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DEPOSITION OF LIGHT ASH MIXES IN MINED SPACES

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ABSTRACT
The possibility of filling empty underground spaces, which exist owing to extracting mineral raw materials, with light ash and cement light ash mixes have been studied for the purpose to reduce the impact of deep mining on the surface. The method of physical modelling was used to study the behaviour of light ash mixes deposited in extracted mine spaces. The models were constructed for two different geometries of underground extracted mine spaces - into cavities of the type of large slits created in the course of mining in steeply lode deposits without subsequently filling the empty space and in vertical shafts of rectangular or circular cross-section with horizontal side headings which have partly caved in due to mine shocks or other seismic events.

KEYWORDS: physical modelling, reducing the impact of deep mining, deposition of the light ash mixes

1. INTRODUCTION

In recent years, more and more attention is being devoted to reduce the impact of deep mining on the surface. The problem of stability of the surface in areas which have been undermined in extracting mineral raw materials is the subject of one of the partial stages of an extensive project dealing with the problems of stability in undermined areas, as well as with research into preventive measures. The possibility of filling empty underground spaces with light ash and cement light ash mixes, which are a waste product of operating thermal power stations, gasworks and incinerators is being studied for this purpose in an effort to reduce the impact of deep mining on the surface.

The method of physical modelling can be used to study the behaviour of light ash mixes being deposited in extracted mine spaces.

The models were constructed for two different geometries of underground empty spaces:

(a) Deposition of light ash mix into cavities of the type of large crevices created in the course of mining in steeply lode deposits without subsequently filling the empty space. These cavities are characterised by two of their dimensions being significantly larger than the third, by at least one order.

(b) Light ash mix deposition in vertical shafts of rectangular or circular cross-section with horizontal side drifts which have partly caved in due to mine shocks or other seismic events.

Three conditions of the underground spaces were modelled in both cases:

1. The underground spaces are dry and the light ash mixes are deposited in these spaces;
2. Once the underground spaces have been filled with dry light ash mix, the mine water begins to rise and soaks the light ash mixes;
3. The light ash mixes are deposited in spaces already flooded by mine water.

The scale of 1:100, which appeared suitable for modelling a sufficiently large area, as well as from the point of view of the technical possibilities of modelling, was selected for all the modelled cases. The process of light ash deposition in models was document on photographs taken during the model experiments.

2. LIGHT ASH MIX DEPOSITION IN CAVITIES OF THE LARGE CREVICE TYPE

2.1. MODEL DESIGN

Physical models were carried out which represented selected extracted blocks of lode idealised for the purpose of testing various configurations. The situation of the lode and blocks from the area of the mines in Lešetice near Příbram (Roček V. & Kotal Z., 1976), in particular the blocks on levels 20 and 22 of Mine 1, served as the model.

The dip of the structures was taken to be 75^{o} - 85^{o}, which was modelled by curving the bedrock of the structure (lode), and the width of the stope 2 - 8 m, i.e. 2 - 8 cm in the model (Fig. 1). The surface of the bedrock was roughened. The models represented an extracted space 143 m long and 80 m high (143 x 80 cm in the model) formed by three blocks A, B, C, with high of 50 m (50 cm in the model) separated from the

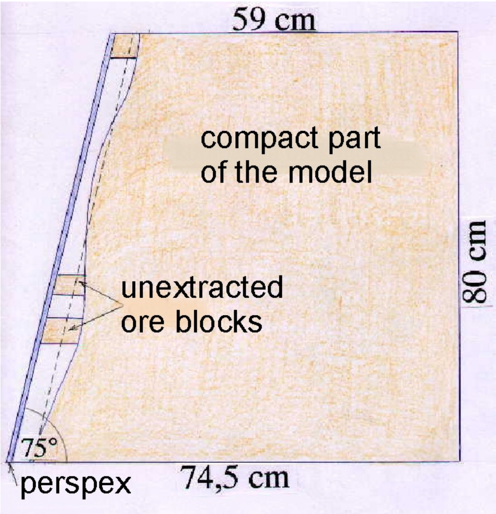

Fig. 1 Model design: side-view.

lower part of the model by the equivalent of a drift with partially preserved, disconnected ores in place above and below the drift (Fig. 2, 3).

The width of the blocks was around 50 m. Block A was modelled by a full extracted section. In its bottom part the ores in place above and below the drift were partly preserved to be able to monitor the falling of the light ash through to the lower modelled block. The latter had also been full extracted with the exception of the ore in place around the break-through chute. In Block B, in the middle part of the models, the ores in places, created by inter-level mining were preserved, as well as the ores in place above and below the drift in its lower part. Block C illustrates the situation in which, e.g., due to weak ore mineralisation, part of the block was left unextracted. The back of the lode was formed by a perspex plate which enabled the distribution of the light ash in the model space to be observed and photographed.

The light ash was poured into the model through pipes located above the centre of each block. In the space below the model stand was located the water centre which fed the water to the space of the model stand.

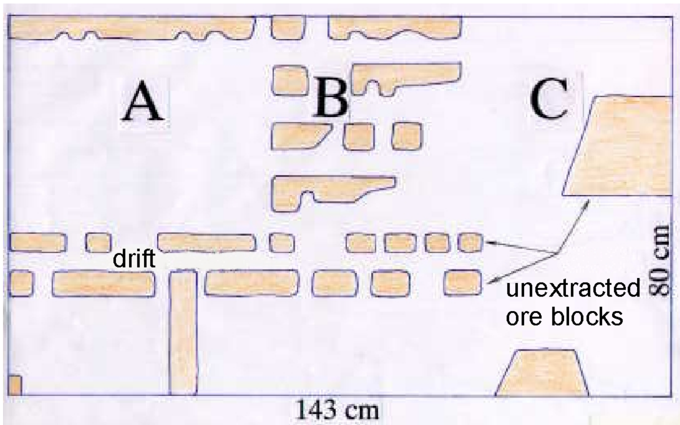

Fig. 2 Model design - blocks A, B, C and distribution of ores in place in the model space.

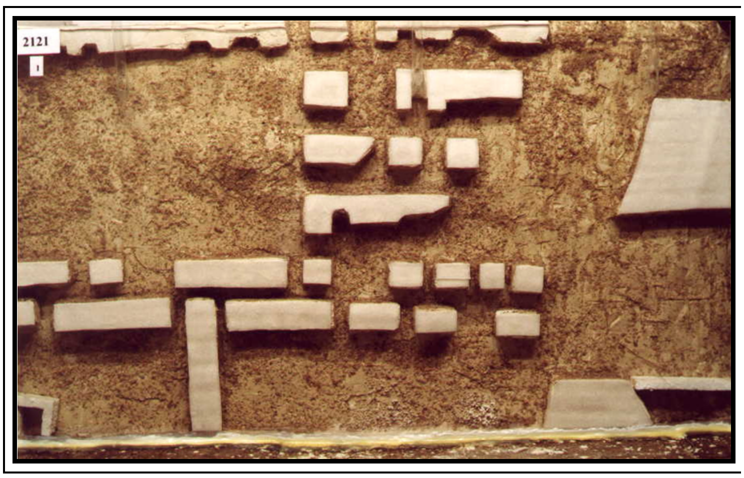

Fig. 3 Photograph of model prepared for experiments

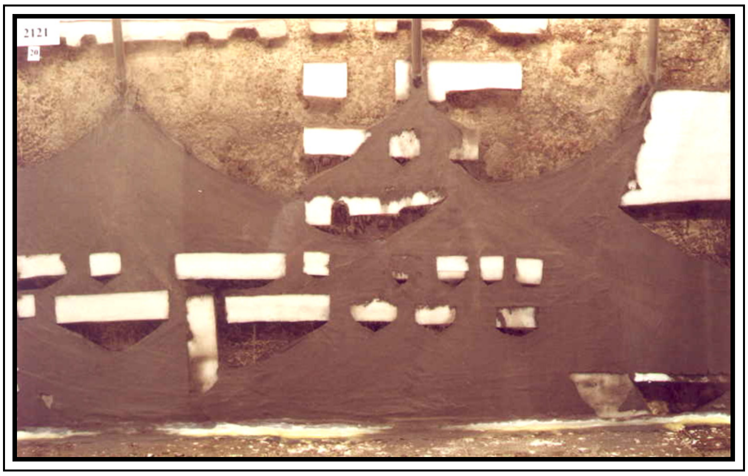

Fig. 4 Situation after the light ash had been poured into all three blocks

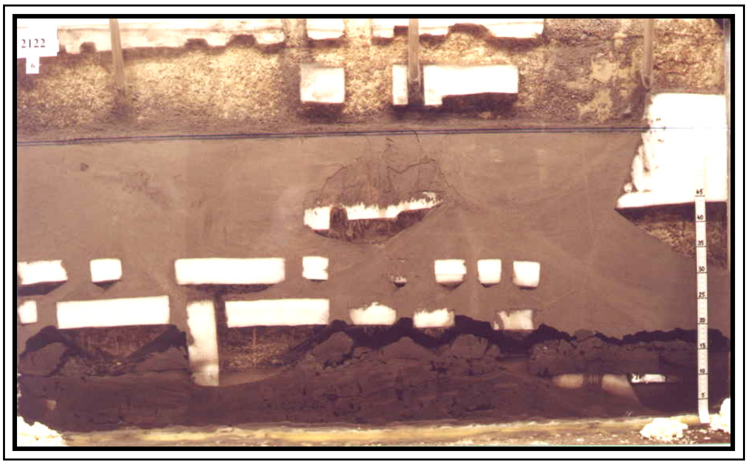

Fig. 5 Gradual soaking of the light ash in the model

2.2. DEPOSITION OF LIGHT ASH IN DRY EMPTY SPACES OF THE MODEL (MODEL 2121)

In pouring the light ash into the model, the light ash gradually fills the whole empty space with the exception of the small parts below the modelled ores in place (Fig. 4). The unfilled part represented only 8% of the total filled space (given by the model geometry). The low angle of slope resulted in the light ash being distributed far out to the sides in the lower part of the model even if it was poured into the middle part of the model (Trčková et al., 2001a).

In spite of the complicated modelled situation in which a larger number of ores in place were put in the way of the light ash, and the latter stuck to the modelled roughened and adhesive bedrock of the cavity, the light ash fell through to the lower part of the model and the passage ways did not become clogged.

2.3. SIMULATION OF GRADUAL RISING OF MINE WATERS (MODEL 2122)

The model, into which dry light ash had been poured in advance, was gradually flooded by the water coming in through the holes in the bottom of the stand (Trčková et al., 2001b). The level of the water surface was controlled. The light ash became soaked and began to settle in the lowest parts of the model. The light ash did not behave like loose material, but whole blocks were dislodged and slid into empty spaces (Fig. 5).

The light ash gradually filled the whole lower part of the model, inclusive of the cavities under the modelled ores in place (Fig. 6). The light ash deposited in water reduced its volume significantly due to the expulsion of the gas phase.

Fig. 6 Situation at the end of the model experiment

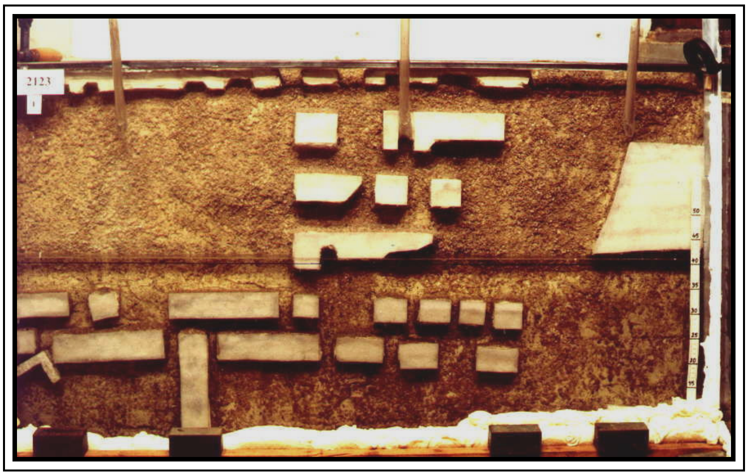

Fig. 7 Model ready for pouring of light ash

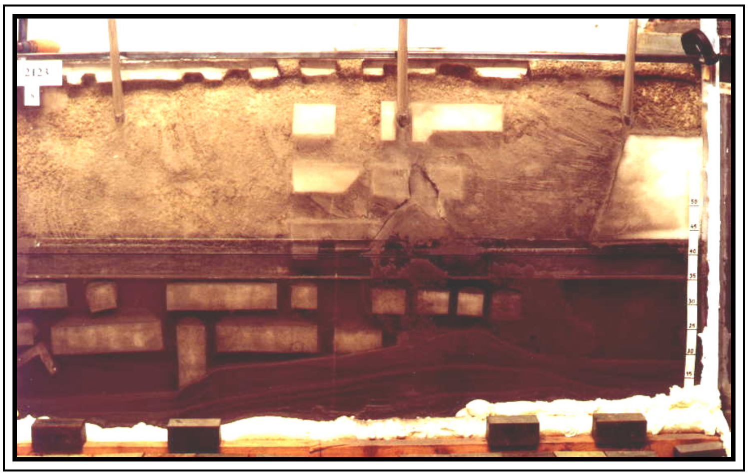

Fig. 8 Deposition of light ash in flooded spaces

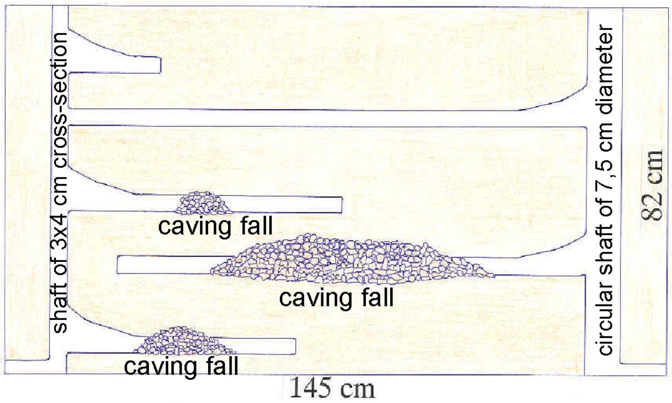

Fig. 9 Design of the model situation

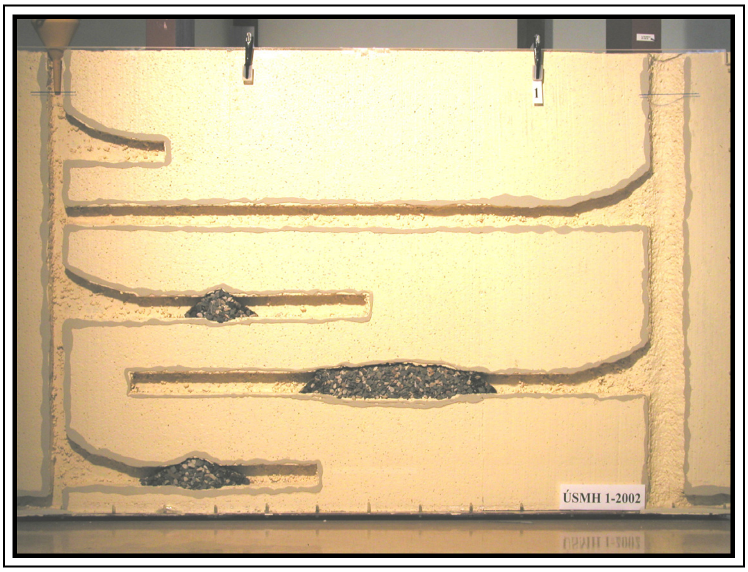

Fig. 10 Photograph of the model ready for experiments

2.4. SIMULATION OF DEPOSITION OF LIGHT ASH IN FLOODED SPACES (MODEL 2123)

The model was filled with water up to a height of 40 cm above the model bottom (Fig. 7).

Gradual pouring of dry light ash into the model followed. Only the middle pipe was used to be able to observe the distance to which the light ash was carried from the centre of the model (Trčková et al., 2001c). The light ash willingly soaked up the water and settled along the whole length of the model bottom. Part of the light ash also settled above the modelled ores in place located higher (Fig. 8).

3. LIGHT ASH MIX DEPOSITION IN VERTICAL SHAFTS

3.1. MODEL DESIGN

Underground workings, designated for filling with light ash mix, were specified as vertical shafts of rectangular 3 x 4 m cross-section, or 2 - 8 m circular cross-section with horizontal side drifts, 8 - 15 m^2 cross-section. The given problem assumed that the underground spaces had partly caved in due to mine shocks and other seismic events, and that the lengths of the caving falls were 10 - 60 m. The purpose of the modelling was not only to find out whether the light ash will also penetrate beyond the modelled caving falls when poured in, but also to assess the stability of the caved ground in case of simulated seismic events.

A model stand, internal dimensions 145 x 82 x 4 cm (length by height by width), whose front wall was again formed by a perspex plate, was used to construct the model. Water cocks with connected hoses for filling the models with water were located in the sides of the model stand just above its bottom. A vertical shaft of rectangular 4 x 3 cm cross-section, running the whole height of the models, was place on the left side of the models (Fig. 9). Three horizontal drifts, whose height of 8 - 9 cm at the entry to the drift gradually reduced to 3 cm, ran sideways from the shaft. The fourth drift, which runs into the shaft on the right side of the model, was only 2.5 - 3 cm high. The width of the drift was no more than 4 cm. Caving falls 10 cm and 20 cm were modelled in the two bottom drifts running into this shaft.

The vertical shaft on the right side of the model was modelled semi-circular with radius 7.5 cm. The drift, already described, running the width of the model and connecting both modelled shafts, ran into the upper part of the shaft. There was another drift in the lower part of the shaft in which a caving fall 60 cm in length was simulated (Fig. 10).

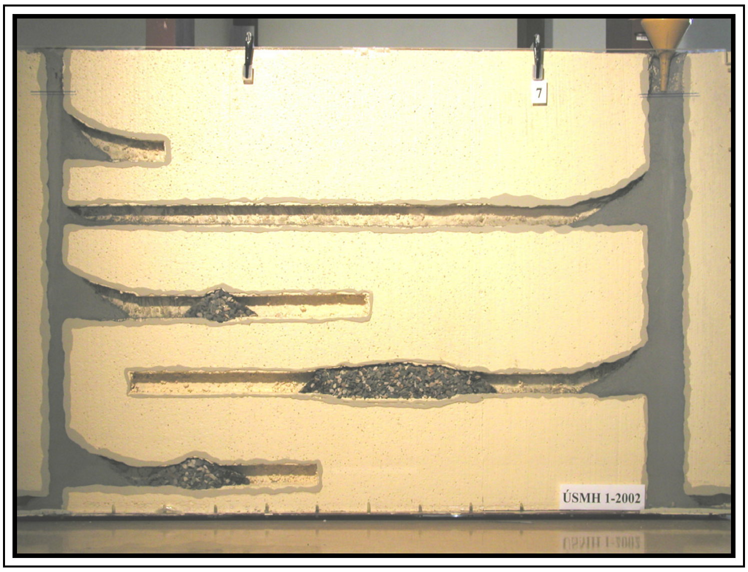

Fig. 11 Photograph taken after the light ash had been poured into the model

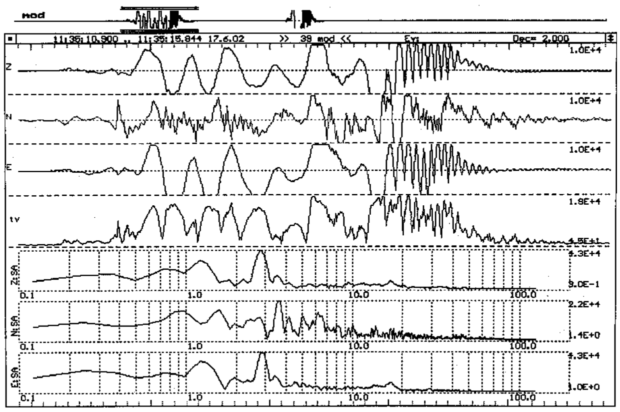

Fig. 12 Record of simulated shock. The vibration speed components (μm/s) are up and the frequency spectrum (Hz) is below.

The models thus conceived enabled several situations to be treated in dependence on the cross-section of the vertical shaft and the length of the caving fall, i.e. situations more or less favourable for the distribution of light ash in the modelled mine working.

3.2. *DEPOSITION OF LIGHT ASH IN DRY EMPTY SPACES OF THE MODEL (MODEL 1-2002)*

The light ash gradually poured into the model filled the vertical shafts, but settled only at the edge of the horizontal drifts running into the shafts, creating a slope with a gradient of 35^{o} - 40^{o}. Further away from the entry the drifts remained practically empty (Fig. 11).

After both shafts had been filled with light ash, the simulation of seismic events was begun. For this purpose a seismic LE3D frequency sensor, range 0.1 - 100 Hz, was fixed in the middle of the upper edge of the modelling stand. A dynamic effect, the record of which is shown in Figure 12, was generated by slightly lifting the stand above the base and letting it drop back.

The light ash in the model was gradually shaken down, but not all spaces, emptied in this way, were filled by the shaken light ash during the next shock. Empty spaces appeared at the entries of the drifts into the shafts (Fig. 13). The loosening of the light ash, which could be seen before the simulation of seismic events, practically disappeared in the filled spaces. In

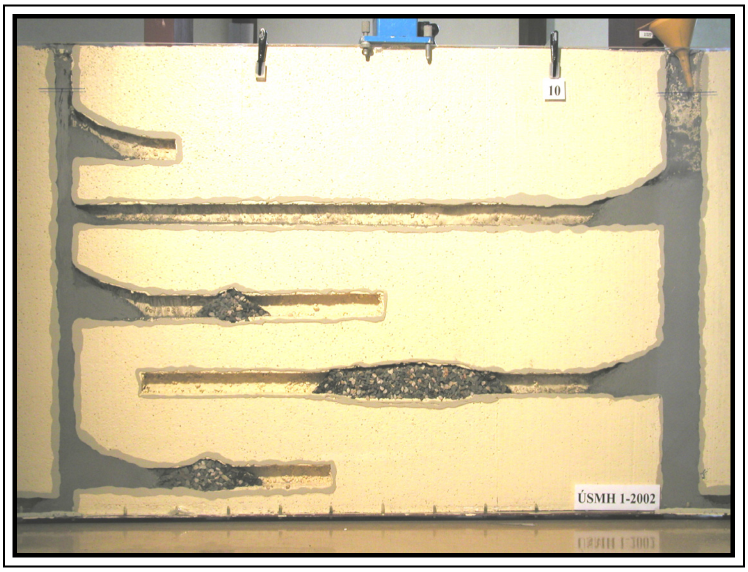

Fig. 13 Photograph of model after simulated shock

Fig. 14 Penetration of the light ash beyond the modelled caving falls

the drifts with the model caving falls, the light ash partly filled the space in front of the caving falls, but in none of the modelled cases did the ash penetrate beyond the obstacle even after the shocks (Trčková et al., 2002a).

3.3. SIMULATION OF GRADUAL RISING OF MINE WATERS (MODEL 2-2002)

The model into which the light ash was poured in advance, is gradually flooded by water fed through the holes in the bottom of the stand. As the water level in the model rose, the light ash soaked it up very willingly and was distributed not only in the empty spaces of the drifts in front of the caving falls, but also penetrated beyond the modelled caving falls to the most distant parts of the drifts (Trčková et al., 2002b).

In the shafts the light ash did not behave as loose material, but whole blocks of light ash broke off and slid into released spaces and under the water level. The light ash deposited in the water reduced its volume significantly. The further spaces were opened up and filled by the upper layers of the light ash. Due to the simulation of seismic events, the remnants of the light ash, which remained dry in both shafts above the water level, became loosened and fell through to the flooded spaces.

3.4. SIMULATION OF DEPOSITION OF LIGHT ASH IN FLOODED SPACES (MODEL 3-2002)

When the light ash was poured into the model of the mine working flooded with water, it remained on the water level for a long time and dropped below the surface only very slowly, settling in the lower parts of the model (Fig. 15). As it became soaked on contact with the water, it clogged and prevented further light ash from dropping below the water surface. Although

Fig. 15 Condition of the model after light ash had been poured into both shafts

this phenomenon may be affected considerably by the scale of the model, one cannot exclude that the same difficulty will occur when the light ash is poured into a real mine working flooded with water (Trčková et al., 2002c).

An important knowledge disclosed by this model experiment was that, as the light ash was poured into the undisturbed unrunning water with which the model was filled in advance, part of the light ash penetrated into the modelled caving falls, but the water remained unpolluted beyond them. Only when the level of the water in the model rose and thus flowed did the light ash penetrate beyond the caving falls.

4. EVALUATION OF MODEL EXPERIMENTS

The experiments with physical models proved that light ash mixes can be deposited in underground cavities, created as a result of mining mineral raw materials, without great difficulties.

In depositing light ash in cavities, created by mining steep lode deposits of mineral raw materials, the light ash willingly falls through the gaps between the ores in place to the lowermost empty spaces. Due to the small angle of slope (30^{o} - 35^{o}) it spreads out to the sides. Not even the roughened and adhesive surface of the cavity bedrock prevents the light ash from falling through. Dry light ash mixes poured into mine workings, consisting of shafts and a system of partly caved in mine drifts, fill the vertical shafts and remain at the openings of the horizontal drifts. The light ash distribution will probably partly change with increasing moisture content, and excessive moisture content could have an adverse effect on the deposition of light ash in excavate spaces.

The deposition of light ash is affected most by flowing water when mine workings are flooded and the very smallest cracks an leaks may cause the light ash to leak into the surrounding rock massif, even to considerable distances. The light ash settles not only in the lower parts of the mine working, but also penetrate beyond the caving falls created, e.g., due to seismic events. In view of higher cohesion (c = 9.5 kPa for dry light ash) the light ash does not behave as loose material, but blocks are formed which gradually become submerged in water. The simulation of rising mine water level causes the volume of the light ash to reduce approximately by 50%. This releases spaces in the upper parts of the mine working. It is necessary to pour additional light ash into the release spaces to ensure the stability of the surface and to reduce the impacts of mining.

In pouring light ash into spaces which have already been flooded by mine waters, the light ash gradually sinks to the lowermost places and is carried by the water far out to the sides under an angle of 20^{o} - 25^{o}.

The behaviour of the light ash mixes may probably also be affected by the kind of light ash used, its volume weight, moisture content, angle of slope, disposition to crumbing and also by the content of aliphatic particles. The higher volume weight of light ash poured into dry empty spaces caused higher consolidation of the light ash in the lower parts, and a smaller angle of slope results in better distribution of the light ash in the horizontal plane. The aliphatic particles inhibit the soaking of the light ash in water.

Seismic events may cause routes to open up for the distribution of the light ash to more distant parts, as well as partly close such routes, thus hindering the distribution of the light ash. Which of these alternatives occur depends mainly on the geometry and properties of the environment into which the light ash is deposited. If the light ash is displaced to the lower parts due to seismic events, it would be desirable to pour additional light ash into the loose spaces to prevent the surface above the excavated space from sinking.

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