Utilization of Energy By-Products for Ground Structures in Terms of Production Process

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Abstract. The article deals with the utilization of energy by-product (EBP) for further processing. The suitability of EBP for ground structures significantly depends on its production process. Its properties are influenced by brown coal flotation and by the usage of desulphurization methods. A comparison of physical-mechanical properties of different types of EBPs was performed. The main goal was to compile an apparent table of utilization and suitability of EBP for ground structures – road earth bodies, dams, and embankments according to the process of their formation.

1. Introduction

Energy by-product is generated during coal combustion and gas desulfurization in conventional coal-fired power plants. Utilization of EBP has become a frequently discussed topic. It is desirable to use EBP for further processing – e.g. for technical reclamation of former mining activities, ground structures, construction products, etc. A significant proportion of EBPs is used as an additive in various construction mixtures, with subsequent commercial use as a certified product. EBP is gradually finding an ever-wider application in traffic construction and in the environmental assets, where it functions as structural layers of earth bodies and dams.

The suitability of EBP for ground structures significantly depends on its production process. Its properties are influenced by brown coal flotation and by the usage of desulphurization methods. At the same time its properties depend on other added components, especially mixing water, and slag. EBPs include fly ash, slag, gypsum, and so-called stabilizer.

Design and implementation of soils (including EBP) for the construction bodies of road structures is specified in Czech national technical standard „CSN 73 6133“. Suitability of soils (including EBP) for various zones of dams and embankments is given via Czech national technical standard „CSN 75 2410“. Grain size of the material is the most decisive physical-mechanical attribute for the above-mentioned use, which can differ fundamentally regarding the method of production of various types of EBPs.

Within the studied issue, a comparison of physical-mechanical properties of different types of EBPs was performed. Most data on EBPs was obtained from a comprehensive archival research, which was supplemented by own laboratory analyzes performed on samples of EBP taken from selected repository. The aim of the work was to compile an apparent table of Utilization and suitability...
of EBP for ground structures – road earth bodies, dams, and embankments according to the process of their formation. The results of work contents also partial characteristic values of main physical-mechanical parameters.

2. Description of the main methods and material of EBPs

2.1. Desulphurization with a wet limestone flue gas scrubber

In the Czech Republic, desulphurization with a wet limestone flue gas scrubber is most often used in energy power plants with granulation boilers, where finely ground limestone is mixed with water to a suspension, which circulators transport to the spray system at the top of the absorber [1].

The finely sprayed suspension falling down encounter flue gases, a chemical reaction takes place and calcium sulphite is formed, which changes to calcium sulphate – gypsum with the supply of oxygen. It is withdrawn from the circulation circuit in the form of a gypsum slurry, dewatered in a vacuum filter and removed to produce the final product: so-called stabilizer (see Figure 1 & 3).

Several samples were taken from the mixing center of EPR Power plant (“EPR samples”).

![Figure 1](image)

**Figure 1.** Liquid form of stabilizer.

2.2. Semi-dry desulphurization method

For smaller older granulation and grate boilers, a semi-dry desulphurization method is usually applied. In most cases, lime is used as an activator in this method.

In the desulfurization reactor of the semi-dry method, a very fine mist of lime milk is formed by means of a rotary atomizer. The lime contained in the droplets reacts with the sulfur oxides in the flue gas to form calcium sulphite. Due to the high temperature of the flue gases in the reactor, water evaporates during desulphurization and the coated ash grains, as a desulphurization powder product, sink to the bottom of the absorber.

Ash fractions, slag, desulphurization product and wastewater are formed here as separate components of EBP. The dry product is usually incorporated into a stabilizer in a mixing center. Several samples were taken from the material storage body (landfill in the field) of EPC Power plant (“EPC samples”).
2.3. Fluidized bed combustion technology

Fluidized bed combustion technology differs significantly from previous technologies. In the case of the adoption of this technology, it was not a question of desulphurization of the existing boiler, but always of the construction of a new, fundamentally different one.

Using this method, ground coal is burned mixed with ground limestone in a fluidized bed. The desulphurization product from fluidized bed boilers is always inseparably mixed with the ash. The coarser bed ash, which always contains a certain percentage of free lime, is removed separately from the bicycle, and the dust fly ash (filter) ash is removed from the flue gas filters. Thus, the separate components of EBP in fluidized bed combustion are ash inextricably linked to the desulfurization product, bed ash and wastewater.

The fly ash from the fluidized bed boiler is produced by the heating plant in the dry state as a gray fine powder. It consists predominantly of dust-sized grains with an admixture of fine sand. Chemical macro-components consist mainly of hydraulic components formed from clay particles contained in burnt coal (SiO$_2$, Al$_2$O$_3$, Fe$_2$O$_3$, TiO$_2$) with sulfur admixture (mainly in sulphate form). CaO is present as free lime and as part of CaSO$_4$, in the undecomposed residual CaCO$_3$ after the combustion process (ground limestone for desulphurization is supplied to the boiler in a mixture with ground fuel) and in silicates and aluminates. Smaller impurities are formed by other oxides and trace elements. Free lime is an index indicator of the solidification and hardening process (it facilitates the start of the hydration process).

To verify the hardening mixtures prepared from EBP fluidized bed combustion, several samples of dry bed ash and filter ash were taken at ELE Power plant (“ELE samples”) during normal operation.

2.4. Collection of the Stabilizer samples

The character of the stabilizer practically eliminates the use of driven or pushed sampling devices and intact samples from boreholes can be obtained only by core drilling [2].

Dry drilling with a simple core is only usable when drilling for mounting the initial lining using short boreholes. In general, the stabilizer is sensitive to the presence of water, but the volume changes of the cured stabilizer are relatively small and develop relatively slowly [3]. Therefore, the effect of water rinsing is rather negligible in this respect. However, in the case of stabilizers prepared from EBP
boilers de-sulphurated by wet limestone washing, the sensitivity of the collected core to contact with flowing rinsing water is shown from the point of view of maintaining its integrity.

The use of a double core drill machine has proven to be significantly more suitable. Likewise, the use of a diamond crown is optimal.

![Drilling core – samples of the stabilizer.](image)

3. Comparison of materials

3.1. EPR samples

In terms of grain size (see Figure 4), the ash mixture has the character of sandy clay. Grains below 0.06 mm are 51%, of which below 0.002 mm is 7%. Fine sand predominates from the coarse sandy fraction. The average apparent bulk density of the mixture of ash fractions of EPR samples was 2 129 kg/m³, the bulk density of the dry mixture was 863 kg/m³.

3.2. EPC samples

The ash has a grain size corresponding to silt. Grains below 0.06 mm are 74%, of which grains below 0.002 mm are only around 2%. About 25% is the grain content of fine sand. The desulphurization product has a similar grain size by the semi-dry desulphurization method. Only the grain content below 0.06 mm is 93% and the grains of fine sand character are only around 6%. The 2:1 mixture of ash and desulphurization product is closer to the shape of the ash curve. The proportion of grains below 0.06 mm is 82%. The apparent density of solid particles is 2 325 kg/m³ in the case of ash and 2 358 kg/m³ in the case of desulphurization product. The dry mixture of ash and desulphurization product in an operating ratio of 2:1 has an apparent bulk density of 2 315 kg/m³ when using alcohol in a pycnometer. Bulk density of dry ash reached up to 695 kg/m³, but for the dry EBP product it was only 441 kg/m³.

3.3. ELE samples – Ash

The average apparent bulk density of the bed ash was 2 655 kg/m³, the filter ash 2 648 kg/m³ and the mixture (bed/filter = 1:1) 2 620 kg/m³ when tested in alcohol. The bulk density of dry fractions is 855 kg/m³ for bed ash and 539 kg/m³ for filter ash.

3.4. ELE samples – Stabilizer

In bulk density determined on the stabilizer sample was 1 513 kg/m³. Due to the nature of the stabilizer corresponding to the semi-rock, the shear strength and the compressive strength were
evaluated in the laboratory instead of the usual grain size distribution curve. The shear strength value was 51 °, the compressive strength of the test specimen ranged from 0.15 to 0.20 MPa.

4. Results and discussions

All tested samples can be evaluated from the point of view of several different standards – for our purpose, the samples were compared with the criteria given in Czech national technical standard “CSN P 73 1005” (Ground investigation) for classification of frost susceptibility and rock extractability. In terms of the granularity curve and of usability, the samples were divided according to Czech national technical standard “CSN 75 2410” (Small water dams) and “CSN 73 6133” (Road earthwork – Design and execution). In addition, the classification criteria of Eurocode 7 were used for the international standard and comparability.

4.1. Eurocode 7

EPR samples corresponded by their composition to saclSi and sasiCl class, EPC samples were classified as clSi and saSi class. Sample of ash from ELE belonged to clSi and saclSi class. Stabilizer sample belonged to grSa class, soft-rock class, respectively.

4.2. CSN P 73 1005

EPR, EPC and ELE samples are dangerously frosty soils as for frost susceptibility. ELE stabilizer sample belong to non-frosty materials and to the I. class of rock extractability (which corresponds to soft rock).

4.3. CSN 75 2410

EPC samples are only slightly suitable as material for homogeneous dam. On the contrary, EPR and ELE samples are appropriate.

In the case of the construction of a heterogeneous dam all tested EBP materials can be applied for the sealing part of the dam, but these are undesirable for stabilization part.

4.4. CSN 73 6133

From the perspective of utilization of EBPs for earth bodies of the road constructions are all tested samples conditionally suitable for direct use without any modification. By modification is meant, for example, the use of a binder or mixing with another fraction.
Other modifications are bound by other normative regulations, e.g. “CSN EN 14227-14” (Hydraulically bound mixtures – Specifications – part 14: soil treated by fly ash) and TP94 – Technical Conditions (Soil treatment).

4.5. Summary table for Utilization of EBP

The main goal was to compile an apparent table of utilization and suitability of Energy by-products for ground structures – road earth bodies, dams, and embankments according to the process of their formation. It was put together using the criteria given mainly in the standards “CSN 73 6133” & “CSN 75 2410”.

| Frost susceptibility | Rock extractability | Earth dam homogenous body | Earth dam sealing part | Earth dam stabilization part | Road construction - earth body |
|----------------------|---------------------|---------------------------|------------------------|-----------------------------|--------------------------------|
| EPCa                 | dangerously frosty  | -                         | suitable               | undesirable                 | conditionally suitable        |
|                      |                     |                           | suitable               |                             |                                |
| EPRb                 | dangerously frosty  | -                         | appropriate            | suitable                    | conditionally suitable        |
|                      |                     |                           | suitable               | undesirable                 |                                |
| ELE-ashc             | dangerously frosty  | -                         | appropriate            | suitable                    | conditionally suitable        |
|                      |                     |                           | suitable               |                             |                                |
| ELE-stabilizerd      | non-frosty          | I. class                  | -                      | suitable                    | conditionally suitable        |

Table 1. Utilization and suitability of EBPs for ground structures.

5. Conclusions

Grain size of the EBP material is the most decisive physical-mechanical attribute for utilization and suitability for ground structures, which can differ fundamentally regarding the method of production of various types of EBPs.

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