IMPROVEMENT OF CURRENT MINING TECHNOLOGY IN ESTONIAN OIL SHALE MINES

Juri-Rivaldo Pastarus1, Merle Otsmaa2, Julia Shommet3, Aleksander Pototski4, Rein Kuusik5

1Tallinn University of Technology, Tallinn, Estonia, juri-rivaldo.pastarus@ttu.ee
2Tallinn University of Technology, Tallinn, Estonia, merle.otsmaa@ttu.ee
3Tallinn University of Technology, Tallinn, Estonia, Julia.shommet@hotmail.com
4Tallinn University of Technology, Tallinn, Estonia, aleksander.pototski@energia.ee
5Tallinn University of Technology, Tallinn, Estonia, rein.kuusik@ttu.ee

ABSTRACT

In spite of high economical parameters of the current room-and-pillar mining technology it is not effective. Backfill technology will be applicable in condition of Estonian oil shale mines. Nowadays attention has been focused on the use of combustion (ash) and mining (limestone) by-products as filling materials. Some backfill materials and mixtures were tested. It is calculated necessary strength parameters for backfill massif/pillar. The choice of a proper backfill material and other mixture parameters is essential for controlling fill costs and backfill properties after placement. Placement of backfill will change the geomechanical stability of the mine area and implicate changes in support.

Keywords: oil shale, limestone, ash, oil shale mine, backfill, backfill mixture, backfill material, strength parameters, room-and-pillar mining, pillar.

Introduction

The oil shale industry of Estonia provides a significant contribution to the country’s economy, but causes a large number of technical, economical, ecological and juridical problems. Oil shale is used as a fuel for producing energy or shale oil. More than 90% of the electricity in Estonia comes from oil shale [1]. The mining sector faces challenges to increase the output of mines and at the same time to minimize the environmental impact of mining. The oil shale reserves in Estonia are estimated to be approximately four thousand million tons [2].

Underground oil shale production is performed using a room-and-pillar method with blasting. This method is cheap, highly productive and easily mechanized. As the main disadvantage is to be underlined that the lost of rock in pillars is nowadays about 25 – 30%. If the depth of excavation is over 60 m, the losses in pillars increase up to 40%. On the other hand, there are problems of use mining and combustions by-products, due to large amount of neutral (limestone) and hazardous (ash) waste generated in oil shale based heat and power production. A complex approach is needed for solving the above mentioned problems.

Nowadays attention has been focused on the use of combustion and mining by-products as filling materials. Backfilling in mining operations is the developing trend over the world. Generally, the effect of backfilling is significant allowing [3, 4]:
1. Minimization of surface deformation.
2. Improvement of safety in mining.
3. Reduction of volume of waste to be deposited on surface and respective area needed.
4. Facilitation of mining operations.
5. Increase of rock extraction ratio.

The backfill technology is considered as applicable in the conditions of Estonian oil shale mines [5, 6]. A number of options were elaborated for different mining methods. On the same time there is lack in data characterizing the above mentioned waste as filling materials and fill mixture. Due to that, the aim of currently presented study was a partial fulfilling of lack mentioned.

Current mining technology

In Estonian oil shale mines the room-and-pillar mining technology with blasting is used. It gives an extraction rate about 70 - 75%. The mining field is divided into panels, which are subdivided into mining...
blocks, approximately 300 – 350 m in width and 600 – 800 m in length each. A mining block usually consists of two semi-blocks. The commercial oil shale bed is embedded at the depth of 50 – 70 m. The height of the room is 2.8 or 3.8 m. The room is very stable when it is 6 – 10 m wide. However, in this case the bolting must still support the immediate roof. The pillars in a mining block are arranged in a singular grid. Actual mining practice has shown that pillars with a square cross-section suit best. A work cycle lasts over a week. Current room-and-pillar mining system is characterized by significant loss of oil shale in pillars (25 – 30%), safety and environmental problems. We need a new, more progressive mining technology.

**Fill materials**

In Estonian oil shale mining and processing industry a wide assortment of wastes could be considered as available fill materials. They are waste rock (limestone) and oil shale combustion ash, which contains binding agents and other additives. The choice of proper backfill material parameters is essential in the control of fill costs and backfill properties after placement.

Oil shale waste rock (limestone) is formed as reject material from enrichment plant and material from crushing and screening operations in aggregate production. It uses two- or three-stage crushing plant with impact crushers. Separation of limestone from the raw oil shale generates large amount of waste, which consists in 82 – 94% of limestone and 6 – 28% of oil shale residues. The main problem of the properties of aggregate is low resistance to freezing and thawing. Uniaxial compressive strength of limestone aggregate is between 35 and 45 MPa. Waste rock which is not usable in civil engineering and road building may be used for backfilling. Because of constant temperature of the oil shale underground mine, which is 6 - 8°C, the resistance to freezing and thawing is not required. Raw oil shale consists about 60% of limestone. It is after separation stockpiled in form of cones (55 m height) and total area of these piles is currently about 3.5 km². Limestone production is about 6.5 Mt per year.

The two Estonian Thermal Power Plants use two different oil shale combustion technologies: pulverized firing (PF) and circulating fluidized bed combustion (CFBC) technology. The compositional and morphological variation between PF and CFBC ashes [7] are principally controlled by firing temperature differences between combustion technologies, and by grain size differences of oil shale fuel. PF technology exploits high temperature combustion (1250 - 1450°C), whereas in CFBC combustion the temperature in furnace chamber is 750 - 950°C. Different composition of ash fractions has significant influence on the potential application of ashes as secondary raw materials. The chemical composition of all ash types is dominated by CaO (up to 50-52%, up to 20 - 28% as free lime). Uniaxial compressive strength standard samplestone from of ash is from 1.2 to 5.7 MPa. From the point of chemistry ash from oil shale combustion is very similar to cement (with exception in alkalinity) and there is no significant difference between the potential environmental impacts from the side of oil shale ash. The amount of ash that remains after burning makes up 45 – 47% of the oil shale mass. The ash deposits together with transportation water sedimentation ponds occupy currently about 22 km². Oil shale combustion residues from power plants are being produced over 5 Mt per annum.

**Strength and elastic parameters of backfill mixtures**

Determination of strength and elastic parameters of backfill mixtures after placement are cumbersome, time consuming and expensive. If it is known the uniaxial compressive strength of backfill, it is possible to calculate the other parameters, using mathematical statistics tools [8, 9]. Below presented calculation method will be used for preliminary determination of backfill compound parameters and for selection of fill mixture.

Internal friction angle is in range of 6.6 – 17.5°. Cohesion of filling material can be calculated by following formula [9]:

\[ C = 0.038 \sigma_c + 0.05 \]  

where \( C \) – cohesion, MPa; \( \sigma_c \) – uniaxial compressive strength, MPa.

Elastic parameters of fill material are characterized by following correlations [9]:

276
\[ E_d = 8.33 \ln\left(\frac{\sigma_c}{1.5}\right) \]  

(2)

\[ E_s = 0.15E_d^{1.4} \]  

(3)

where \( E_s \) – static Young’s modulus, GPa; \( E_d \) – dynamic Young’s modulus, GPa;

Above presented formulae (1, 2 and 3) are valid if the uniaxial compressive strength is between 2 and 10 MPa. The general calculated parameters of fill materials are presented in Table 1.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Uniaxial compressive strength, MPa</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>2.0</td>
</tr>
<tr>
<td>Cohesion, kPa</td>
<td>126</td>
</tr>
<tr>
<td>Static Young’s modulus, GPa</td>
<td>0.5</td>
</tr>
<tr>
<td>Dynamic Young’s modulus, GPa</td>
<td>2.4</td>
</tr>
</tbody>
</table>

Some fill mixtures containing different amount of limestone and ash have been tested. Measurements showed that the uniaxial compressive strength of backfill compound is in range of 1.8 - 5.6 MPa what gives the static Young’s modulus 0.4 - 3.0 GPa. Analysis showed the coincidence of calculated and experimentally determinate strength and elastic parameters of filling materials prepared from Estonian oil shale mining and processing wastes.

**Design of pillars**

The calculation methods for pillar strength parameters are following [9]:

1. Backfill is loaded with the whole weight of the overburden rocks up to surface. In this case the structure of backfill can be changed, but not stability. The quality of backfill is only determined by compression parameters.

2. Pillars being in area of constant rock pressure. The stable parameters of the pillars will be calculated by conventional calculation methods [10, 11].

3. Pillars being located in the area of a stope. In this case there are not exact calculation schemes.

Load on the pillar depends on the depth of excavation and percentage by volume of backfill in underground room. Dependence between the percentage of backfill in a room and necessary uniaxial compressive strength of a pillar calculated according [9] is presented in Fig. 1.

![Fig. 1: Pillar load dependence on percentage of backfill by volume](image-url)
Analysis showed that the reasonable percentage by volume of backfill is from 50% to 80%. In this case the load on a pillar is less than 4 MPa. Consequently, the uniaxial compressive strength of the backfill (pillar) after placement does not exceed 4 MPa. Load on a pillar depends on applicable technology, in particular on roof stability conditions and on quantity of available backfill materials (ash and limestone).

**New mining technology**

A number of options were elaborated for different mining methods and different ways of backfilling [12]. In Fig.1 is presented a scheme of advanced room-and-pillar mining technology with backfill in condition of Estonian oil shale mines.

![Fig. 1: Room-and-pillar mining technology [12]](image)

By this mining technology the extraction of oil shale will be made by using continuous miner [13] or blasting works [14]. It is visible that extraction and backfill are fully correlated. Advance of mining is limited by efficiency of fill process.

The width of the room is determined by stability of the immediate roof. Although the latter is very stable when it is 10…12 m wide, bolting must still support the immediate roof. Pillars supported the main roof. The width of the pillar is about 10 m. The load on the pillar is 3…4 MPa, depending on the depth of the oil shale bed (60…80 m).

**Conclusions and recommendations**

In spite of high economical parameters of the current underground mining (room-and-pillar) technology it is not effective. If the excavation depth is over 60 m, the extraction factor is only 60 – 70% being a main disadvantage if this technology. Backfill technology is evaluated to be for Estonian oil shale mines in this context more effective one.

Underground utilization of oil shale combustion and mining wastes reduces volume and area required for their surface disposal, and should guarantee higher efficiency of mining works as well as the stability of ground surface. Limestone from enrichment stage together with ash forming at combustion of oil shale and having binding properties are the promising fill materials in Estonian oil shale mining.

Applicability of calculation methods for determination of backfill parameters was demonstrated - by using empirical formulas it is possible to calculate the strength and elastic parameters of backfill compounds, compiled on bases of oil shale processing wastes, after placement.
Investigations proved that the load on a pillar depends on the depth of excavation and percentage by volume of backfill in underground room. If the percentage by volume of backfill in a room is 50 – 80% and the excavation depth 60 – 80 m, the load on a pillar does not exceed 4 MPa. Available mixture parameters after placement guarantee the stability of a mining block. The process of backfill in oil shale mines should be preceded which an analysis of some important questions connected with environmental protection and cost estimation.

Acknowledgements


REFERENCES