Potential use of fly ash to soil treatment in the Morava region

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Abstract. Soil treatment by binders is a standard technology and leads to optimal utilization of excavated soils in road constructions. Soil treatment is controlled in the Czech Republic by EN 14227-15 and Technical Requirement TP 94. Soil treatment using fly ash has not been performed in the Czech Republic, although there is a sufficient normative base. Fly ash produced by burning of hard coal in the Moravian region was tested as a potential binder. Fly ash samples were mixed with loess loams (CI). Tested siliceous fly ash of class F (ASTM C618) did not show hydraulic properties but it showed positive effect on reducing maximum dry density of mixtures, increasing the IBI value (Immediate bearing index) and decreasing tendency to volume changes when the amount of fly ash was increased. The results of laboratory tests demonstrate the possibility of using fly ashes as a binder for soil treatment.

1. Introduction and background

Treatment and stabilization of soils change the properties of soils to improve their engineering utilisation. Bulk density, moisture content, plasticity, susceptibility to volume changes, shear strength and bearing capacity are the most improving properties of treated soil [1]. Hydraulic road binders, which are used in soil treatment, contain mainly cement and/or lime. Recommended alternative to traditional binders becomes fly ash [2, 3].

Fly ash is an inorganic product of combustion of pulverized coal in power and heating stations. Fly ash consists of small particles of siliceous glass and it is collected by electrostatic precipitators flue gases. Basic mechanical properties of fly ash, that are required for use in engineering, are maximum dry density, granularity, pozzolanicity and absorbability. Mineralogical composition and unburned particles content belong to its important chemical properties [3, 10].

Research on the potential use of fly ash and ash from thermal power stations began in Europe during World War II in the UK. Fly ash was first used as an admixture in concrete to reduce the consumption of Portland cement. Later, the fly ash produced by combustion of coal has been marked as PFA (Pulverized Fly Ash), thus distinguishing it from derivatives produced by combustion of other of types material. PFA has been introduced in the construction industry as a material for construction of embankment of roads [4]. By the end of the 20th century, fly ash was used in road construction only for the construction of embankments and for levelling adjacent surface near its source. Then, the use of fly ash in civil engineering projects increased substantially in the Czech Republic, for example, in 2009, 100 000 tonnes of fly ash were processed per year during the construction of the D11 motorway [2,5].

Fly ash is used in geotechnical applications closely connected with road construction to increase strength properties of soils, to control contraction and swelling of soils, to reduce water content in soils and to modify a particle size distribution [1].
2. Standards and requirements
Soil treatment by fly ash in the Czech Republic is governed by the European standard EN 14227-15 Hydraulically bound mixtures - Specifications - Part 15: Hydraulically stabilized soils, which was adopted in 08/2016, Technical Requirement TP 94 - Soil treatment, valid since 11/2013 and Technical requirements TP 93 - Design and construction of highway structures using fly ash and ash, valid since 02/2011. Regulations contain technical requirements for materials, material testing, requirements for the construction of road layers, effects of soil treatment and environmental aspects.

3. Materials and methods
Fly ashes from the Morava region were tested as potential binder to soil treatment. First one (FAO), produced by Arcelor Mittal Ostrava power station was collected from the tip near its source. Second one (FAP), was produced in the Heating station of Přerov. This fly ash was deposited on tip in Předmostí until 1996 and then the tip was reclaimed. Fly ash samples were collected from depth of two meters below surface. Both fly ash samples were produced by burning of coal from the Ostrava-Karvina coalfield. Tested soils were sampled from the sites of planned construction of roads in the Morava region, soil SO from the construction of “the Road I/11 Ostrava – the elongation of the Rudná street” and soil SP from the construction of “the D1 Motorway Přerov – Lipník nad Bečvou”.

![Sampling of materials.](image)

Laboratory tests were carried out both on untreated and treated soils. Soils were mixed with 10% and 15% of fly ash. Several sets of chemical and mineralogical analyses were performed on samples, including leaching of the FAP sample. Leaching of heavy metals is one of the important environmental aspects. The limit values are set in the TP 93. Fluorescence Spectrometry and Scanning Electron Microscopy were carried out in the ICT VŠB TU Ostrava - Institute of Clean Technologies.
The Proctor Standard test sets a maximum dry density and optimal moisture of untreated soils, treated soils and fly ashes. Then values of immediate bearing index (IBI), and California bearing ratio (CBR) after 96 hours of soaking and three days of curing were determined. Minimal value of IBI for utilisation of treated soils as fill is 10% (see TP 94). Volume changes (swelling) represent a crucial parameter of fly ash - they limit its utilisation as fill in road construction. The maximal allowable linear swelling is 3%. This value is measured in CBR mould after 3 days of curing in wet conditions, according to the TP 93. All tests were carried out under laboratory conditions.

4. Results and discussion
Chemical analysis was performed to classify fly ash and determine its reactivity. The analysis showed that SiO$_2$, Al$_2$O$_3$ and Fe$_2$O$_3$ represented more than 70% content. The CaO content was 5% maximum (Table 1). Fly ash samples were classified as class F - siliceous (ASTM C618). Siliceous fly ashes are characterized by low volume changes and higher pozzolanic activity.

| Element | FAO (%) | FAP (%) |
|---------|---------|---------|
| SiO$_2$ | 42.70   | 51.28   |
| Al$_2$O$_3$ | 24.53 | 30.78   |
| Fe$_2$O$_3$ | 4.57  | 6.29    |
| CaO     | 4.89    | 1.61    |
| MgO     | 0.66    | 0.80    |
| SO$_3$  | 0.95    | 0.08    |
| K$_2$O  | 2.39    | 2.98    |

Electron microscope snaps of fly ash FAO from the AMO power station and sample of the SO soil are shown in Figures 2 and 3. Spherical particles of fly ash microspheres and mica particles were observed. Microspheres are formed during combustion in the temperature range of 1200-1500°C and they influence fly ash properties (density, porosity etc.). Soils were represented by loess loams (clays of low to medium plasticity CL-CI).

Results of leachate in case of the FAP sample showed, that this fly ash is suitable in roads construction. Any element does not exceed the limit set by the Czech specification TP 93 and all
values are several times lower than the limit ones (Table 2). The highest content of the leachate occurred in case of As, Co and V.

**Table 2.** Results of leaching test of the FAP sample.

| Element | Max (mg/l) | Meas. (mg/l) |
|---------|------------|--------------|
| Ag      | 0.1        | < 0.005      |
| As      | 0.1        | 0.0140       |
| Ba      | 1          | 0.0230       |
| Be      | 0.005      | < 0.005      |
| Pb      | 0.1        | < 0.01       |
| Cd      | 0.005      | < 0.003      |
| Cr celk | 0.1        | 0.0070       |
| Co      | 0.1        | < 0.01       |
| Cu      | 1          | < 0.01       |
| Ni      | 0.1        | < 0.006      |
| Hg      | 0.005      | < 0.0003     |
| Se      | 0.05       | < 0.012      |
| V       | 0.2        | 0.0170       |
| Zn      | 3          | < 0.01       |
| Sn      | 1          | < 0.02       |

The Proctor Standard test set an optimal moisture $w_{\text{opt}}$ of soils in range of 15 - 17%. Maximum dry density of mixture of soil and FAO was $\rho_{\text{dmax}} = 1780$ kg.m$^{-3}$ (mixture with 10% FAO). In case of the mixture of soil and 10% of FAP a maximum dry density was $\rho_{\text{dmax}} = 1670$ kg.m$^{-3}$. Measured values of all samples are showed in Table 3. Addition of fly ash caused reduction of the maximum dry density of the mixtures about 100 kg.m$^{-3}$ under the same optimal moisture.

**Table 3.** Results of the Proctor Standard tests.

| Sample   | $w_{\text{opt}}$ (%) | $\rho_{\text{max}}$ (kg/m$^3$) |
|----------|-----------------------|---------------------------------|
| FAO      | 36                    | 1080                            |
| SO       | 16                    | 1850                            |
| SO+10% FAO | 16                  | 1780                            |
| SO+15% FAO | 15                  | 1740                            |
| FAP      | 45                    | 890                             |
| SP       | 16                    | 1740                            |
| SP+10% FAP | 17                  | 1670                            |
| SP+15% FAP | 17                  | 1630                            |

All tested mixtures exceeded minimal value of IBI (min = 10%) for utilisation of treated soils as fill (Figure 4.). The IBI value immediately after compaction was 11% and 16% for untreated soil SP respectively SO. The greatest change was observed in case of both mixtures with 15% of fly ash. The IBI values increased to 15% and 21%. Fly ash alone did not cause the hydraulic behaviour of mixtures. CBR values after soaking of samples with FAP were not considerably different. Measured CBR values were 11% - 15%. CBR values increased by approximately three times, from 4% to 11%, in case of samples with FAO (Figure 5). Hydraulic binder is recommended to add to mixtures to increase the IBI and CBR values. Hydraulic binder will be an activator and subsequently will initiate pozzolanic properties of fly ashes. It will cause the ion exchange reaction between soil particles and
fly ash, and it will be resulted in the increase of strength properties of treated soils. All samples fulfil requirements of Czech specification regarding value of volume changes. The curves indicate decreasing tendency to swell when the amount of fly ash is increased (Figure 6). Linear swelling of mixture with FAO ranged between 0.8 and 1.6%. Critical values occurred in mixtures with FAP, values were 1.8% - 2.8%.

![Figure 4. Dependence of IBI values of the mixtures of soil and fly ash.](image1.png)

![Figure 5. Dependence of CBR values after soaking of the mixtures of soil and fly ash.](image2.png)

![Figure 6. Changes of volume for soil treated with siliceous fly ash.](image3.png)

5. Conclusions and recommendation to future work
Laboratory tests show the potential of utilisation of siliceous fly ash from the Morava region in road construction. Based on the results from executed tests fly ash can be used in mechanical treatment of soils (tests were carried out with loess loams) without admixture of any hydraulic binder. In the further research it is recommended to verify parameters of mixtures with different lime content. The next step would be to check the mixture properties in large-scale tests on construction site using the appropriate machinery. Fly ash from the Předmosti tip will be used as fill in embankments of the D1 motorway. In 2017 is planned starting of earthworks. However, fly ash is designed to be used as fill only. Its utilisation as a binder is not expected.
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