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PHYSICAL AND MECHANICAL PROPERTIES OF COAL FUEL ASHES

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1. Introduction

Thermal power stations burning low or medium quality solid fuel produce large quantities of ashes. The character of the ash on the dumps depends on the properties of the fuel, on the burning process and on the mode of transport and deposition. The hydraulic transport is advantageous from the standpoint of service and perhaps economy too, but the geotechnical properties of the resulting sediment are poor especially when saturated. Liquefaction of ash dumps caused by seismic, dynamic or seepage forces can reach even catastrophic forms with hard consequences for people and property. For the design and construction of safe dumps with minimum impact on the environment the knowledge of the geotechnical properties of sedimented ashes plays a decisive role.

The results presented here have been obtained on the ash samples collected on largest impoundments of Slovakia. The impoundments are used for still working brown-coal heated power station in Zemianske Kostoľany.

2. Physical properties of coal fuel ashes

2.1 Grain size distribution and grain density

The range of grain size curves of ashes is in Fig.1. According to soil mechanics classifications corresponding soils would be called medium and fine sands, sandy silts and silts. The clay fraction (particle diameter < 0,002 mm) is usually absent.

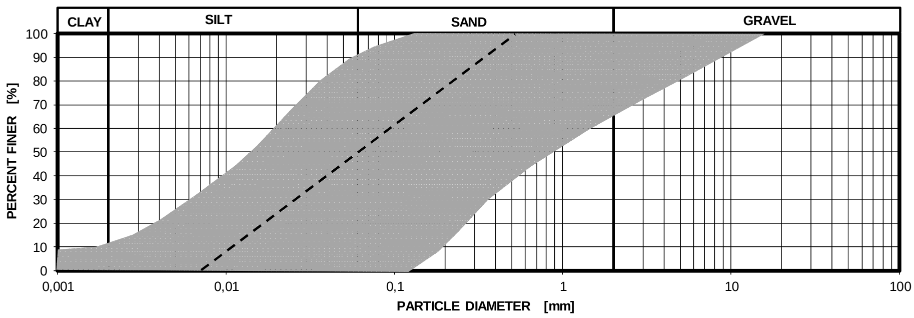

Fig.1 The range of grain size curves of ashes

The dashed line in Fig.1 separates ashes with the predominant effect of the sand fraction from those with the prevailing influence of silty group. As ashes exhibit no true cohesion and no plasticity, their properties are governed by their grain size distribution. In order to get a more complete review, from a set of 303 grain size curves the diameters d_{10}, d_{30}, d_{60} and the coefficients $C_u = d_{10}/d_{60}$ and $C_c = d_{30}^2/d_{10}.d_{60}$ were determined and statistically analysed. Special attention was paid to the statistical distribution of the diameter d_{10} for its considerable practical significance in regard to the permeability of the non-cohesive materials. The probability distribution of d_{10} is shown in logarithmic-normal coordinates as the histogram in Fig.2. It can be well approximated by the symmetric bell-shaped (Galton´s) curve with the parameters (1) :

$$f(\ln d_{10}) = 0{,}389 . e^{-\frac{1}{2}\left(\frac{\ln d_{10}+3{,}727}{1{,}026}\right)^2} \quad (1)$$

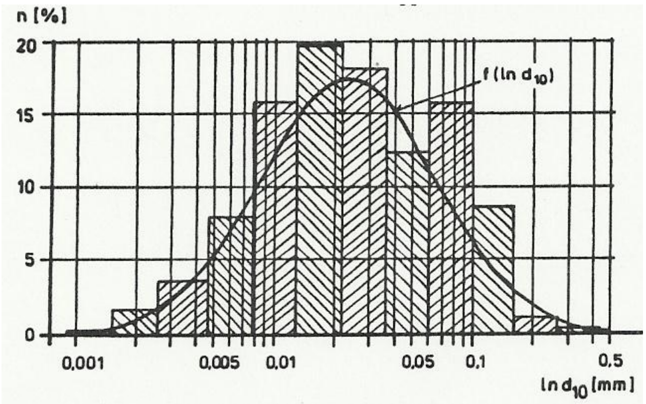

Fig.2 The probability distribution of d_{10}

The uniformity coefficient C_u is in 84 % of all cases $C_u < 15$. The ashes demonstrated a high grade of uniformity, probably consequence of grain assorting during burning process, hydraulic transport, floating and sedimentation. The coefficient C_c shows, that the ashes are prevailingly poorly graded.

The average of grain density of ashes is about 2,0 – 2,4 g.cm^{-3}. The value greater than 2,4 g.cm^{-3} for grain density is exceptional.

2.2 Porosity and unit weight

High porosity of sedimented ashes results into metastable structure and makes the taking of undisturbed specimen difficult. Many good specimens got disturbed even when transported thoroughly packed. To avoid these problems, a laboratory sedimentation method of uniform layers with various assorted grain size distribution has been developed in order to produce homogeneous samples without the thin layering as it is to be found on the dumps. The porosities are fully equivalent.

The porosity and the unit weight of the ashes are considerably variable throughout the dumps depending on the system of floating and the dominant grain fraction. The scatter of the porosity of fine-grained ashes is 53 – 57 %, of coarse-grained ones 63 – 69 %. The dry unit weights of fine-grained ashes are 8,5 – 9,7 kN.m^{-3}, of coarse-grained ones 6,6 – 8,9 kN.m^{-3}. The higher porosity of coarse-grained ashes (in average by 11 %) was unexpected and proved to affect also the mechanical properties, especially the compressibility of these ashes.

3. Mechanical properties of coal fuel ashes

3.1 Compressibility

The compressibility of ashes was investigated in one-dimensional conditions on 12 fine-grained and 12 coarse-grained samples. The average values and the scatter of the results are presented in Fig.3 as the void ratio versus stress e = f(σ) (2), (3) and the oedometric modulus versus stress E_{oed} = f(σ) (4), (5).

$$e = 1{,}33 - 0{,}16.\sigma^{0{,}53}$$ [-] – fine-grained ashes , (2)

$$e = 1{,}33 - 0{,}16.\sigma^{0{,}53}$$ [-] – coarse-grained ashes , (3)

$$E_{oed} = 2{,}6 + 36{,}6.\sigma$$ [MPa] – fine-grained ashes, (4)

$$E_{oed} = 2.8 + 14{,}7.\sigma$$ [MPa] – coarse-grained ashes. (5)

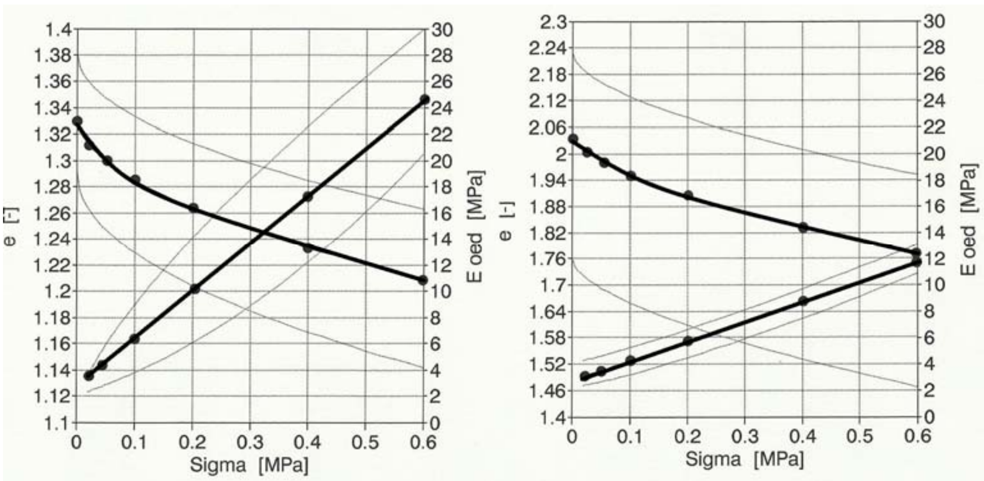

Fig.3 The compressibility of ashes

The results are unexpected. At the maximum stress level occuring in the dumps of about 0,2 MPa is the oedometric modulus of fine-grained ashes round 1,8 times higher than that of coarse-grained ashes. As this could not be the consequence only of the higher initial porosity, an additional explanation was necessery. Micrographs showed that while the fine graines are prevailingly spherical and compact, the coarse ones have irregular, angular shapes with sharp edges and points and inner closed pores Fig.4. At increasing stresses the edges and the thin walls of closed pores get gradually destroyed and contribute to the compressibility. The effect of grains break down was confirmed by experimental measurements. Different values of the stresses worked on the sample of ash during compressibility test. After the compressibility test the change in the grain size distribution was evaluated. The experiment results are shown in Fig.5.

The consolidation of both fine and coarse-grained ashes is very fast. The coefficient of unaxial consolidation was measured in range $9{,}7.10^{-5} – 5{,}0.10^{-3}$ $m^2.s^{-1}$. The increase of vertical stresses at normal conditions of floating and sedimentation with an annual rate of some meters can not evoke excess pore pressure which could seriously threaten the stability of the dump slopes.

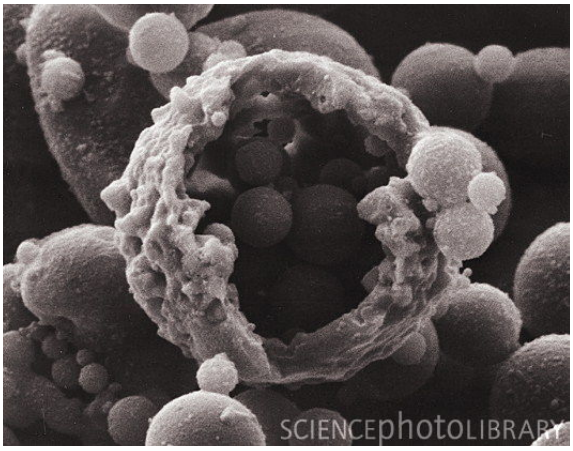

Fig.4 Micrographs of ashes (SCIENCE photo LIBRARY)

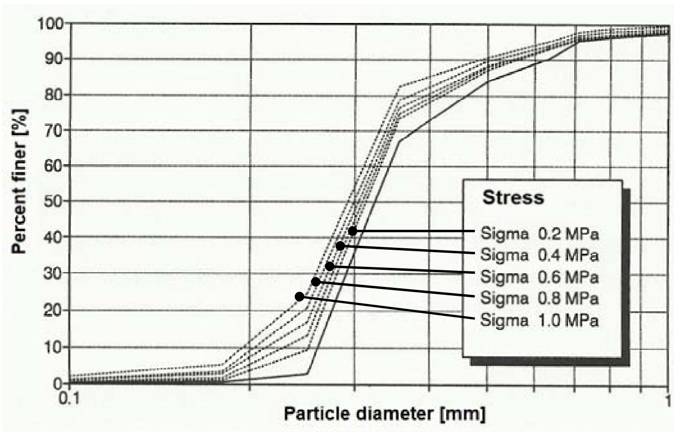

Fig.5 The changes in grain size distributions after loading

3.2 Shearing strength

The most important imput data for conventional stability calculations are the parameters of the shearing strength. Samples were prepared with various granulometry and initial porosity as to cover the whole range of values occuring in the dump. The shear box tests were carried out on saturated samples with various speeds. Values of the angle of internal friction were measured in the range 27 – 38^o with a statistical mean of 32,5^o and standard deviation s = 3,8^o. In 58 % of the tests also cohesion was measured (only in two cases was c > 10 kPa), probably as a consequence of capillarity and the linear envelope according Coulomb´s theory. At low normal stresses (25 – 50 kPa) a part of the samples showed slight dilatancy during shearing, at higher stresses behaved all as an expressively contractant material. In the whole series of 48 stress-strain curves no post-peak decrease of the shear strength occured.

The correlation between grain size distribution (diameter d_{10}) and the shearing strength of the ashes (angle of internal friction φ_{ef}) was expressed based on statistical evaluation of the set 204 grain size distribution and corresponding measurements of the shearing strength. The whole range of grain was divided into intervals. In Fig.6 the average values of the angle of internal friction φ_{ef} are expressed in each interval. The correlation (6) is presented in Fig.6.

$$\varphi_{ef} = 36 + 2{,}75.\log d_{10}, \quad d_{10}\ [\text{mm}]\ ;\ \varphi_{ef}\ [^{o}]. \tag{6}$$

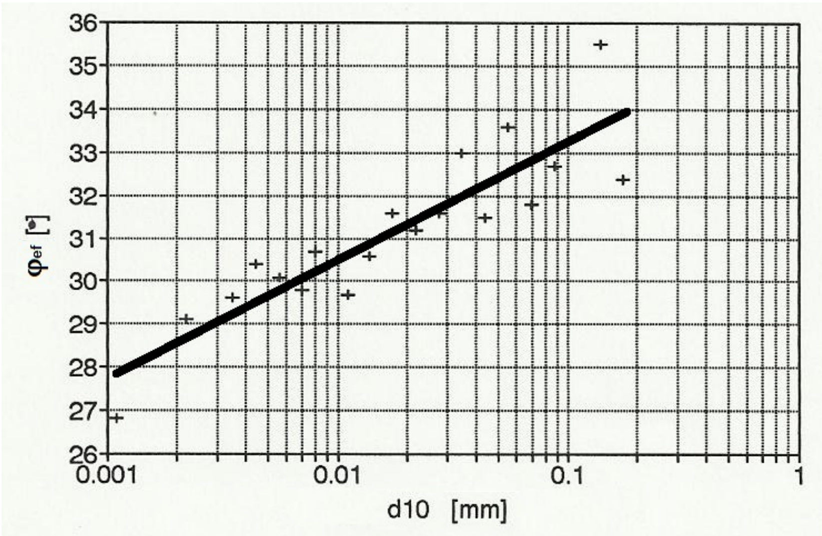

Fig.6 The correlations between grain size distribution and shearing strength

3.3 Permeability

The seepage of water through the dump slope considerably influences its stability and safety. Reliable determination of the permeability of sedimented ashes is very difficult because of their thin-layered texture and large variable anisotrophy.

The permeability of ashes was determined on samples with ϕ = 56,5 mm, height 20 mm (variable hydraulic gradient i_o = 15) and on samples ϕ = 100 mm, height 100 mm and 200 mm (constatnt gradient i = 1,0 – 1,5). Values of the permeability coefficient were measured in range $1{,}5.10^{-7}$ – $4{,}0.10^{-5}$ $m.s^{-1}$. Higher values (up to 7.10^{-5} $m.s^{-1}$) were found only on samples with artifically removed fines.

The correlation between grain size distribution (diameter d_{10}) and the permeability coefficient (k) of the ashes was expressed on statistical evaluation of the set 146 grain size distribution and corresponding archival and own measurements of the permeability. For the same diameters d_{10} were averaged different values of the permeability coefficient k. In Fig.7 the average values of the permeability coefficient k are expressed depending on diameters d_{10}. The resulting correlations between grain size distribution and the permeability coefficient (7) is presented in Fig.7.

$$k = 8.9.10^{-4}.0{,}27^{0.49^{\log d_{10}}}, \quad d_{10}\ [\text{mm}]\ ;\ k\ [\text{m.s}^{-1}]. \tag{7}$$

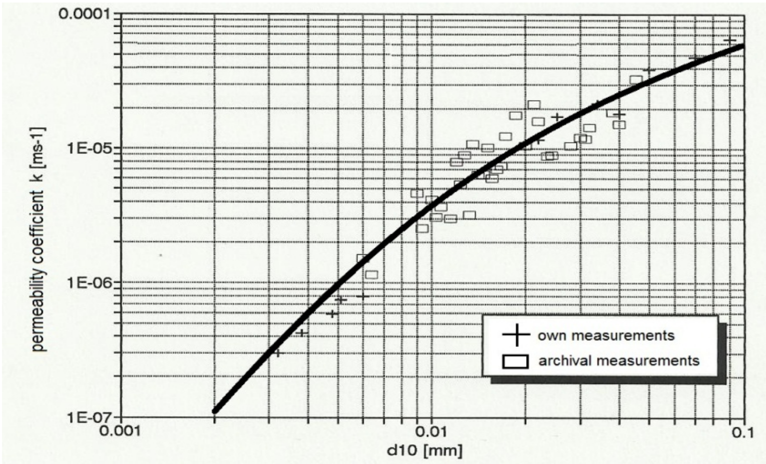

Fig.7 The correlations between grain size distribution and permeability coefficient

4. Coclusion

Hydraulically transported brown-coal fuel ash is an artificial geomaterial with extremely high porosity and metastable structure. Its grain size composition is uniform. The effctive unit weight of sedimented ashes is very low, especially below the water table (only about 4 $kN.m^{-3}$). The shear parameters of the ash are similar like taht of sands and silts with equivalent grain size distribution.

Seismic, dynamic or hydrodynamic effects can provoke a break-down of the metastable structure. Saturated ashes can easily liquify and change into a heavy slurry – this process may set in instantaneously or progressively. Until the laws of liquefaction of fine-grained thin-layered media are not fully known, the best measure for increasing the stability of slopes of impoundments of fuel ash or other similar media is a solicitous deep drainage and superficial dewatering of the dump.

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References

[1] Slávik, I. : Geotechnical problems of hydraulic dumps of granular wastes, PhD thesis, STU - SvF Bratislava, 1997, 173 s.

FYZIKÁLE A MECHANICKÉ VLASTNOSTI POPOLOV

Anotácia

V príspevku sú uvedené základné fyzikálne a mechanické vlastnosti elektrárenských popolov. Prezentované sú závislosti zmeny dôležitých mechanických vlastností na zmene pôsobiacej napätosti ($E_{oed} = f(\sigma)$ resp. na zmene ich zrnitostného zloženia ($\varphi_{ef} = f(d_{10})$; $k = f(d_{10})$).