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Road and Rail Infrastructure V

Stjepan Lakušić – EDITOR

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SUBGRADE TREATED BY ALTERNATIVE TECHNOLOGIES BASED ON FLY ASH FROM FLUIDIZED COMBUSTION

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Abstract

The paper reflects the current topic, processing of energy coal combustion products (CCP). This issue has been the subject of research intentions not only in the Czech Republic for many years. This paper focuses on the use of CCPs from fluidized bed combustion for road construction, especially for treatment of pavement subgrade. Because of increasing emission limits, energy industry invests lot of money to modernize current technologies. One of the options is combustion in special boilers on fluidized bed. Specifications of this technology are combustion at lower temperatures. The process of desulphurisation of flue gases with sorbent, most frequently limestone leads to residual lime remaining in the fly ash in the form of softly burnt lime which is capable of further hydration. At the same time there is the possibility of burning multiple types of fuels at the same time, which could be a potential danger influencing the quality and homogeneity of CCPs. The paper deals with the usage of untreated fluidized fly ashes, and it also focuses on possible processing of these ashes by high-speed milling technology and their potential use as a replacement for current hydraulic binders. High-speed milling process initiates the ability of the processed material to further hydrate. We try to use this property in the pavement industry, where activated fluidized fly ash has the potential to substitute the current hydraulic binders. The laboratory comparison was performed on the mixtures of soil with and without CCPs from different sources and on a selected soil treated by standard hydraulic binders and binders based on CCPs. The main parameter was CBR test. The paper also deals with the issue of swelling, which is a very common problem of fluidized fly ash application. In terms of laboratory assessment, linear swelling was measured during saturation before the CBR test.

Keywords: CBR, Fluidised fly ash, Fluidised coal combustion, Soil treatments

1 Introduction

Fluidised bed combustion (FBC) is based on the firing of coal and sorbent (most commonly limestone) mixture in a fluidised layer, i.e. a layer which behaves as liquid because of the jets of air blown in. Compared to traditional fixed bed combustion [3, 4, 7, 9], the main advantages of fluidised bed combustion include lower combustion temperatures (the temperature ranges from 800 °C to 900 °C), the possibility of reaching an effective output regulation, superior boiler efficiency and the option of combining varying grades of fuel from various sources where the only condition is the identity of their granularity level. Lower combustion temperatures along with the desulphurisation agent result in lower emissions of hazardous substances released in the atmosphere and reductions of pollutants contained in the fly ash. Disadvantages include the pace of operation start, which amounts to over 15 hours, complexity of the apparatus and high purchase cost of the technology. The FBC technology can be divided into two basic types, combustion operating at atmospheric pressure and pressurised

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combustion, which is currently a focal point for the specialist public, particularly in relation to the problems of biomass firing. Atmospheric FBC is further divided into BFBC – Bubbling Fluidized Bed Combustion and CFBC – Circulation Fluidized Bed Combustion [3, 4]. The BFBC and CFBC technologies differ as to the speed of the air jets piercing the fluidised bed, particle size of the inert material forming the fluidised layer, and the method of fuel firing itself; for BFBC, the fuel burns in the lower part of the boiler, the fluidised bed ends with this layer and no particles can fly off. CFBC utilises higher air jet speeds where no fluidised bed surface is obvious. Turbulence and circulation provide an improved bed combustion and homogeneity. With CFBC, light-weighted particles flow off and are subsequently separated in cyclones and re-circulated back to the fluidised bed [3, 8]. Therefore, CFBC has a very high fuel combustion efficiency (see [4]) of 98 to 99.5 %. BFBC is employed in facilities with lower output, up to 20 MW, while CFBC is applied in technologies with installed capacity over 30 MW, i.e. in the power industry in particular. This paper focuses on the processing of fluidised bed ashes from the Ledvice and Tisová power plants and on the application of CCPs from CFBC. BFB side products are not examined in this paper. Besides untreated soil, the reference samples also include high-temperature fixed-bed combustion fly ash from the Mělník power plant.

2 Byproducts from fluidized bed combustion

In CFBC, the fuel (hard coal, soft coal, biomass and others) is re-crushed to particle size of approx. 20 mm and, together with the limestone, jetted in air into the boiler at 5 – 10 mm/s, where the mixture circulates turbulently, facilitating better firing of the fuel. The fuel combustion itself occurs on a fluidised layer composed of inert material, most often silicate sand with particle size of 0.2 to 0.4 mm. The added sorbent, limestone ($CaCO_3$) or dolomite, reacts – under suitable thermal and aerodynamic conditions – straight in the boiler with sulphur dioxide (SO_2), and the resulting solid product ($CaSO_4$) forms a part of the ashes, see chemical diagram in Eq. (1 and 2) [10] The product obtained is a mixture of ashes from the original fuel, unreacted desulphurising agent (CaO with possible $CaCO_3$ residues), calcium sulphate, products of the reaction of the ash components with CaO and unburnt fuel. The residual lime is found in the ashes in the form of soft-slaked lime [6], which demonstrates a potential for further hydration. The typical proportion of soft-slaked lime in the fly ash amounts to roughly 15 %, and with increasing stringency of desulphurisation limits, we can expect the proportion to increase up to 30 %.

$$CaCO_3 \rightarrow CaO + CO_2 \left(\text{Decomposition}\right) \tag{1}$$

$$CaO + SO_2 + ½O_2 \rightarrow CaSO_4 \left(\text{Sulfation}\right) \tag{2}$$

3 Mechanical chemically activated materials

High-speed milling [11, 14] is one of the high-energy grinding solutions characterised by a huge quantity of energy transfer per unit of material processed. The term of high-energy and high-speed milling (grinding) lacks an exact definition in most literature sources. It shares all basic characteristics of milling in its classic form, i.e. refining granularity, increasing specific surface, opening individual particles etc. In contrast to traditional grinding, however, high-speed milling involves certain phenomena (effects) not observed in standard grinding. These effects consume a part of the input energy which uselessly transforms into heat in the standard grinding process. In anorganic materials, these phenomena include inter alia:
- mechanical-chemical (mechanical) activation,
- formation of higher proportions of micron particles and nanoparticles,
- in some cases, a higher level of effectiveness of energy exploitation for new surface formation purposes.

The mechanical-chemical activation effect employed by high-speed milling allows a significantly better use of energy put in the grinding of the substance. This stems from the accumulation of a part thereof in the form of increased enthalpy of the substance processed. The aforementioned effect also allows the grinding equipment (disintegrators) to:

- induce chemical reactions in the solid state of the material during grinding (e.g. oxidising or exchange reactions),
- initiate phase changes (besides amorphisation) in various substances,
- create mechanical alloys of metals during the grinding process,
- initiate catalytic reactions in both organic and inorganic systems during the grinding process.

Research efforts of the CTU Prague road building laboratories, focusing on high-speed grinding for several years, have been centred on waste material transformation into valid alternative fillers and binders since 2010. High-speed grinding principles are applied to the processing of fluidized fly-ash, reclaimed concrete material, limestone filter dusts and sludges and other materials. Partial results are presented e.g. in [12, 13].

4 Materials

The project used local soil obtained during the reconstruction of highway D1 and fluidized-fly ash from various sources (LL, TL, TÚ, KÚ). Mechanical-chemically activated materials based on fluidized fly-ash wherein the AM-D binder is on the basis of high-speed grinding principles and is manufactured and sold on a commercial scale, were assessed as well. The AM-S1 binder is the first version of the binder developed within CTU in Prague; AM-S2 is the second generation thereof. The AM-K binder is a mechanical-chemically activated ash an unprocessed version of which was also used and marked KÚ. Portland cement CEM II / B-M (S-LL) 32.5 was chosen as the reference material according to CSN EN 197-1 ed. 2.

4.1 AM-D

In compliance with a valid Czech national patent, AM-D is a dry anorganic hydraulic binder prepared by mechanical-chemical activation of fluidised bed combustion ashes and other additives, depending on the requirements for the ultimate application of such binder. The high-speed milling technology allows achieving a higher internal energy of the material, formation of active surfaces on the material particles while increasing the specific surface (refining the granularity) of the materials, which drives the chemical reactivity of the material up considerably. The input materials thus yield an alternative hydraulic binder which can be used separately or together with a filler (e.g. various kinds of aggregate) for applications in building or road construction (e.g. within soil improvement, in the production of vibropressed construction elements, for granulra materials bound by hydraulic binder, for sludge stabilisation or solidifcation etc.). The basic physical parameters of dry hydraulic AM-D binder usually fall in the range of: apparent density approx. 680 – 860 kg/m^3, bulk density approx. 2100 – 2200 kg/m^3, specific surface approx. 800 – 900 m^2/kg. This paper presents AM-D type AX2 binder prepared with fly ash FBC from the Poříčí power plant (ČR). The fine granulate ashes were collected from the electric filters of the Mělník III plant (ČR).

4.2 AM-S

A ternary binder based on two different types of fly ash was developed in the Czech Republic based on fly ashes typical for this country. As already stated above the binder composition is covered by a patent and contains fly ash from fluidized combustion, siliceous fly ash, water and lime hydrated. The binder is currently going through a further development stage. Most often, the combination involves cement and other components, in this case fly ashes from coal-burning power plants where the main effort in recycling the waste material while using it as a valuable binder for structural layers or foundation structures in road construction. This paper reflects two development stages of this alternative binder nambed as AM-S1 and AM-S2.

4.3 AM-K

Dry anorganic binder based on fluidized fly ash from a thermal power plant near Prague (KÚ), modified by mechanical-chemical activation technology. At present, the binder is being researched at CTU in Prague. The fluidised bed combustion ash from KÚ were used in an unmodified form, too.

5 Methodology of testing

The methodology of assessing improved soils intended for pavement subgrade layers involved the application of the CBR test which is one of the most widely used indirect methods of predicting the load-bearing capacity of the proposed pavement subgrade. The CBR (bearing ratio) of the soil in the subgrade is determined for a sample compacted at optimum humidity by Proctor compactor using the Proctor Standard method. The test specimen is then saturated in water for 96 hours. In the case of soils iproved by hydraulic binders, the sample is left to cure (prior to the saturation) for 72 hours at 20±2 °C during which the sample may not dry up. The CBR is determined according to EN 13286-47 with additional load of 4.5±0.2 kg. Any potential volume changes were monitored during sample saturation prior to the CBR test, when so-called linear swelling was observed.

6 Results and discussion

The data based on the CBR assessment as presented in this paper indicate the possibility of substituting standard hydraulic binders with fluidized fly-ash based alternatives. In many respects, mechanical-chemically activated materials (AM) demonstrate parameters similar to hydraulic binders used as a standard at the moment. The designs of individual versions are based on the assumed final price of the product. The assumed price of alternative binders should rest at roughly 50 % of the standard price of Portland cement used in this paper as well to compare the mechanical effect of the modified mixture. The comparison involved 3 versions which correspond to the standard binder doses in subgrade treatment (1-3 %). In the case of higher doses of standard hydraulic binders, the modification is uneconomical and with respect to practical application, the material is usually replaced or its granularity is modified. Based on long-term experience with alternative binders, we chose higher doses which also reflect the expected price that should be roughly one half in relation to the standard hydraulic binders.
The values presented in Fig. 1. and Fig. 2. declare the possibility of using alternative binders where the load-bearing capacity of soils modified by alternative binders AM-C1, AM-C2 and AM-D demonstrate similar, or superior results in relation to the reference mixture bound by Portland cement. Only with higher doses in Fig. 3 the alternative binders observed to have a slightly lower load-bearing capacity. However, this might be due to an excessive dose of binder where the CBR reaches a value rather typical for subbase layers. The question remains how appropriate the CBR assessment is for such layers, and whether it would be more suitable to test compressive strength and verify resistance to frost and water. Assuming thorough laboratory examination and observation of technological discipline, the data measured recommend alternative hydraulic binders AM-C1, AM-C2 and AM-D as substitutes for standard hydraulic binders. Solely in the case of the AM-K binder, the load-bearing capacity as measured was considerably low and a certain improvement in the soil was only demonstrated with a higher dose. Although soil modification by AM-K is possible, and a certain contribution

in the form of recycling of energy production byproducts can be acknowledged, this form is too expensive from the economic perspective. For the sake of practical applications, the mechanical-chemical activation process for AM-K must be further refined as the probably reason behind the limited efficiency of the alternative binder is a lower CaO content in the fly-ash variants.
From the perspective of linear swelling, the mixtures as designed did not demonstrate any changes in volume. In the future, it is recommended to monitor the versions under research in order to rule out any changes in volume that might be recorded over a longer time frame.

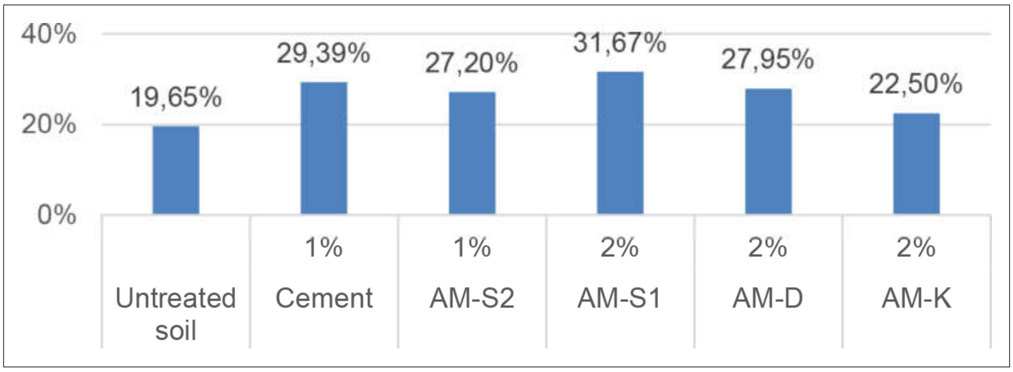

Figure 1 CBR of activated material variant 1

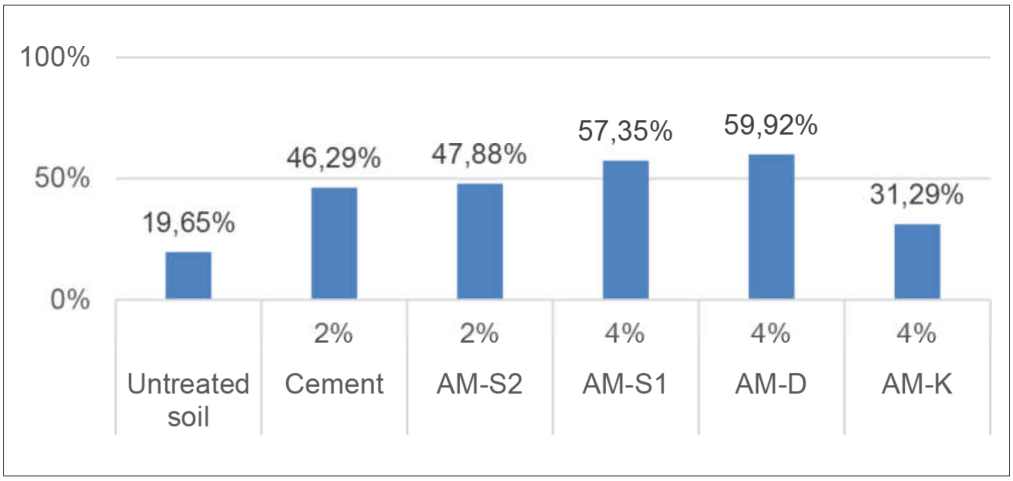

Figure 2 CBR of activated material variant 2

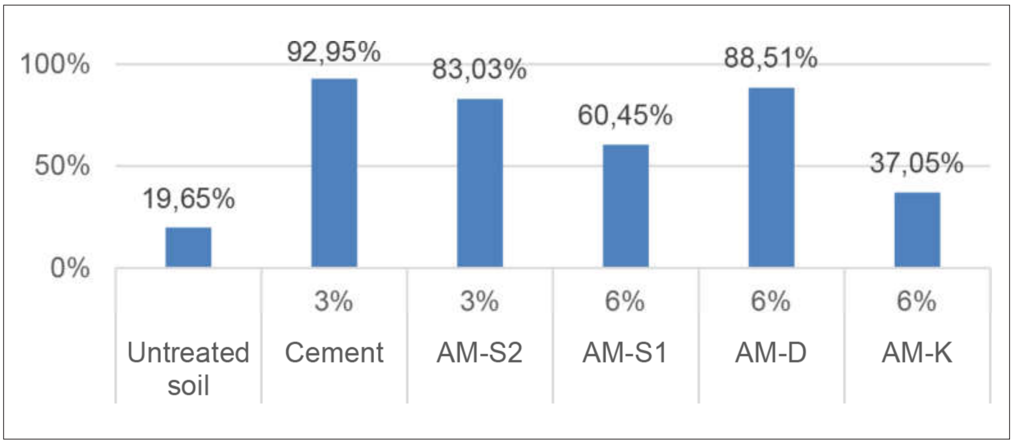

Figure 3 CBR of activated material variant 3

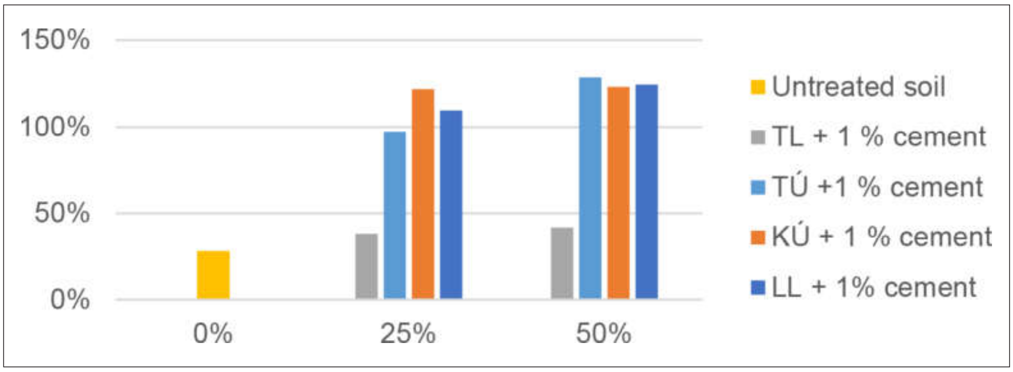

Figure 4 CBR of soil mixed with different fluidized fly-ashes

From the perspective of assessing soils partially substituted by fluidized fly-ashes, 25 % and 50 % of soil was substituted in combination with 1 % cement. The data presented in Fig. 4. show the high potential of such substitution where the addition of energy byproducts from fluidised bed combustion meant a significant increase in the load-bearing capacity of the treated soil with the exception of the versions involving combustion bottom ash TL where, although possible, substitution has a very little potential from the point of view of added value. Even in this case, no changes in volume occurred within the saturation of samples. In the future, it would be good to check options with lower contents of fluidized fly-ash and focus on long-term monitoring of volume changes.

7 Conclusions

The results presented herein suggest possible ways of utilising fluidised bed combustion byproducts in the treatment of the local soil in the pavement subgrade layer, and point out a potential path to processing and beneficial recycling of such materials in practice. However, the application of the fluidised bed combustion byproducts is preconditioned by meticulous design and laboratory assessment of the final mix, aiming to minimise any potential negative properties of the material, particularly in terms of volume changes. An important aspect from the point of view of application is also observation of fluidized fly-ash homogeneity where the individual power plants have different input sources of fluctuating quality (coal, limestone, biomass etc.). At the same time, not even the fluidised bed combustion technology is uniform. Therefore, the FBCA behaviour cannot be globalised and fly ashes from individual power plants must be carefully distinguished while the quality of input material is taken into account. Despite these risks, there is a point in using some fluid ashes in road construction. Not only the reuse of material which would otherwise require storage with no further use should be viewed as added value; there is more added value in selected materials' ability to further hydrate, thus substituting for standard hydraulic binders whose production is expensive and associated with a certain environmental burden (e.g. increased carbon footprint).
The paper presents a part of a broader research of such materials and the application thereof in road construction. In this case, the research focused on the potential exploitation of such materials in the treatment of pavement subgrade layers where the local soil is handled. The paper presents the possible use of untreated fluidized fly-ashes and ashes which are further processed to yield alternative hydraulic binders. The individual variants are assessed by the California Bearing Ratio (CBR) test while the linear swelling parameter is monitored throughout sample saturation.
The measurement values prove there is sense in the use of unmodified fluidized fly-ashes, as the CBR values increased severalfold in the versions with TÚ, KÚ and LL. When optimised, these versions undergo another reduction of the fluidized fly- ash addition when CBRs are too high, exceeding the range of usability in pavement subgrade layers. Mixtures with CBR over 100 % would be rather more useful in base layers where, however, soils treated by hydraulic

binders should be evaluated by compression strength testing and the test should also be performed with specimens subject to frost cycles from the curing perspective.
In the case of alternative binders, we have managed to prove the point of treating local soils where selected mixtures with fluidized fly-ashes processed by high-speed milling demonstrate parameters similar to those of mixtures treated by standard hydraulic binders. Particularly the AM-S2 version scored comparable values with the same doses as standard hydraulic binders. Another two versions, AM-S1 and AM-D, confirmed the long-term trend of increasing the content of such alternative binders. However, from the economic perspective, the increase is at par with the use of cement, so the benefit can be seen as reuse of byproducts which would otherwise be dumped. The paper further presented the AM-K alternative binder which failed the criterion of sufficient load-bearing capacity – in other words, the application of this binder would be uneconomical. On the other hand, even this binder demonstrates an improvement of the soil treated and there is a certain potential for working with the binder design in the future. Therefore, selected variants can be recommended for the treatment of local soils although the execution must be preceded by a careful design and laboratory assessment.

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