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Part 3

ASH AND SLAG HANDLING

3.5. Applications of ash and slag from power coals

3.5.3. Combined processing of ash, slag and wastes from other industries

3.5.3.2. Application of fluidized bed combustion ashes for enhancement of mining waste management

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ABSTRACT

In coal-mining industry a major environmental and economical problem are mining wastes. Particularly troublesome, due to their consistency, are the coal slimes. In this form they are difficult to be managed, as well as to be safely stored. More often coal slimes are granulated using quicklime or hydrated lime.

The studies and tests conducted on industrial installations have shown that the traditional lime binders can be replaced by combustion by-products containing active compounds of calcium. Application of fluidized bed combustion ash (FBC ash) allows receiving granulated slimes of physicochemical properties that meet the requirements of low-calorific fuels, as well as a component of fuel blends. The granulated slimes with grinded bottom ash from fluidized bed boilers (FCB bottom ash) have shown the highest mechanical resistance to the weather conditions, transport and storage.

Through the selection of medium-grained waste produced in settling lagoons and appropriate mixing with selected calcium ashes (FBC fly ash and FBC bottom ash) the aggregate-binder blends have been obtained that meet the requirements applicable to materials used in construction of roads, highways and hydrotechnical engineering.

The implementation and investments made allowed for the management of waste to produce granulated fuels and aggregate-binder blends, what resulted in reducing the amount of stored mining waste and ash, as well as in obtaining the additional environmental and economic benefits.

1. INTRODUCTION

Southern Poland Coal Company SA (Południowy Koncern Węglowy S.A.) being a part of the TAURON Polska Energia S.A. Capital Group pursues a policy of reduction of the amount of produced mining waste aiming at their complete management in the future, as well as conducts activities leading to processing of coal slimes and waste rock into useful products [1].

The research and deployments made bring the Southern Poland Coal Company the intellectual, environmental and economic values. Several solutions are protected by patent applications, and some of them received an international award [2]. The conducted waste recovery has decreased their quantity in landfills. At the same time it has caused a decrease in consumption of natural mineral resources, as well as increased the acreage of restored and revitalized facilities and areas that had been degraded. Most of the recovery processes that have been run contributed to reduction of waste disposal costs, while bringing profits from the sale of pelletized fuels, aggregates and aggregate-binder blends.

It was possible to obtain these results thanks to the implementation of the Company environmental policy and good cooperation with universities, branch associations, industry and technology centers, as well as through investment made. The investment projects that have been implemented so far were characterized by a payback period of 8 to 24 months.

2. APPLICATION OF ASH TO THE COAL SLIMES GRANULATION

Depending on the properties of coal and rocks associated with mining process, ore enrichment methods and ways of treatment of process and underground water, the coal slimes have different chemical, mineralogical and physical composition. Depending on the solution of water and sludge management we are dealing with slimes produced in:

– Filtration equipment (forced filtration – chamber filter press, drum filter press, pass-band filter press);
– Slime settling lagoons (filtration and gravity segregation, also applies to settling lagoons of underground water).

Slimes containing large amounts of clay, take one the consistency of a paste. Received filtered slimes - the so-called “filter cakes”, are not spontaneously disintegrate and resistant to grinding and eventually mixing with steam coal. In our climate conditions the slime filter cakes pulverize when they are dried, under the influence of rain they are blurred contaminating water and soil and in the winter they form icy solids. For these reasons, inter alia, despite the interest in them the coal slimes are used in power sector to a small extent. The characteristics of tested coal slimes is given in Table 1.

Water and slime slurry deposited in settling lagoons, usually undergo gravity grind and densimetric separation, as well as dewatering. In these cases, you can get the slimes containing the considerable amounts of coal grains with small amounts of clay, as well as strongly clayed slimes. Even if the slimes have the properties acceptable by the consumers (Q, W, A and S), usually the main obstacles to use them are: the above-mentioned consistency, high content of water (up to 40%) and the lack of resistance to the transport and storage conditions. In order to eliminate a number of these defects, the technology of granulation has been developed and implemented.

Table 1. **Physicochemical characteristics of coal slimes and FBC ash**

Parameters	Unit	Coal slimes (filter cakes)			CCP (coal combustion products)		
		Average, annual values	Min/max, annual values	Tested slime	Fly ash silica type PL	FBC bottom ash	
						Raw PF	Grind PFM
1. Coal slime content:							
- moisture, W^{tr}	%	31,4	25,0…37,3	30,7			
- ash, A^{r}	%	27,5	19,4…45,5	29,6			
- calorific value, Q^{ir}	MJ/kg	10,14	5,4…13,8	10,45			
- sulphur, S^{tr}	%	0,58	0,37…0,96	0,67			
2. FBC ash content:							
- silicon, SiO_2	%				53,00	46,60	46,60
- calcium, CaO	%				5,81	23,20	23,20
- CaO_{free}	%				0,21	11,90	11,90
- sulphur, SO_3	%				0,78	9,60	9,60
- loss on ignition (LOI)	%	59,7	42,6…65,8	57,4	3,60	0,81	0,81
- grains over 0.25 mm	%	14,2	4,6…21,1	-	2,90	59,10	9,80

According to the available knowledge the process of coal slime granulation was performed in the disc and drum granulators [3-6]. In this process pellets in the form of balls or oval granules were obtained. However, the efficiency of these granulators is small with reference to their weight and electricity consumption. In the first instance, described already in the 20's of the last century, the calcium compounds {CaO, $Ca(OH)_2$} has been used as a binder.

To optimize the granulation process of coal slimes the studies on other kinds of binders, as well as on the selection of the granulation technology have been carried out.

Attempts of coal slime granulation using combustion by-products were carried out with ashes: FBC fly ash silica type "PL", FBC bottom ash "PF" and FBC grained bottom "PFM". Physicochemical characteristics of studied ashes are given in Table 1. In all samples the pellets of grains size from 2 to 8 mm have been obtained. However, the properties of pellets and their durability, resistance to the transport, storage and climate conditions varied.

Coal slimes with ash PL formed granules, *in statu nascendi* of low-resistance to the technological transportation, and subjected to seasoning (including air-drying) underwent disintegration even under the influence of small strokes. In this case, the clay contained in slime coal was a binder. The grains of ash facilitated the slime sticking to them - forming granules. Furthermore, using of this kind of ash resulted in an adequate deterioration of calorific properties of slime granules.

Application of ***bottom ash PF*** caused that the granulation process took place, however it showed that the granules contains significant quantities of bottom ash grains, what prevented from the full utilization of the active components of the ash. Most of seasoned granules underwent hardening despite the changeable weather conditions, and the part containing large grains underwent cracking in over-irrigation conditions.

The best results were obtained using ***grinded bottom ash*** **PFM**. Granulated product were characterized by good calorific properties and resistance to external factors, with the smallest doses of the binder.

The role and mechanism of action of FBC ash in the process of coal slimes granulation. FBC ash, in comparison with fly silicate type ash, is characterized by significant amounts of calcium compounds (Table 1). Several of them reacts with the ingredients contained in coal slimes, as well as the environment, substantially affecting the occurrence of the granulation process and the properties of the obtained granulated product, namely, inter alia:

- Dehydration phase:
  $CaO + H_2O = Ca(OH)_2$
  $CaSO_4 + 2H_2O = CaSO_4 \cdot 2H_2O$
  $CaSO_4 \cdot 0{,}5H_2O + 1{,}5\ H_2O = CaSO_4 \cdot 2H_2O$
- Bonding phase:
  $Ca(OH)_2 + CO_2 = CaCO_3$
  $CaSO_4 + 2H_2O = CaSO_4 \cdot 2H_2O$
  $CaSO_4 \cdot 0{,}5H_2O + 1{,}5\ H_2O = CaSO_4 \cdot 2H_2O$
  $(SiO_2)_n \cdot (Al_2O_3)_m + zCa(OH)_2 =$
  $(SiO_2)_n \cdot (Al_2O_3)_m \cdot (CaO)_z + z\ H_2O$
- Phase of desulphurization of flue gas in the process of granulated coal slime combustion:
  $Ca(OH)_2 + SO_2 = CaSO_3$
  $CaCO_3 = CaO + CO_2$
  $CaO + SO_2 = CaSO_3$
  $CaSO_3 + 0{,}5\ O_2 = CaSO_4$

In this way, each mole of CaO (56 g) binds one mole of water (18 g). It means that it is possible to bound water contained in the slime in an amount adequate to CaO added to the slime. Calcium sulfate (CaSO4, CaSO4·0,5H2O) contained in the ash also binds water. In the case of anhydrous calcium sulfate – for one of its mole (136 g) two moles of water (32 g) accrue. Effect of the quantity of ash on the reduction of coal slime moisture is illustrated in Fig. 1.

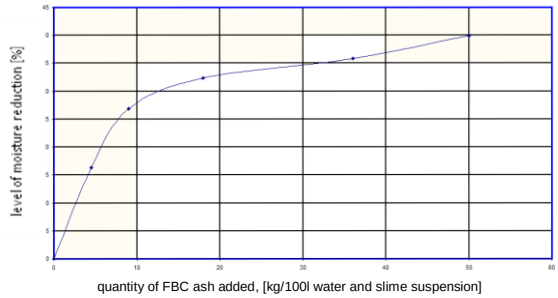

Fig. 1. Effect of the added FBC ash on the reduction of coal slime moisture.

Dewatering reactions act simultaneously as a binder for formed granules. However, "after fulfilling the role of the binder" the formed calcium hydroxide creates calcite by undergoing the carbonization reaction with carbon dioxide, resulting in consolidation of the internal structure of granules. For these reasons, the seasoning process increasing mechanical strength of granules is very important. Longer seasoning of such granulated slimes can also lead to the occurrence of pozzolanic reaction, leading to the additional hardening of granulated product. The slimes granulated with FCB bottom ash cause, in the process of their combustion, a partial waste gas desulphurization.

The conducted research, as well as the conditions established for the application of ash containing active compounds of calcium instead of quicklime or hydrated lime became the basis for filing a patent application [7]. In this way, for coal slime granulation not only the typical calcium binders are used but also FBC ash and calcium type of ash – Fig. 2.

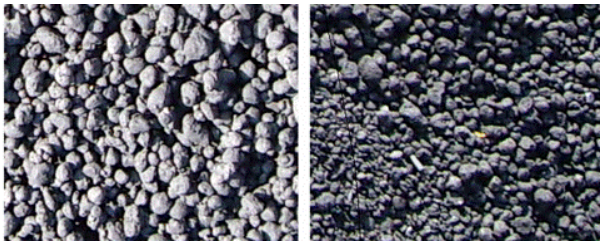

Fig. 2. Granulated coal slimes with the content of FBC ash.

Installation for coal slime granulation. In order to eliminate some of the mentioned negative characteristics of coal slime and to enable their use, the slime is often granulated with binders in disc and drum granulators, as well as in typical concrete mixers of periodic operation.

To increase the possibility of rational slime management the technology of continuous operation has been developed for enrichment, solidification and granulation of coal slime as a low-calorific fuel or neutral material for reclamation works etc. and for their safe storage, as illustrated in Fig. 3 [1, 2, 8, 9].

The essential elements making the newly developed technology different from the existing ones are, inter alia, as follows:

- Replacement of traditional granulators with the intensive mixer;
- The amount and method of binder (FBC ash) dosage are strictly specified;
- There is a possibility of simultaneous enrichment of produced slime granulated product properties;
- Possibility of granulation of all kinds of waste and small-grain fractions using FBC ash.

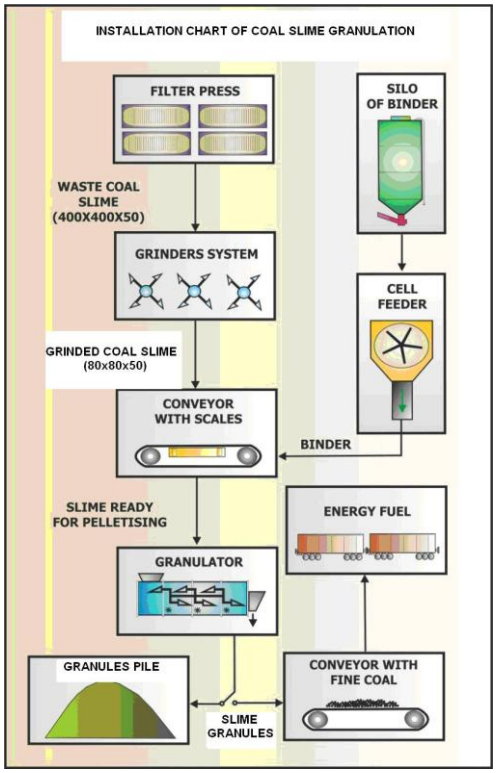

Fig. 3 Technological process of continuous coal slime granulation.

The obtained granulated slime is resistant to the atmospheric environment effects (sun, rain, temperatures below 0ºC), as well as transport and process requirements. An additional advantage of developed and implemented technology is the possibility of slime processing during the running production, as well as its storage in settling lagoons and piles.

The implemented coal slime granulation installation has enabled to produce the granulated fuel. The profits made on it covered the costs of investment in 6 months.

3. APPLICATION OF ASH TO PRODUCE AGGREGATE-BINDER BLENDS.

In years 2009-2010 Southern Poland Coal Company SA, together with the Research Institute of Roads and Bridges (IBDiM), Laboratory of Civil Engineering Labotest and Ecocoal Consulting Center, conducted a series of tests to determine the suitability of waste rock in the process of enriching coal as an aggregate applicable in the infrastructure engineering. During the tests the possibilities of producing various types of aggregates (coming from direct production and mining dumps), as well as aggregate-binder blends (produced on the basis of these aggregates and various kinds of active ash from power sector) were established.

Based on the findings and technical approval obtained from IBDiM the aggregates produced by PKW from direct production and mining dumps meet the requirements for the materials used in infrastructure engineering for the construction of embankments, auxiliary and key hydraulic substructures, reclamation, land leveling and hydrotechnical construction of dikes.

In order to allow sale of PKW aggregates a Plant Control of Aggregates Production system (Zakładowa Kontrola Produkcji Kruszyw) was introduced which is an essential element of aggregate production and sale. At the same time, in the processing plants a technological line was adjusted in a way enabling to produce aggregates.

Having met all the conditions, Southern Poland Coal Company SA was able to offer their customers a rock aggregate/PKW aggregate suitable for usage, in accordance with the obtained technical approval of IBDiM No AT/2010-03-2576. Technical characteristics of the produced aggregates are given in Table 2.

Table 2. **Engineering characteristics of PKW aggregate and aggregate-binder blend.**

Parameters	Units	PKW aggregate		PKEW blend
		Saturated for 4 days	Saturated for 15 days	Saturated for 4 days
		Fraction 0…2 mm		Fraction 0-2 mm +24 % FBC ash + 1 % cement
Moisture	%	16,4	13,4	15,5
Density of volume	g/cm^3	1,884	1,806	1,871
Density of frame	g/cm^3	1,584	1,593	1,606
Load capacity	%	20,3	18,2	341,80
Swelling	%	0,13	0,17	0,00
		Fraction 0…30 mm		Fraction 0…30 mm + 25 % FBC ash
Moisture	%	11,9	9,2	16,5
Density of volume	g/cm^3	2,111	2,165	1,832
Density of frame	g/cm^3	1,887	1,953	1,572
Load capacity	%	15,0	8,6	228,2
Swelling	%	0,82	0,53	0,04

Successfully completed work resulted in 20 000 tons of aggregate sold in 2010 for road constructions and around 60 000 tons of aggregate for construction of dikes.

However, due to low load capacity, which limited the use of PKW aggregate in various engineering works and in order to reduce the swelling coefficient, the improvement in these parameters was made by blending PKW aggregate with active ash and slag, including FBC ash and cement.

The obtained results met the expectations regarding the improvement of physical parameters of developed blends and became the basis for obtaining the Technical Approval of the Research Institute of Roads and Bridges for "The stabilized aggregate-binder blend PKEW". Technical properties of the U type blend are shown in Table 2.

Simultaneously, a procedure for purchase of installation for continuous production of aggregate and ash blends was initiated. Among the several proposals an Italian installation (Ciepiela Technology Promotion Company) of continuous operation with a capacity of 150 tons of compound / hr. was chosen and installed – Fig. 4.

Fig. 4. Installation for the production of aggregate-ash blends in Sobieski Mining Company.

The installation was adjusted to the technological line of processing plant from which the selected waste rock/aggregate is mixed with a specified quantity and type of a binder (ash, cement, lime).

The installation allows producing the stabilized aggregate-binder blends of different technical parameters, according to one of the 20 procedures for creating blends for different purposes. All add-ons, in particular, FBC ash and binders produced on its base, containing the active compounds of calcium, are designed to improve the physical and chemical parameters of PKW aggregates increasing, inter alia, their mechanical strength (load capacity, compressive strength) and reducing the permeability coefficient, swelling and solubility [10-12].

The installation launched in June 2011 in the Sobieski Mining Company produced, by the end the 2011, 66 000 tons of blends with the adds-on of various types of ash for the purpose of road construction – Fig. 5. About 56 000 tons of mining waste and about 10 000 tons of FBC ash was managed in this way. The results of such activities are, inter alia, economic effects in the form of revenues from the sale of blends, as well as savings resulted from avoided costs associated with mining waste and ash storage.

Fig. 5 Construction of ring road of city of Chrzanow using the aggregate-binder blend from Sobieski Mining Company.

Janina Mining Company is planning to launch a similar installation in 2012. However, in 2011 production and sale of aggregates made of waste rock of current production was already being carried out. To improve the geotechnical properties of produced aggregates and to increase sales the additional installation aiming at "drying" the aggregates by adding FBC fly ash was launched. In 2011 it produced about 130 000 tons of blends containing about 10 000 tons of FBC ash for the construction of dikes – Fig. 6.

Fig. 6. The construction of dikes alongside the Vistula river using the „dried" aggregate with ash from Janina Mining Company.

4. CONCLUSIONS

1. The conducted studies have shown that the traditional lime binders used for granulation of small-grained waste and improving the geotechnical properties of medium-grained coal waste can be successfully replaced with by-products of coal combustion with high content of active compounds of calcium.
2. Among the combustion by-products the FBC fly ash and FBC bottom ash turned out to be the most active ones.
3. In case of properties of granulated coal slimes not only the type and amount of added ash binder has influence on them but also the way of fuel preparation, as well as the choice of binder dosing and granulation methods.
4. The geotechnical properties of the aggregates produced from waste rock can be largely improved by enriching them with the add-on of FBC ash and by producing the aggregate-binder blends.
5. Construction of the installation for granulated fuel production and aggregate-binder blends have enabled to manage a large mass of mining waste, reducing their amount in the mine dumps, while resulting in significant environmental and economic benefits.

In the subsequent years, the Company's environmental activities and directions of the adopted policy aiming at launching of "zero waste coal mine", will be further extended by the management of mining waste along with the combustion by-products. Such a trend will, without a doubt, contribute to the sustainable development of our region for the sake of the environment for us and future generations.

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