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P a r t 3

ASH AND SLAG HANDLING

3.5. Applications of ash and slag from power coals

3.5.5. Mine and open cast filling, reclamation of open pits

3.5.5.1. Utilization of fly ash and slug from tpps in undeground mining in Poland

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ABSTRACT:

In last years in Polish coal mining industry special attention has been paid to the environmental protection. The disposal of coal combustion products (CCP-s) and mine waste represents capital and operating cost to mining operation. Waste fill used in Polish coal mines have evolved from early dumped rocks and hydraulically or pneumatically placed crushed rocks up to today's hydraulically transported, densified and cemented fills with fly ash and flue-gas desulphurization by-products. Over the last decade attention has been focused on the underground mine waste disposal and on the use of CCP-s as filling material of underground workings or grouting of roof fall rocks in caving area. Grouting the caving area results in reduction of surface subsidence and spontaneous ignitions of coal, in improved ventilation and face conditions in particular the stability of gates. The use of fly ash, tailing, binder and water mixture as compaction grout of roof fall rocks in caving area has great impact on mining practice in Polish coal mines. Coal combustion by-products are highly differentiated in terms of their mineralogical and chemical composition in dependence of type of coal, technology of combustion, and desulphurization method. This variability of properties between power generation waste implicates wide range of mechanical properties of stabilized mixtures made with use of these waste, and further, different possibilities of their use in underground mining technologies. In underground coal mines two general types of environment could be met: wet, which is relevant to common coal mine climate conditions, and water, which means flooded workings and create extreme conditions for curing of fly ash – water slurries. The paper presents a brief description of mining technologies, which use coal combustion by-products.

1. INTRODUCTION

All kinds of mining activities are accompanying by generation of waste. Waste, which have not been utilized or reused, are disposed on waste disposal sites, mostly on the ground surface (landfilling), where they affect negatively the environment by emissions of contaminants into air, soil, ground waters, and surface waters. Due to large volumes, very oppressive for the environment are waste being generated by power industry.

In Polish coal mining industry the use of waste from coal power generation for many years is used to be an integral part of mining activities. This can be demonstrated by percentage of power generation waste among all extraneous waste, which have been utilized by mining industry in underground workings, i.e. 88,7 % in the year 2004 and 92,1 % one year later. Distribution of types of extraneous waste utilized in underground workings of Polish coal mines in year 2005 has been presented on Fig. 1.

Amounts of fly ashes and their mixtures with flue gas desulphurization by-products consumed by Polish coal mining industry between years 2002 and 2006 has been illustrated on Fig. 2. During the years 2005—2006 there were 33 underground coal mines operating with total output of about 95 millions tones per year. In average Polish coal mines use almost 2,5 millions tones of these waste per year.

About 96 % of underground mined coal in Poland is mined using the longwall methods. As a consequence of this coal extraction technology, the surface subsides. In the last few years, increasing environmental pressure against surface waste disposal, especially coal combustion products and mine waste as well as concern about subsidence in mining areas have resulted in an increase in the popularity of filling of mine voids. Waste rock, tailings, fly ash, slag, flue gas desulphurisation materials and polluted mine water is placed underground as a backfill.

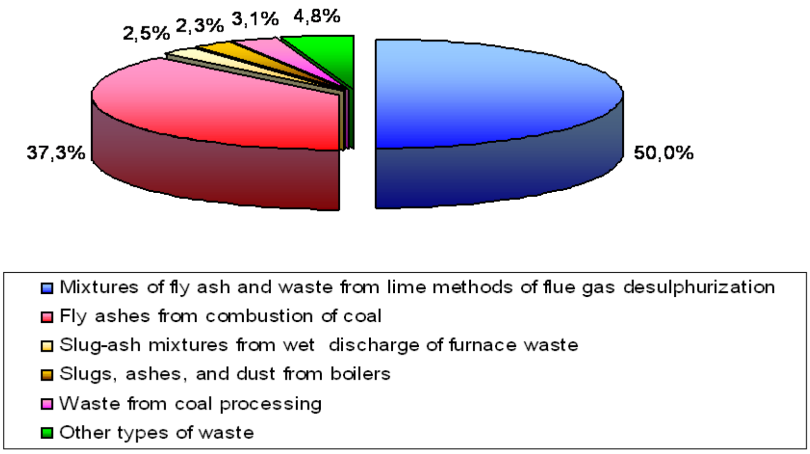

Fig. 1. Percentage distribution of types of extraneous waste utilized in underground workings of Polish coal mines in year 2005 [3]

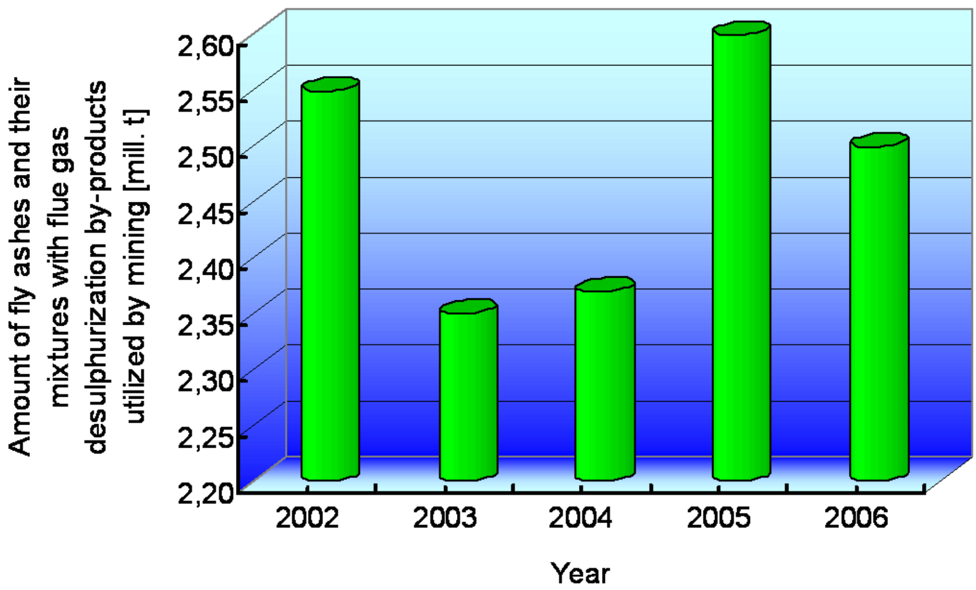

Fig. 2. Amount of fly ashes and their mixtures with flue gas desulphurization by-products utilized by coal mining industry in years 2002—2006 [5]

Fly ashes are very differentiated in respect to mineralogical and chemical composition, in relation to type of combusted coal, technology of combustion and method of flue gas desulphurization.

For these reasons, the way to develop new methods of utilization of coal combustion by-products leads through wide range of research with use of mixtures, which include wide range of these products and different binders and other admixtures, in aim to achieve beneficial mechanical properties and characteristics of solidified slurries, meeting the requirements of technologies and conditions of application.

2. TECHNOLOGIES OF UNDERGROUND MINING THAT EMPLOY FLY ASH

Classification of underground mining technologies, which use coal combustion by-products has been shown on Fig. 2. The most often used types of power generation waste in these technologies are in first place many types of fly ash, generally in a form of fly ash – water slurries. Technologies listed in Fig. 2. are differentiated significantly in respect to frequency or scale of application, as well as to types and volumes of power generation waste, which could be utilized during their use.

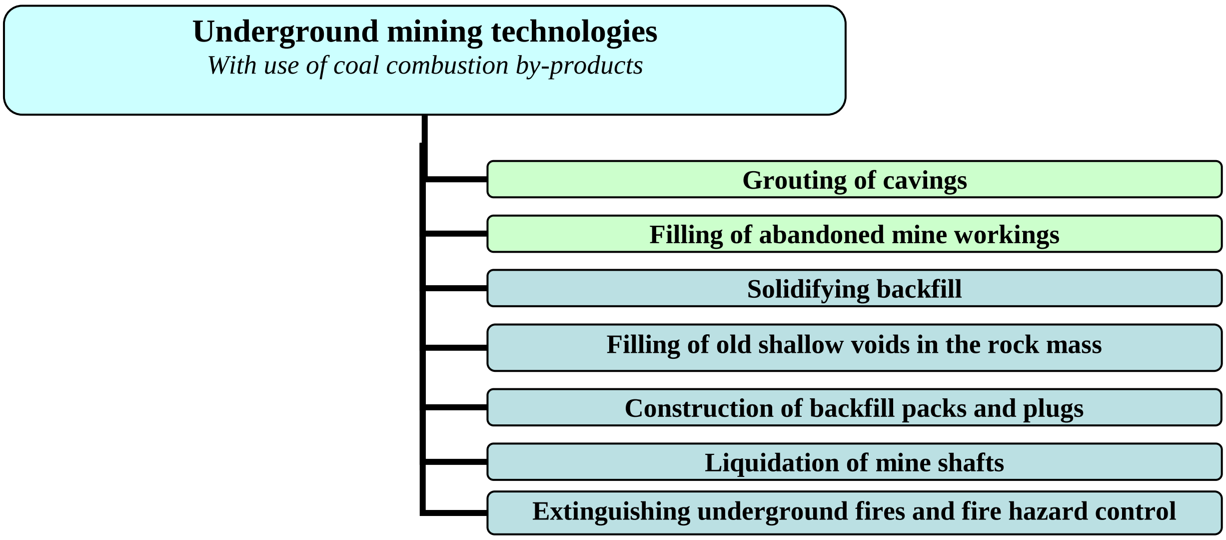

Fig. 3. Technologies of underground mining, which apply coal combustion by-products

2.1. Grouting of cavings

The most widely propagated within Polish coal mining industry technology, which adapts coal combustion by-products is grouting of cavings. Significant part of fly ash that is consumed by coal mines is utilized just by grouting works. A predominant mining system in Polish coal mines is the longwall system with caving. At that point important is only that the voids, which become into existence as the result of coal extraction are left unsupported behind the longwall. This leads to break and fall of the roof rocks and subsequent subsidence of the whole overburden. A space that consists of rock rubble, rests of coal and voids, which conduct air and are able to collect hazardous gases is referred as cavings. Elimination of these voids is the main goal of grouting of cavings. A scheme of one variation of that technology has been presented on the Fig. 4. The indispensable infrastructure consists of two main parts: slurry preparation plant located near to a mine shaft and a network of transport pipelines, which deliver the slurry from the preparation plant down to the all places of application. In the tailgate pipe outlets are installed, which are inserted into the cavings. Often the tailgate is equipped with dams, which allow to liquidate unnecessary part of the gate and protect the front of the longwall against outflow of grouting slurry. Fly ash – water slurry flows in such a system gravitationally, thus range and efficiency of transport depends mainly on geometric parameters of the pipeline.

Its popularity this technology owes to simplicity of necessary equipment, not too much demanding properties of the grout, and benefits, which mines accomplish in the result of grouting. Among others to the goals of grouting belong:

- Reduction of endogenic fire hazard, that can be generated by coal residues, which are left in cavings behind the front of the longwall,
- Improvement of ventilation conditions in workings in the result of reduction of air stream losses by its migration through the cavings.

As secondary benefits of grouting of cavings with fly ash – water slurries could be also mentioned a possibility for utilization of mine own waste – saline ground waters and flota-

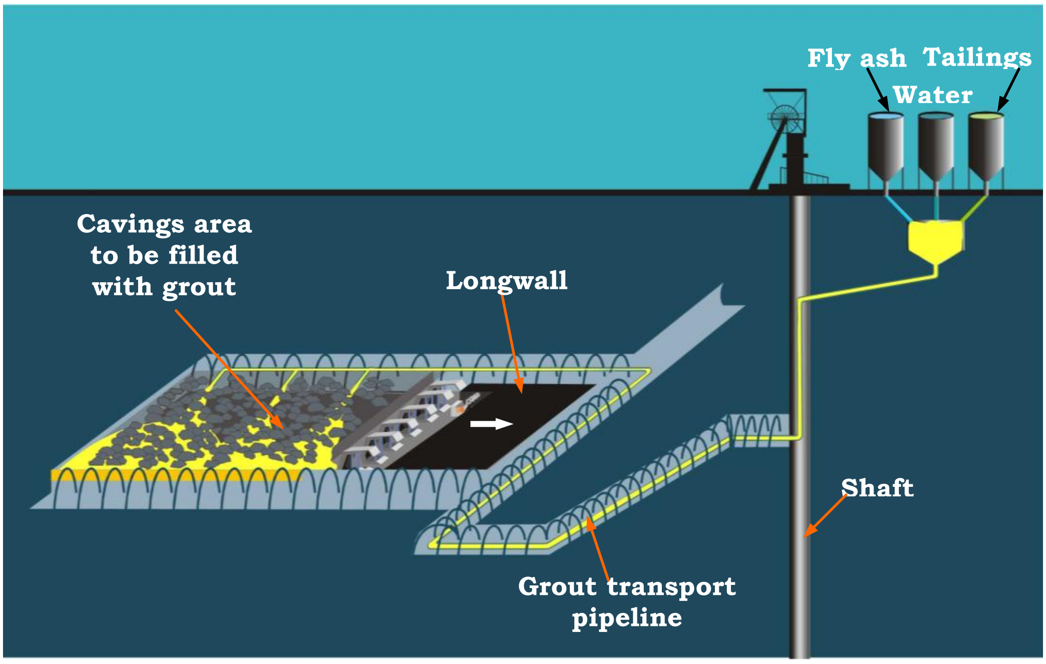

Fig.4. A scheme of typical technology of grouting of cavings behind a front of a running longwall

tion tailings and faster reconsolidation of rubble rock zone, which is important factor i.e. by extraction of thick coal seams in slices.

As grouts for insulation of coal mine cavings fly ash – water slurries of relatively low concentrations are used. Good flow properties in cavings and ability to fill up even small voids at large distances are more important than mechanical properties of the fill.

The successful grouting of caved rocks, the best productivity and lowest cost of production is achieved for:

- seam or slice with dip 5-10° and thickness from 2,0 to 2,5m;
- roof strata with good rock fragmentation and regular caving;
- longwall: wide 200 to 220 m, working up-dip and grouting from face pipeline.

Figure 5 shows the development of surface subsidence above the longwall with grouting of roof fall rocks and longwall with caving. It can be seen that the grouting of fall rocks contributes to reduction of surface damages by about a – half. The traditional backfill decreases the parameters of surface deformation by about 70-80 % when compared to the caving method.

2.2. Filling of old shallow mine voids in the rock mass

The old and shallow workings pose great danger to buildings, infrastructure and people. Over the workings of up to 100m deep, there are sinkholes and depressions created on the surface. However, there are some large surface subsidence depressions coming from the workings deeper than the above ones. To eliminate the surface effects and to minimize the danger of gas outlet and underground fire, all the shallow workings in old mines should be filled with backfill materials. Not all the roadways can be reached from other underground workings, so there is a need to do the bore-holes from the surface, Figure 6. They are situated in uch a way the best filling of the voids can be achieved and sudden inrush of water can be avoided, otherwise, cavings around the bore-holes could be created. Void filling is done through the bore-holes of 120 ÷ 200 mm diameter, using the following methods:

- pneumatic transport of the dry fly-ash with the capacity up to 30 t/h, while the pressure is about 0,25 MPa;
- pneumatic transport of the fly-ash moistured with water at the outlet of the quantity of up to 20 l/min.;

supply by gravity or by means of the pump of the ash-water mixture or mixture of ash (up to 70 % of the dry mass), tailing (up to 25 %), cement (up to 10 %), and calcium chloride (2 %) — concentration of the mixture is to be decided each time accordingly to the state and conditions of the void filling (mixture concentration < 75 % by mass).

2.3. Use of CCPs for fill of abandoned mines

Planning for mine closure needs to cover underground facilities, water and gas management, surface facilities and infrastructure, site rehabilitation and all the local issues associated with closure (socio-economics). Responsible underground mine closure involves:

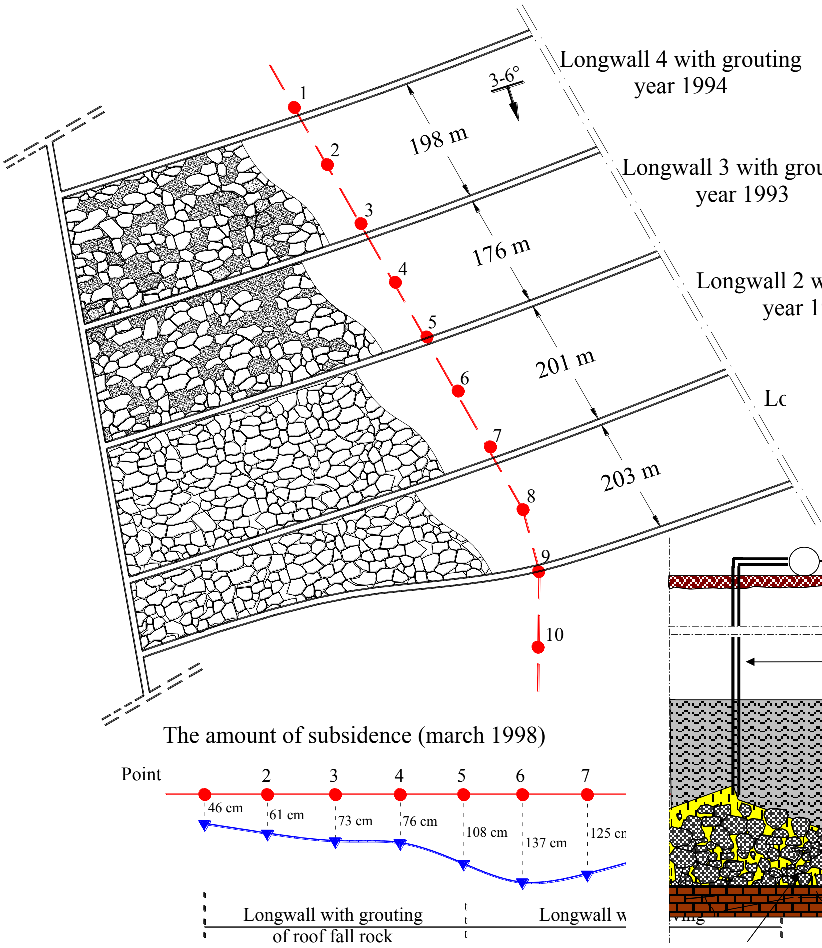

Fig. 5. Surface subsidence for extraction with caving (longwall 1 and 2) and grouting of caving area (longwall 3 and 4); seam thickness 2,01-2,10 m, depth 480-532 m

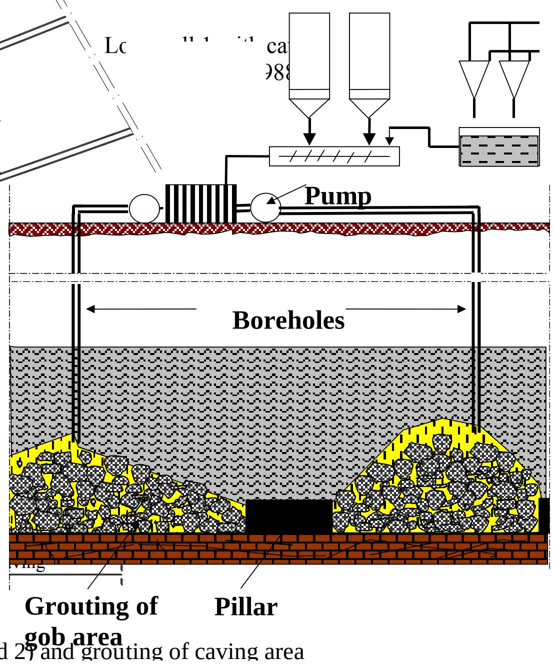

Fig. 6. Grouting technology through the surface boreholes

- removing fixed plant, equipment and hazardous materials,
- sealing and filling openings,
- stabilization of caving areas and loose backfill,
- securing the waste disposal facilities,
- site rehabilitation,
- taking all necessary monitoring to avoid water pollution and gas emission.

Much research has been done in resent years about stabilization of rock mass, filling of underground mine workings, covers for tailings and other waste dumps. The CCP-s are used as a fill, cover and injection materials in the active and passive stage of mine closure, Figure 7.

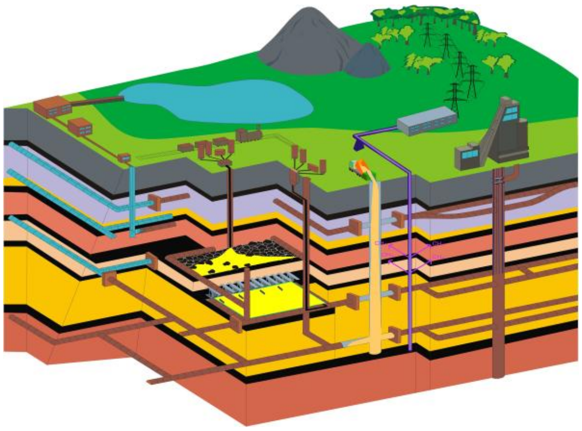

Fig. 7. Closure process of mine

In the life of the mine, number of boreholes has been drilled as prospecting, gas drainage and water wells. The primary importance of plugging to abandon boreholes is to prevent contamination of groundwater and gas seepage. Fly ash slurries and slag are the present plugging and fill materials. The plugging slurry composition includes a water-swellable clay, a particulate filler, such as fly ash and others components. The components are mixed with water to form a slurry and the slurry is pumped into borehole.

The abandoned shafts are filled or they are left without any filling to be used for pumping water. Before filling the shaft all the equipment, guides, cables, ropes, pipes or ladders must be removed, and the shaft insets must be prepared for constructing the stoppings, fill dams, causing the caving zones or creating the plugs from the material used for filling the shafts, Figure 8.

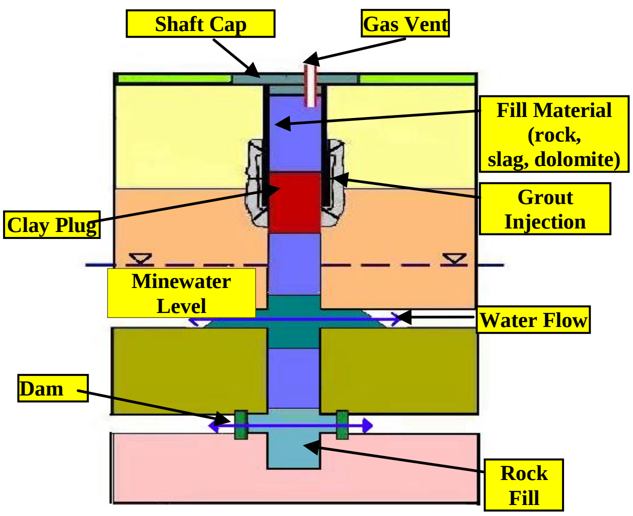

Fig. 8. Shaft after proper filling

A core in the form of broken rock or slag 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 (crashed brick, concrete) and coal combustion products (bottom ash and slag). When water or gas flows into the shaft it is necessary to prepare clay or concrete (cement and fly ash) seals; their thickness and depth depend on geological conditions in the shaft, technical state of its support, and on the material used for its filling and seal construction. Capping represents the final operation of mine closure.

3. Selection of fill mixture

Variability of chemical and mineralogical properties of power generation waste implicates differentiation of mechanical properties of stabilized mixtures and further, variable possibilities of their use in mine technologies. In many technologies of underground mining (backfill plugs and packs, liquidation of workings, etc.) use of additional binders in mixture with coal combustion by-products is necessary to in aim to obtain satisfactory level of relevant parameters after solidification.

Moreover to chemical and mineralogical properties of coal combustion by-products, on the mechanical characteristics of stabilized fine-grained mixtures great influence exhibit conditions of their curing: temperature, moisture, and aggressiveness of the environment. A wide range of 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 cavings – requirements and test procedures". Parameters that have to be provided due to mentioned above standard can be easily divided into three groups:

- Properties, which influence flow conditions of a slurry in a transport pipeline – density, table spread, rheological parameters of the slurry,
- Properties that describe the stabilizing process of a slurry – bleeding, stiffening time, binding time, and
- Properties of already stabilized fill material – compressive strength, soak resistance, compressibility, and permeability.

Table 1 presents typical range of values of the most important parameters of mixtures with power generation waste for use in underground mining technologies.

Table 1. **Criteria of use of mixtures with coal combustion by-products in underground mining technologies**

Technology	Parameter							
	Table spread R **[mm]**	**Stiffening time** C_t **[doby]**	**End of binding** T_k **[doby]**	**Compressive strength** R_c **[MPa]**	**Soak resistance** R_{28} **[%]**	**Bleeding** w_n **[%]**	**Compressibility** S **[%]**	**Permeability** K **[m/s]**
Stabilized backfill	160 ÷ 180	< 1	< 2	0,5 after 7 days	< 20	< 7	< 15	< 10^{-7}
Grouting of cavings	210 ÷ 250	- *	< 28	0,1 after 28 days	< 80	< 14	- *	< 10^{-7} (10^{-9} **)
Filling of abandoned workings	160 ÷ 210	< 7	< 14	0,5 after 28 days	< 20	< 7	- *	- *
Construction of backfill packs and plugs	160 ÷ 180	< 2	< 2	0,5 after 7 days	< 20	< 7	< 5	< 10^{-7}
Insulation of fires including construction of anti-explosion dams	160 ÷ 210	- *	< 28	0,1 after 28 days	< 20	< 14	< 5	< 10^{-8}
Liquidation of shafts – insulating plugs	160 ÷ 180	< 2	< 3	0,5 after 7 days	< 10	< 7	< 5	< 10^{-9}
Liquidation of shafts – fill of the column	160 ÷ 180	- *	< 28	0,1 after 28 days	< 80	< 7	- *	- *
Grouting of loose or porous rocks	160 ÷ 210	- *	< 14	0,5 after 28 days	< 20	< 7	< 7	< 10^{-7}

* — lack of a specific value does not mean that any limitations can result from specific technological requirements
** — grouting in special conditions

4. Fly ash based products in underground mines

The Polish companies have developed fly ash products for the underground mining industry. The products are all pozzolans which means they react with lime to form silicate hydrates. The preparation of components and production process are controlled to provide high performance (strength and durability). Cost effective products for underground mine construction from shotcrete to the mine packs are used for roadways support. The shotcrete is pumped over long distances and is used in wet sprayed concrete. The grout for a pack support is in slurry form and consists of fly ash, slime or tailing, special mix of binders and water. The high load and low compression of grout pack support makes it an effective competitor against timber chocks.

5. Conclusion

In the paper application of coal combustion by-products in Polish coal mining industry has been described. Presented data show that Polish coal mines consume in average almost 2,5 million of tones of power generation waste per year. Due to their beneficial physical and chemical properties coal combustion by-products are widely used as fill materials, mainly in a form of mixtures with water, and, in some more advanced applications, also with cement and other additives, which are able to modify binding characteristics of the slurry. In large part coal combustion by-products are used for grouting of cavings, where often preferable is to achieve large volumes of slurry by minimal costs of materials with physical properties of secondary importance.

There are also several technologies exist, where composition of fill mixtures must be thoroughly selected though complex measurements of physical and chemical properties of wide range of coal combustion by-products types, binders and other admixtures, and concentration of solids in mixture, all these to meet requirements of technology in relation to durability, mechanical strength, permeability etc.

Differentiation of chemical and mineralogical properties of coal combustion by-products, which come from different sources (thermal power plants), combustion technologies, or flue gas desulphurization by-products forces the designers to precise selection of materials for particular application. It also allows to find best types of waste for each type of application.

By increasing demand for certain types of coal combustion by-products from different branches of industry, coal mines begin to suffer lack of these waste, especially in case of demands for large volumes required for large scale applications.

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