performed gradually increasing the load up to sample destruction .Value of destructive load was fixed.

Strength under tension is determined by Brazil method on regular form samples: diameter of the cores is 57-58 mm. Height of the cores is equal to the diameter. Determination was carried out by the method of diametrical compression. It means that cylindrical samples were broken by the forces applied along diametrically opposite elements.

Characteristic of the rock hardness under displacement is its shift resistance created by two physical factors: internal friction and cohesion. Internal friction can be comparatively easy calculated as it represents the interacting force under deformation taking place between mineral particles. This deformation is proportional to regular stresses caused by external load.

Cohesion is that part of shift resistance which is not connected with stresses caused by external load. It is determined by only molecular binding forces and cannot be constant value.

So, complete resistance of the rock to the shift is expressed by the sum of internal friction caused by external forces and cohesion. It was determined on the regular form samples (Turchaninov E.A., Medvedev R.V. & Panin V.E., 1967). Sample test was carried out on the press with the help of inclined cores with angles of $\alpha_1 = 35°$ and $\alpha_2 = 55°$.

It is known that the rate of distributing elastic waves depends on the module of material elasticity. Therefore, nowadays method of determining rate of compression and cross elastic wave distribution – sound dynamic method – is widely used to determine elastic values of rock properties (elasticity module and Puasson coefficient).

At present this method is one of the most perspective as it is much cheaper and simpler then other well-known methods (particular statistic ones).Besides, it enables to determine rock properties within massif. That makes it unique while performing field operations. Elastic values of rock properties obtained under statistic and dynamic loads are different due to various character of rock deformation.

Ultrasound defectoscope UK-10P, selective amplifier EGU-60, audio generator LEG-60, vacuum tube voltmeter, conductors made of zirconate-titanate barium with δ = 10000 were used to determine Yung module and Puasson coefficient using dynamic method. Resonance of compression and cross waves were determined with the help of these devices. The rate of compression and cross wave transmission was determined according to this resonance.

The value of dynamic elasticity module was determined after finding out the rate of compression and cross wave transmission within the samples.

Table 1 shows averages of determining physical and mechanical rock properties.

Estimation of result reliability of experimental study using the method of Monte-Karlo probability theory was carried out (Ventsel E.S., 1972).It was stated that the level of confidence is equal to 0,84 - 0,99. It enables to confirm that the amount of tests taking into account while determining physical and mechanical rock properties is enough to be considered as a true one.

Table 1. Mechanical properties and elastic characteristics of graphite ore and enclosing rock.

No	Rock	Compression		Extension		Dynamic method			Module of shifting, 10^{-10} Pa
		Amount of samples	$\sigma_{сж}$, MPa	Amount of samples	$\sigma_{раст}$, MPa	Amount of samples	Elasticity module, 10^4 MPa	Puasson coefficient	
1	Graphite	9	20,2	6	1,0	8	1,55	0,26	0,61
2	Quartzite	8	60,3	7	8,8	8	5,42	0,21	2,24
3	Calciphyre	8	40,1	7	6,7	8	4,79	0,25	1,81
4	Gneiss	7	31,4	6	6,8	8	4,51	0,32	1,68
5	Calc-silicate hornfels	8	64,1	7	10,3	6	7,10	0,22	2,92

3 SUBSTATIATING PARAMETERS OF HEADING-AND-STALL MINING METHOD

Development with consolidated stowing means that sizable chambers are worked-out beforehand. After that worked-out chambers are filled in consolidated stowing. The areas (pillars) left between chambers are worked out in three months after complete stowing consolidation. Pillar size is usually equal to the chamber size.

The study of rock stress-strain condition using the method of finite elements was carried out to substantiate chamber and pillar sizes (Zienkiewicz O.C. & Taylor R.L., 2000).

Ore and enclosing rock are considered as elastic body and the problem is described in terms of elasticity theory. Chamber roof and interchamber pillars are loaded by the press force of overlying rock. These forces are perpendicular to chamber direct axis. All cross-sections are in the same conditions and there is no shifting in longitudinal direction. As cross-section conditions are the same, it’s enough to consider thin layer between two sections. The distance between them is equal to one. The system is in condition of the plane deformation.

Chamber location is periodic in both sides. Due to the symmetry only the area between symmetry axis is considered.

The problem was solved under the following boundary conditions:

- the absence of horizontal point shifting of the left and the right boundaries due to the symmetry;
- external forces are not applied to the right and the left boundaries as well as to the internal points (gravity forces are not taken into account), rigid fixing prevents area turning as a whole one;
- the weight of overlying rock is replaced by concentrated forces applied to the points of horizontal line.

Study of stresses within chambers and chamber roof was carried out to the following tasks.

Task 1. Chamber width is 10 m, height is 48 m, pillar width is 10 m. Chamber shape is symmetric. Due to the calculation stresses in the gravity center finite elements were obtained. Stress epures were build according to them (Figure 1).

Maximal tension stresses in the center of chamber width is $7 \cdot 10^5$ Pa. Strength margin in the center of the roof is 1,4.

Maximal compression stresses within the chamber is $-44,1 \cdot 10^5$ Pa. So, strength margin is 4,5.

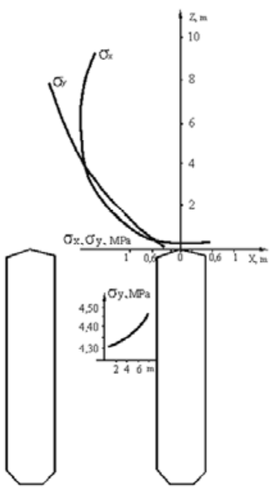

Figure 1. Stress epures around the chambers. Variant 1.

Task 2. Chamber width is 10 m and the height is 48 m, pillar width is 10 m. Chamber shape is not symmetric. Stress epures are built taking into account the results of calculation (Figure 2).

Maximal tension stress in the center of the chamber roof is $7,5 \cdot 10^5$ Pa. Strength margin is 1,3. Maximal compression stresses is $-43,2 \cdot 10^5$ Pa. Strength margin is – 4,6.

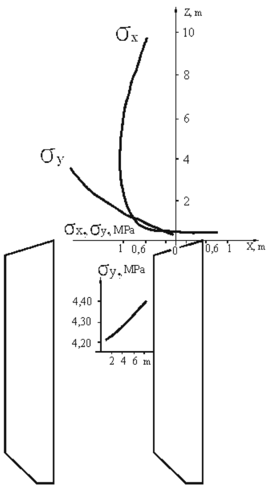

Figure 2. Stress epures around chambers. Variant 2.

Task 3. This strength margin within the roof is insufficient for durable construction stability. The change which the roof in the shape of basket described by two radius brings in to the stress field is considered. Pillar width and chamber span are the same - 10 m. Stress epures are built according to the calculation data (Figure 3). In this case strength margin is sufficiently increased and it is 5 in the center of the roof as well as within the pillars.

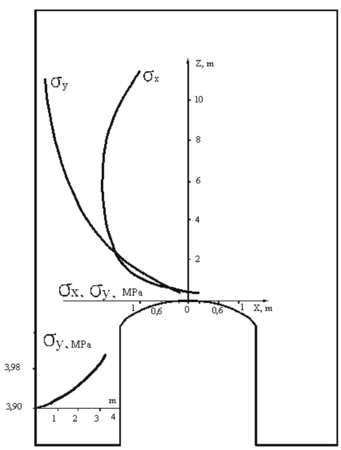

Figure 3. Stress epures around chambers. Variant 3.

Task 4. The width of chambers and pillars should be chosen to ensure safe support of the roof with the help of enterchamber pillars.It is required to find out optimal size and shape of the roof meeting the demand of stability as well as increased graphite extraction.

Stress distribution around chambers with the width of 14 m and pillars with the width of 6 m were considered to choose optimal pillar and chamber sizes Stress epures were build taking into account calculation (Figure 4). In this case tension stresses in the center of the roof is $2,99 \cdot 10^5$ Pa, that corresponds to the strength margin equal to 3,3.Compression stresses within the pillars is $52,47 \cdot 10^5$ Pa, strength margin is 3,7.

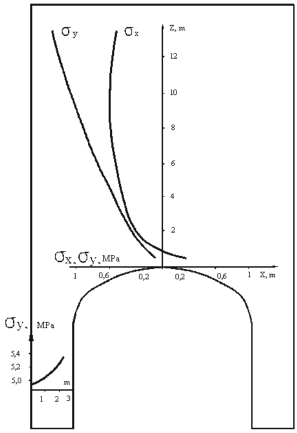

Figure 4. Stress epures around chambers. Variant 4.

4 CONCLUSIONS

It is recommended to work-out the deposit using combined method, that is, to carry out further quarry development up to the point of 19 m and transition to level- chamber mining method filling the goaf with consolidated stowing.

The choice of system development parameters was based on the study of stress distribution character according to four schemes in Figure 1, 2, 3, 4 in the form of epures. Two first calculation schemes showed that strength margin within the roof was 1,5 that is not enough for long-term construction reliability. That is why these schemes cannot be recommended to apply. According to the third scheme where distance between chambers is 10 m and arch is outlined by the basket curve, strength margin within roof and pillars is sufficiently increased and is 5. According to the fourth scheme where distance between chambers is 14 m and pillar width is 6 m, strength margin correspondingly is 3,3 and 3,7.

Taking into account that heading-and stall method with stowing worked-out area will be used in the quarry and to increase graphite extraction it can be recommended to apply the following parameters: chamber width is 14 m, pillar width is 6 m, chamber height is 48 m, the shape of the roof is basket.

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