

# The Future of Backfill in Underground Coal Mines— Underground Placement of Fill Material Based on Fly Ash and Coal Processing Waste

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## ABSTRACT

Polish underground coal mines successfully adopt new method of filling of gob area in longwall. Currently, due to cost reasons, most of conventional backfill operations have been stopped, however many mines are equipped with the hydraulic backfill infrastructure. This infrastructure, mainly pipelines networks, can be easily applied for transportation of fine-grained mixtures used for filling of gobs. Placement of ashes, slag and processing waste in mined areas at Silesian coal mines began in XIX centuries. Such practices have been employed at both active and abandoned coal mines. The current filling technology of gob area in longwall operation allows to avoid surface subsidence, utilize fine waste and saline mine waters, improve stability of rock mass and reduce some of the ventilation problems such as loss of air into the gob in the headgate area (the loss can reduce the air available to ventilate the longwall face), gas emission and spontaneous coal combustion. The purpose of this paper is to present the current fill operation, the results obtained by applying a new method in longwall mining and a number of problems related to environmental and safety issues. Physical properties and requirements for fill materials and mixtures will be discussed.

## INTRODUCTION

Coal mining operations create a variety of environmental impacts involving e.g. surface subsidence, emission of gases and water pollution. Current Polish underground coal mining expands into increasing depths. The use of conventional coal extraction methods - room and pillar and longwall with caving - is becoming increasingly difficult. Control of the roof by caving has numerous technical advantages and does not generate additional costs, which in case of traditional hydraulic backfill can easily make the coal mining operations unprofitable. However, presence of caving zones generates many problems related to the stability of the rock mass and mine subsidence, mine water inflow, spontaneous coal ignition, methane hazard etc., which are generally considered as environmental and safety issues. Currently, due to cost reasons, most of conventional backfill operations have been stopped, however many mines are equipped with the hydraulic backfill infrastructure. This infrastructure, mainly pipelines networks, can be easily applied for transportation of fine-grained mixtures used for filling (grouting) of gobs. The Polish coal mining is modifying existing methods and testing innovative technologies. Filling of caving zone is an important component of modern underground mining operations. This method is used increasingly to achieve required safety factors for underground hazard mitigations. Additionally, the fill

technology serves a number of functions in coal mining operation and offers many environmental benefits. What is more, filling of voids in caving does not interfere with longwall production and does not involve significant additional costs. In Silesia, mining activities have been carried out for hundreds of years. Some current longwalls are overlaid by historical room and pillar workings and other cavities from XIX and XX centuries. These old mining voids exist approximately at depths between 30-1,000m. The historical underground cavities can be filled by different materials such as crushed waste rock, sand, tailing and coal combustion by-products. Placement of ashes, slag and processing waste in mined areas at Silesian coal mines began in XIX centuries. Beneficial use of tailing and fly ash for coal mine reclamation occurs in varying degrees across Silesia. In various locations, fly ash slurry has been injected into underground abandoned coal mine workings to provide structural support for subsidence reduction.

## **COAL MINING METHODS IN POLAND**

Polish coal mines produce round 72 million tons of coal per annum (year 2015), from which 92% come from longwall with caving and with filling of caving zone, 3% from longwall with traditional backfill, while the remaining 6% comes from room and pillar and development workings in the coal seams. Figure 1 shows different longwall mining methods used in Polish mines. Mining with caving is the most environmentally unfriendly type of mine operations. A major part of the Silesia Coal Region in Poland is undermined. Surface subsidence due to the loss of subsurface support after the removal of coal has resulted in a vast amount of damage to properties and infrastructures. In addition waste and saline water from coal mines are significant environmental problems in this region.

Therefore, the Polish coal industry uses filling in operating mines and in abandoned underground mine workings. In coal mines this technology allow, among other things, the reduction of surface damages, the disposal of waste materials and utilization of polluted water and safety improvement of underground operations. In Poland, the traditional filling of the voids created by underground coal mining operations is probably as old as coal mining itself in the Silesia Region.

Currently, most of Polish coal mines successfully adopts new technologies of filling of voids in caving area.

## **LONGWALL WITH FILLING OF CAVING**

Economic factors and technological limitations of backfill motivate the search for new fill methods for coal mines. One of them is the longwall method with filling (grouting) of roof fall rocks (Figure 1c,d and Figure 2). Increasing surrounding pressure against waste disposal, particularly the fine waste on the surface, and concern about mining damages and safety of underground operations have resulted in an increase in the popularity of using fly ash, tailings and binding agent mixtures as compaction slurry (grout) for roof fall rocks in gob areas of longwalls.

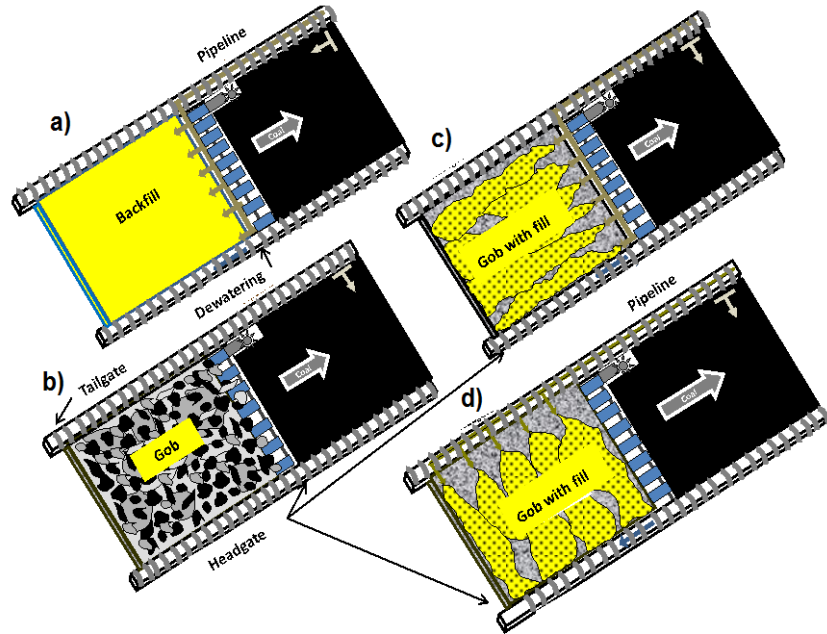


Figure 1. Longwall methods used in Polish underground coal mines; a) longwall with backfill, b) longwall with caving, c, d) longwalls with filling of gob – 2 methods (Palarski 2013)

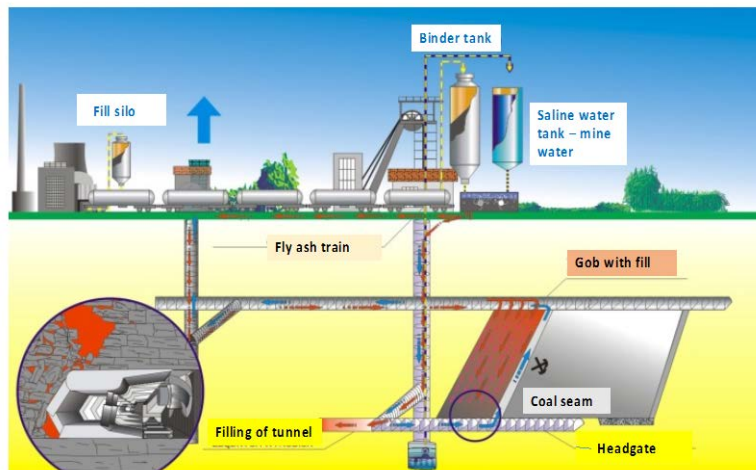
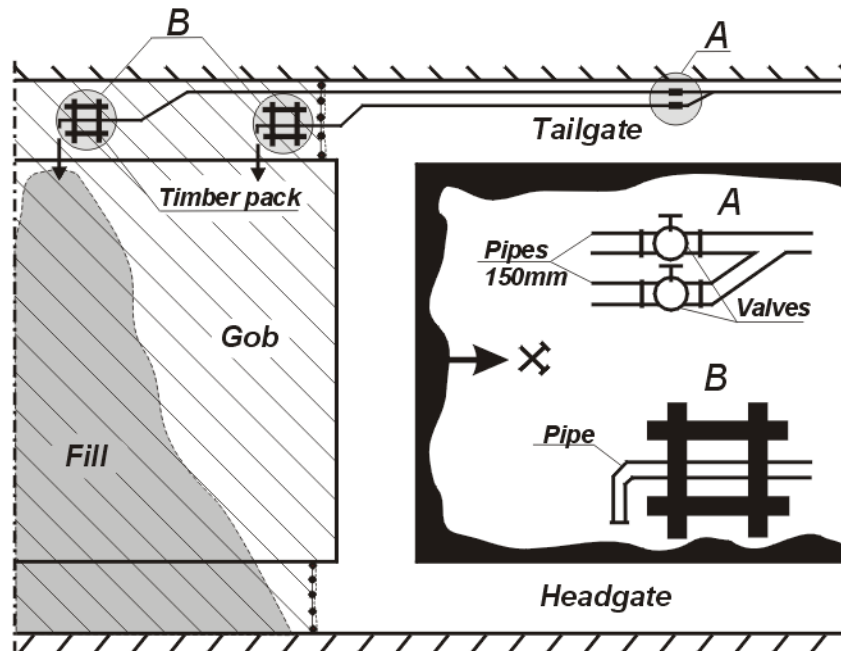


Figure 2. Gob fill infrastructure (Zajac 2015)

The filling of roof fall rocks is based on a longwall with caving. The method does not need to keep open the room behind the longwall support, in comparison with other backfill methods. This technology allows separate extraction from the filling process. The injection of a slurry is carried out through pipes in two ways (Figure 1c,d):

- the fill pipes are drawn behind the support line and reach unconsolidated cave rocks up to 15 m away from the line (Figure 1c),
- the pipes are left in a mined-out area or they are placed in a bore hole drilled to the gob from a tailgate (Figures 1d and 3).



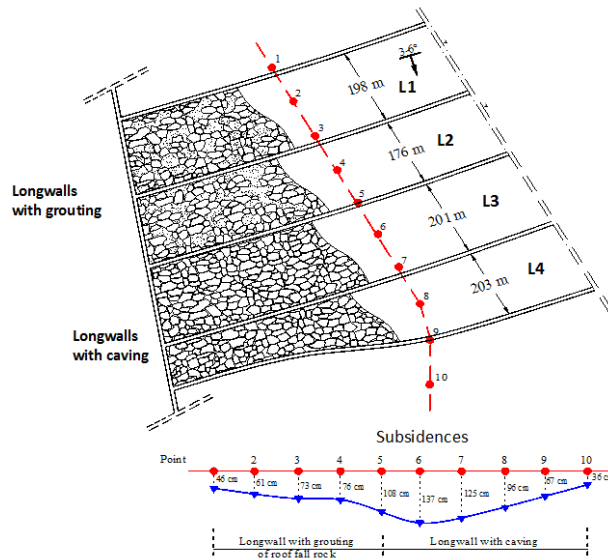
**Figure 3. Gob filling from tailgate**

Application of voids filling in caving is able to reduce numerous problems related to mining operations, but generally it is not able to reduce significantly the fracturing process in the rock mass above mining operations. It has been noted that the grouting of fall rocks contributes to a reduction of surface damages by up one half (maximum) when compared to the standard caving method. Figure 4 shows the development of surface subsidence above the longwall with grouting of roof fall rocks and longwall with caving.

The traditional backfill decreases the surface deformation by about 70-80% when compared to the caving method. From the other side, simplicity of this technology and low costs (both capital and operational) encourage the mining industry to apply filling of voids in caving zone as a cheap and reliable method.

Additionally, coal spontaneous combustion and some ventilation problems are reduced by using this technology. In thick seams (slicing mining), by filling of caved rocks in the upper slice, a new artificial roof is created for the next slice. In longwall with grouting of caving, the best productivity and lowest cost of production is achieved for cases where:

- seams or slices have dips of 5–10° and thicknesses from 2.0–2.5 m;
- roof strata has good rock fragmentation and regular caving, and longwall conditions: face length (width) 200–250 m, working up-dip and grouting from the face pipe



**Figure 4. Surface subsidence for extraction with caving (longwall 1 and 2) and grouting of caving area (longwall 3 and 4); seam thickness 2,01-2,10 m, depth 480-532 m**

## SELECTION OF FILL SLURRY

To improve the safety, environmental performance and economics of coal mining operations, fill mixtures (grout) are produced from various waste materials. To ensure the maximum safety of the filled caving area, the challenge is to use a slurry that is able to tightly fill the free spaces and stabilize the goaf without being affected by potential long-term strength loss due to chemical weathering.

The mechanical and rheological properties of fill slurry depend on mineralogical, physical and chemical properties of the waste materials, binder types, and their proportions. The important parameters for determining the suitability of placed fill are the compressibility, strength, binding time and strength loss during and after curing periods due to chemical weathering caused by the presence of aggressive mine water (chlorides, sulphates and others). A wide range of other physical properties of fine-grained mixtures undergo testing procedures, as it is defined by Polish standard PN-G/11011:1998: “Materials for stabilized backfill and grouting of caving – requirements and test procedures”. The standard requirements can be divided into three groups:

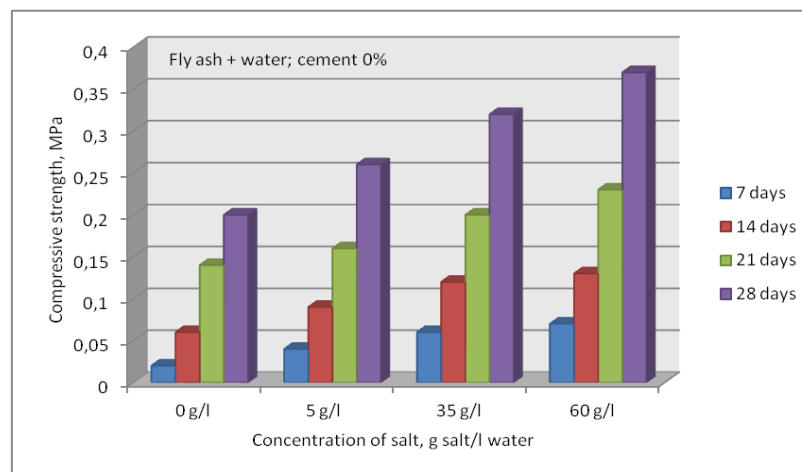
- Properties affecting flow regime changes in a transport pipeline – density, slump, rheological parameters of the slurry;
- Factors influencing the fill placement process –draining, stiffening time, set time;
- Properties of already stabilized fill material – compressive strength, wetting resistance, compressibility, and permeability.

The high mechanical properties for stabilized mixtures can be achieved with use of coal combustion by-products (fly ash) and/or with addition of binders, like commonly used Portland cement. Filling of caving does not require specific parameters of mixture of fine grained solids and water in comparison with other underground technologies like stabilized backfill, construction of backfill plugs and packs etc. The draining of fill might be relatively high due to absorption of excessive water by the rocks. Relatively poor mechanical properties of solidified fill together with high water content allow to use mixtures with slump flow values between 210 and 250 mm. High slump flow is required to achieve long distance

migration range, which in this application is much important than supporting properties of the final fill material. Generally, the concentration of mixtures for filling of caving is between 20% and 50%. This means, for example, that a longwall caving with volume of 500 000 m<sup>3</sup> creates an opportunity to dispose more than 100 000 m<sup>3</sup> of saline water, which makes significant environmental benefit from the application of caving filling.

## INFLUENCE OF WATER SALINITY ON PROPERTIES OF GROUTING SLURRIES

When traditional backfill operations are undertaken to reduce mine subsidence or improve the insulation properties of the rock mass, a maximized concentration of solid in the fill slurry is the target. In a case where maximum deposition of saline waters is the target of grouting operations, the composition of a fill mixture must be determined according to minimal bleeding (excessive water presence) and the water absorptivity of the rock mass. The presence of chlorides and sulphates in water also influences the chemical processes of pozzolanic reactions of fly ash and binders with the water. Laboratory tests show that the presence of salt in water in a concentration up to about 60 g/dm<sup>3</sup> (as is the case for most mine waters from underground Polish coal mines) significantly increases the 28 days compressive strength of cured fly ash-water slurries (Figure 5) and reduces the binding time of slurries.



**Figure 5. Compressive strength of fly ash-water slurries in relation to the salinity of water; solids to water ratio 1.1:1.0; slump flow 250 mm**

However, unconfined compressive strength of such fill decreases about 20 to 35% with the increase of curing time i.e., from 28 day to 90 day. Generally, the compressive strength after 28 days decreased with the increasing salt concentration and pH of the fly ash. So, increasing of salt concentration in fill mixture has a negative effect on working time and compressive strength.

## THE GOB ABSORPTION OF FILL SLURRY

Directly after extraction of some amount of coal from a longwall, the total volume of void being created is equal to the volume of extraction. In later stages of caving and fracturing processes, this volume is distributed between large voids in caving, voids of all fractures and also the volume of surface subsidence. Therefore, the volume of extraction clearly represents the theoretical maximal absorption (accumulation, filling) of slurry. A roof fall rocks absorb a fill mixture or part of it; part of water flows out.

Practically the absorption of caving area is limited in the first place due to presence of caved rocks in the space available for gravitational filling as well as due to many other conditions, like geometry of the longwall panel, continuity of the voids, migration properties of fill mixtures and so on. Because direct observation of the state of caving filling is impossible, absorption of voids was analysed statistically. Data under analysis were taken from 65 longwalls in Polish coal mines, where caving filling was adopted (Palarski Plewa and Strozik 2014). The selected results from filling of voids in Polish coal mines are presented in Figure 6. The absorption values (fill accumulated in caving) for the considered longwalls ranged from 3% to 85%. Presented results do not specify the type of fill mixture used in each case nor any other data related to specific local conditions of the considered longwalls. Results of this analysis demonstrate that the overall level of filling is relatively low. The absorption for 40 of the analyzed longwalls was smaller than 25%. It means that the amount of introduced fill mixture could only create a thin isolation layer along the isolation dam in the headgate of the longwall panel. Such level of filling allows to achieve nothing more than an improved ventilation and reduction of fire hazard, due to elimination of air penetration into the caving. Influence on roof subsidence and reduction of the fractured zone evolution may be achieved only in the cases where intensive process of voids filling were conducted, with a level of filling higher than 40%, as shown in Figure 7.

## **GOB EMISSIONS AND ASSOCIATED VENTILATION ISSUES IN A LONGWALL**

### **Methane**

In most Polish longwall operations, the formation of methane-air mixtures in the mined-out gob is observed. Injection of fill mixture into gob can effectively reduce the volume of methane zones. However, during the filling, there is a risk arising from the presence of methane in caving area, which may migrate from the gob into active face in longwall or can be pushed around inside the gob and close to the face, as shown in Figure 8. Slow, targeted and continuous filling is a recommended technology to avoid methane accumulation in the filled gob and in active longwall face.

### **Ammonia (NH<sub>3</sub>)**

Fly ash used as fill material must meet, inter alia, permissible limits of ammonia content based on exposure limits for miners. In power stations, reduction of nitrogen oxides in flue gases causes an increasing of ammonia concentration in fly ash. Therefore, filling of gob with ammonia-contaminated fly ash-water mixture may be impacted due to ammonia release after placement in the caving area. This ammonia can migrate from gob area into active face in longwall and pose safety hazard. The ammonia released from the fill in gob can be diluted and removed by large ventilation system. It should be noted that moving vast quantities of air through the longwall will increase oxygen penetration into the gob, especially in the tailgate area with a U-type ventilation system. This may increase the tendency for spontaneous combustion. Therefore, tight gob filling and reducing the face air velocity can effectively control spontaneous combustion risk in filled gob.

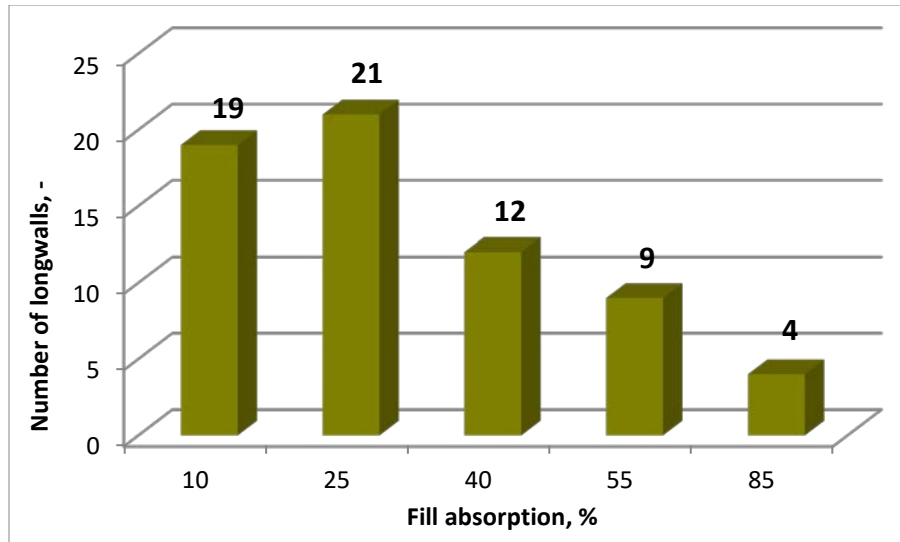


Figure 6. Fill absorption in different longwalls

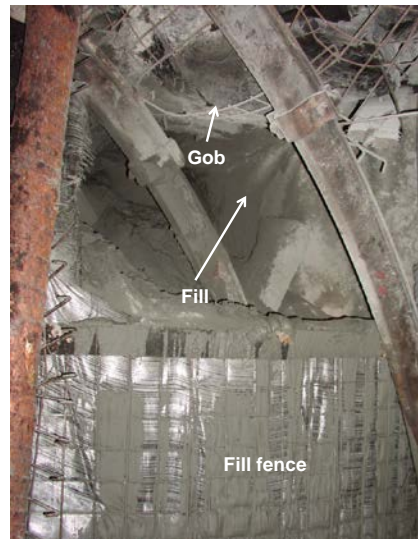


Figure 7. Gob with fill and fence in headgate

However, large quantities of ammonia-contaminated fly ash-water fill in the gob and small amounts of ventilation air lead to increased ammonia concentration in adjacent, active areas of the longwall and gates. Modeling and underground measurements show that a particularly dangerous area is near the tailgate corner of the longwall. Partial ammonia removal from fly ash before being sent to a fill plant can significantly reduce the risk of air pollution in the longwall. So far, in Silesia coal mines, there were no exceedances of the exposure limit for ammonia in longwalls filled with fly ash.

## BACKFILLING OF ABANDONED UNDERGROUND WORKINGS

Mining in abandoned coal mines in Silesia was carried out in at least several seams at depths of between 50m to 1,200m. The abandoned mines contain huge volumes of unfilled workings, often flooded or gas filled and also contain considerable quantities of coal in pillars and the surrounding

strata. All these closed underground coal mines are subject to some risk of spontaneous combustion of unmined coal.

In the Silesia coal mining region in the period between 1993-2015 it was necessary to fill or seal a length of about 5,500km of mine workings and 120 km of shafts. The filling of mine workings during closure processes allowed mines to reduce the possibilities of subsidence, surface damage, gas movement, underground fires and sudden intrushes of mine water, thereby opening up under-mined areas for further beneficial use. Not all the openings can be reached from other underground workings, so there is a need to drill bore-holes from the surface to fill the voids. The holes are situated to get the best filling of the voids and to avoid sudden intrushes of water. Void filling is executed through boreholes of 120 and 200mm diameter, by the following methods:

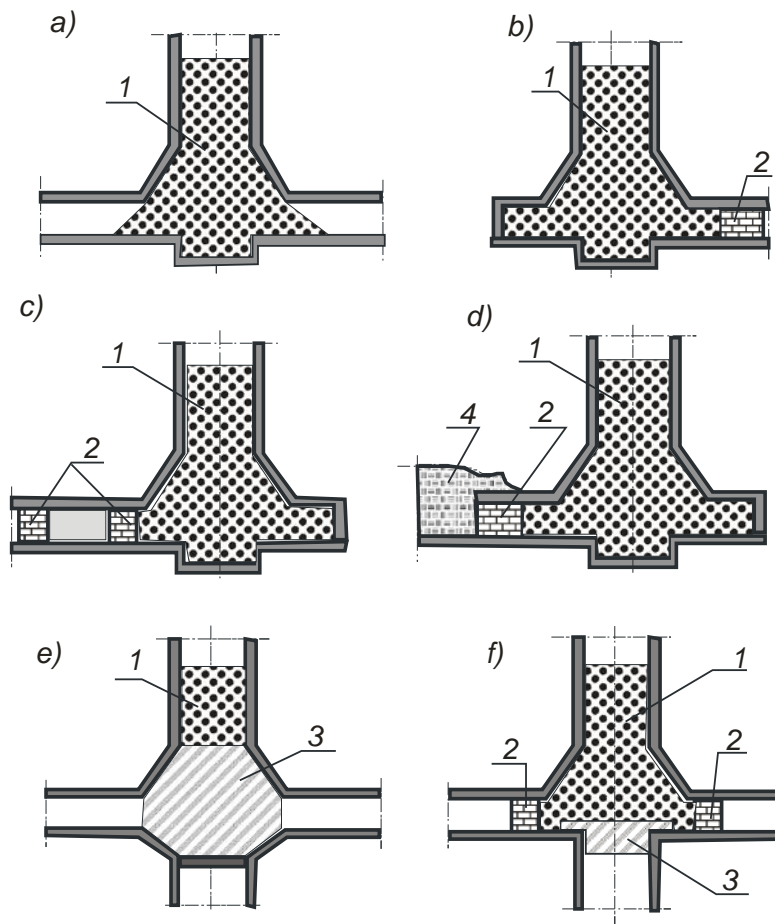
- pneumatic transport of dry fly-ash with capacities up to 30t/h, at a pressure of about 0.25 MPa;
- pneumatic transport of fly-ash moistened with water at the outlet at quantities up to 20 l/minute;
- supply by gravity or by pump the water-ash mixture or a mixture of ash (up to 70% of the dry mass), tailing (up to 25%), cement (up to 10%), and calcium chloride (2%) and water; the concentration of the mixture sets each time according to the state and conditions of void filling (mixture concentration < 75% by mass).

The last solution is the most effective and it has been frequently used in Polish collieries.

The abandoned shafts are filled or left without any filling due to water pumping. Before filling the shaft, all equipment such as guides, cables, ropes, pipes or ladders must be removed, and the shaft insets must be prepared for constructing the stoppings and fill dams, causing the caving zones or creating the plugs from the material used for filling the shafts, as shown in Figure 9. Hard core in the form of broken rock is recommended for shaft inset locations and sumps. The remaining part of the shaft can be filled with mining wastes as well as with demolition materials (crushed brick, concrete etc.). When water or gas flows into the shaft it is necessary to prepare clay seals; their thickness and depth depend on geological conditions around the shaft, the technical state of its support, and on the material used for its filling and seal construction. Additionally, a product suitable for the stabilization of shaft fill material was engineered from fine mining waste, fly ash, binder and additives.

## CONCLUSIONS

Filing of caving is widely applied among Polish coal mines. Most of the mines have unused backfill infrastructure, which can be easily adopted for the purposes of caving filling. The main reason for use of this technology is for reduction of spontaneous ignition of coal residues in caving, which can exclude a longwall for long time from operation. Utilization of large volumes of saline waters is also important benefit of filling of voids. If a range of criteria are met, filling of voids in caving could have significant influence on subsidence reduction and surface protection.



**Figure 9. Closure mine shaft – dams and plugs in the area of insets; a) hardcore fill, b) brick or concrete dam at inset, c) roadway (inset) stopping with fill plug, d) roadway stopping with caving zone, e) shaft plug, f) concrete plate (1- hardcore fill, 2- dam, 3- concrete plug, 4- caving zone grouted if required)**

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