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Characteristic of ash in storage ponds

Caractéristique des cendres dans les lacs d'emmagasinement

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SYNOPSIS: The paper delineates the properties of insitu fly ash following periods of sedimentation and subsequent settlement in a lagoon environment and discusses the hydraulic fill aspects in relation to toxic properties and subsequent use. Details of a storage lagoon at Przezchlebie, Poland is used to compare insitu properties with properties of other fly ash from Poland, United Kingdom, United States, Sweden and Finland.

1 INTRODUCTION

The usual technique in disposing of the ash created by the generation of electrical energy from coal-fired power plants is to use hydraulic transport systems, in which the slurried ash is pumped via a pipeline from the power plant into a lagoon. An alternative technique used in Poland is to deliver dry ash by rail in specially designed dumpwagons. Dry ash is removed from the dumpwagon using hydromonitors before the ash-water mixture is spread onto the surface of the lagoon. Considerable separation occurs during sedimentation and it is expected that a lateral gradation would exist as well as selective deposition of coarser grains close to the discharge point. Thus the deposited fly ash ranges generally from highly stratified, alternating layers of coarse grained ash particles and thin layers of fine particles near the discharge point to less destinct stratifications at the outflow zone. In addition regular cyclic movement of the discharge point will result in a complex heterogenous sedimentary profile.

2 PROPERTIES OF FLY ASH

A knowledge of the "intermediate" strength, permeability and settlement, consolidation parameters of lagooned fly ash is essential when considering reclamation alternatives and subsequent use of the lagooned material. In addition a knowledge of other properties such as chemical composition, particle shape, grain size distribution and moisture content, are essential in evaluating the lagoon deposits and their potential environment effects.

The properties of fly ash deposited in the Przezchlebie lagoon are used for comparison with data obtained from other lagoon deposits in Poland and in the United Kingdom /Table 1/ as well as from USA, Sweden and Finland.

2.1 Chemical Composition

The principal constituents of pulverised fuel ash are silica /SiO_3/, alumina /Al_2O/ and iron oxide /Fe_2O_3/ minor quantities of calcium oxide, magnesium oxide, sulphur trioxide, unburnt coal and other compounds are also present. Typical ranges for the various chemical components of various pulverised fuel ashes are shown in Table 2 /Leonards, Bailey 1982/, /Landby et al. 1985/.

There is good correlation with the level of silica, alumina, calcium oxide and unburnt coal content and the materials pozzolanic properties. It has also been found that the different fractions have slightly different chemical composition i.e. the amount of free carbon in the sand fraction was about 12 % and in silt was about 14.5 % /Broś 1981/.

In order to investigate the pollution of ground and surface water several testing points at

Table 1. Properties of Fly Ash Deposited in Lagoons

Properties	Unit	Name of the lagoon Gale Common UK	 Valleyfield UK	 Brotherton Ings UK	 Kędzierzyn Poland	 Przezchlebie Poland
Uniformity Coefficient	-	6.7	-	-	2.5-32	3-17
Specific Gravity	-	2.24	-	2.1	1.9-2.31	2.06-2.19
Moisture Content	%	45-50	60	30-50	62-70	23-52
Dry Density	kN/m^3	-	-	-	7.84-8.66	7.3-13.34
Maximum Dry Density	kN/m^3	14.6	11.53	-	8.96-12.33	11.97-12.3
Optimum Moisture Content	%	17.9	33	23-25	28-45	23-30
Permeability Coefficient	m/s	10^{-6}	10^{-7}	10^{-3}-10^{-6}	10^{-2}-10^{-6}	10^{-6}-10^{-7}
Angle of Internal Friction	deg	29	39	35	36-39	26-38
Cohesion	kN/m^2	0	5	0	12	0-25

Table 2. Typical Values of Main Chemical Components of Various Ashes.

Chemical Composition	Percentage by Weight			
	British Ash	USA Ash	Swedish Ash	Polish Ash
SiO_2	38-58	30-58	30-53	43-52
Al_2O_3	20-40	7-38	14-33	19-34
Fe_2O_3	6-16	10-42	10-14	0.7-10.7
CaO	2-10	0-13	0.9-6.1	1.7-9.4
MgO	1-3.5	0-3	4-6	1-2.9
SO_3	0.5-2.5	0.2-1	0.4-1.5	0.3-0.8
Na_2OK_2O	2-5.5	0.4-2	1.6-3.5	0.4-0.9
C	-	0-48	0.9-33	1.9-9.9

Przezchlebie lagoon and on the adjacent area were selected /Table 3/. The lagoon, located in an abandoned flooded sand quarry, is underlain by partly coal waste fill and by glacial sand of about 10-20m in thickness, directly overlying Tertiary clays. The ground water table ranges from 2-7.5m. In the period of June 1984 - October 1985 the chemical analysis of water samples showed the influence of ash lagoon on the drainage water. The highest value of chloride 511 and 1993 mg/dm^3 were determined there. No influence on the ground-water /piezometers and draw wells/ was found.

Table 3. Chemical Composition of Water from the Przezchlebie Lagoon Drainage, Piezometers and Draw Wells in the Vicinity of Lagoon.

Test Points	pH	Chloride $mgCl^-/dm^3$	Sulphate $mgSO_4^{2-}/dm^3$	Total Iron $mgFe/dm^3$
Drainage Outlets	7.7-8.7 7.5-8.5	1993 511	182 157	0.25 0.12
Piezometers 200 m from Lagoon	6.7-7.8	178	174	0.28
Draw Wells 500 m from Lagoon	7.3-8.1	272	120	0.05
Drinking Water^x Dz.U.18.77	6.5-8.5	300	200	0.5
Surface Water^x Dz.U.42.87	6.5-8 6-9	250 400	150 250	1 2

x/ Polish Standards.

2.2 Specific Gravity

The specific gravity of lagooned ash may vary from about 1.9 to about 2.5, the variation being dependent on a combination of factors such as gradation, particle shape, composition and segregation /Gray, Yen-Kuang 1972/, /Haws et al. 1976/, /Leonards, Bailey 1982/. The degree of segregation may be dependent on the materials distance from the discharge points. The predominant values for pulverised fuel ash tested in the Przezchlebie lagoon showed that the specific gravity varied from 2.17 at the discharge zone, 2.13-2.06 in the outflow and transitional zones and 0.8 for the floating scum /Zawisza, Skarżyńska 1987/. The lower values were due principally to the high concentrations of cenospheres and hollow particles in the tested zones.

2.3 Particle Shape and Composition

Qualitative estimate of particle size and detailed description of fly ash from Przezchlebie were determined by scanning electron microscope examination. Particle size ranged from submicron fragments to grains in excess of 200 microns. There appeared to be a relationship between size and particle shape. Findings of other authors /Chaney et al. 1983/, /Gray, Yen-Kuang 1972/, /Leonards, Bailey 1982/, have identified four main groups of particles having different shapes and compositions.

Scanning electron microscopy of Przezchlebie ash identified mainly spherical particles ranging in diameter from 1-40 microns. The other particles could be described as either "platy" /4x10x60 microns/ or large grains having a pumiceous like structure. The groups of spheres appeared in the form of aggregates up to 280 microns in lenght and the morphology of the aggregate surface was irregular and diversified /Figure 1/.

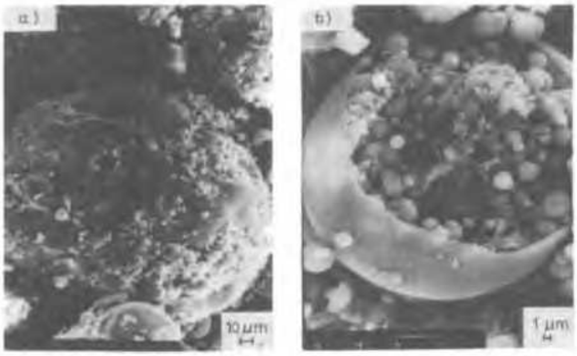

Figure 1. Scanning Electron Micrographs of Ash Particles, /a/ Large Irregular Grain /250 microns/. Smaller Spherical Particles in Forегrounds, /b/ Spherical Hollow Particle /48 microns/ Infiled with Smaller Spherical Particles.

2.4 Grain Size Distribution

Fly ash may range in size from silt through sandy silt to gravelly sand. The curves of particle size distribution obtained for Przezchlebie lagooned ash are shown in Figure 2a. For comparison typical values and ranges of particle size

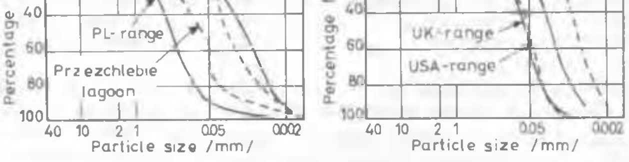

Figure 2. Grain Size Distribution of Ash Materials. /a/ from Poland, /b/ from UK and USA.

distribution of ash from other sources in Poland are also presented /Broś 1981/, /Symposium 1973/, /Rainbow, Skarżyńska 1987a/ as well as these from the UK. and USA. /Figure 2b/. All the curves indicate that there is a predominance of silt sized material.

2.5 Moisture Content

Theoretically the moisture content in lagooned ash will reduce as a result of sedimentation, subsequent consolidation and evaporation from the surface and it may be expected that it will decrease with depth. Results of moisture content at Przezchlebie varied from 23-52 % but they did not display any correlation with depth /Figure 3a/. It is interesting that the results obtained from Brotherton Ings lagoon /Haws et al. 1976/ also showed no significant decrease in moisture content with depth /Figure 3b/. The results of Dutch deep soundings for the same lagoon showed that there was an increase of resistance to cone penetration with depth suggesting that the strength was increasing as a consequence the moisture content decreasing. However though there should be an increase in strength values with time due to water reduction and consequent reduction in pore pressure. Vane tests performed at Przezchlebie lagoon confirmed that in the consolidated areas of the lagoon there was an increase in strenght with depth.

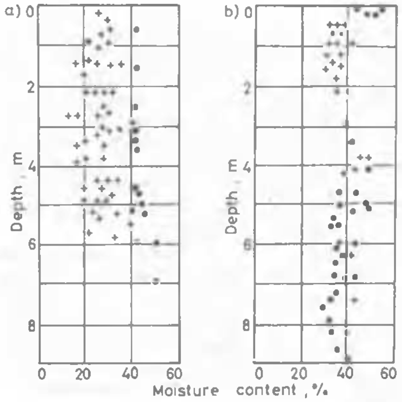

Figure 3. Moisture Content of Ash Deposits. /a/ Przezchlebie Lagoon, /b/ Brotherton Ings Lagoon, /•/ Samples from Wet Part of Lagoon, /+/ Samples from Dry Part of Lagoon.

2.6 Permeability

Lagoon ash deposits are highly stratified and as a result the values of horizontal permeabilities are larger than those measured vertically. The ratio of horizontal to vertical permeability may vary from 1.1 to 6.1 /Broś 1981/. The coefficient of permeability obtained from lagoon ash at Przezchlebie /remoulded samples having various degrees of compaction/ varied between 1.5×10^{-6} to 5×10^{-7} m/s. As would be expected permeability degree decreased with increasing degrees of compaction. Data on British fly ash compacted at maximum dry density yield values of permeability ranging from 10^{-6} to 10^{-8} m/s. Coefficients of permeability of Swedish and Finnish fly ash are 10^{-7} to 10^{-9} m/s /Rainbow, Skarżyńska 1987b/, /Möller, Nilson 1985/.

The knowledge that fly ash may have permeabilities range from impermeable to permeable is valuable in the utilization of the ash. Low permeable ash may be used to reduce the probability of extensive ground water percolation and the consequent danger of soluble materials leaching for the fill. Conversely the use of low permeable fill produces a structure with a corresponding high run-off factor and it may be necessary to prevent external erosion effects.

2.7 Compaction

Two types of tests are being used to evaluate the maximum dry density and optimum moisture content of the lagooned ash deposits - standard Proctor and modified AASHO. Both methods produced very wide ranges of maximum dry density /8.96 - 14.6 kN/m^3/ and optimum moisture contents /18 - 45 %/ /Table 1/.

During compaction tests it was observed that dry density increased with moisture content until a critical values was achieved at which point the water bled to the surface and further improvements in compaction were impeded. The critical moisture content was in the range 31-32.4 % /Leonards, Bailey 1982/, /Zawisza, Skarżyńska 1987/. The same phenomenon has been observed by other investigators /Symposium 1973/ but in this case the critical moisture content has been reported as being as high as 60 %.

The results of the compaction tests demonstrated an essential influence of particle size distribution, specific gravity and carbon content on the compaction characteristics of investigated lagoon ashes /Sutherland, Finlay 1964/. The characteristics of shape and composition of ash particles /i.e. hollow, spherical, clustered, etc./ explain the lower compacted densities of fly ash relative to conventional earth fill compacted with the same effort.

The lagoon ash grain size analysis before and after compaction tests showed that considerable particle degradation occured in almost all ashes, i.e. the increase of particles smaller than 0.05 mm ranges from about 5 % to 25 % /Broś 1981/. Degradation was also found to have a significant effects on the degree of compaction. The modified AASHO curves show that the maximum dry density for fresh sample was 10.5 kN/m^3 and 11.2 kN/m^3 for the reused sample for the same ash. The optimum moisture content changed from 40 % to 33 % respectively /Möller, Nilson 1985/.

2.8 Deformation Behaviour

Model tests to study deformation of the substratum ash were performed on the fly ash from the outflow zone at Przezchlebie lagoon /Zawisza, Skarżyńska 1987/. The results of these tests confirm that deformation is highly influenced by moisture content. Saturated ash has a very low bearing capacity. The ultimate bearing capacity was not greater than 95 kN/m^2 when side loading conditions were low. Unsaturated ash has higher bearing capacities and ultimate bearing capacities of 290 kN/m^2, where obtained. In the case considered no influence of side loading was observed.

Compressibility of coarse and fine ash displayed very similar characteristics. Under low pressure the modulus of compressibility was low and could be compared to cohesive soils. At higher loading pressure of 0.2-0.3 MN/m^2 the modulus of compressibility was significantly higher and ranged from 41-50 MN/m^2. These values are compatable with non-cohesive soils of medium density.

2.9 Strength Properties

The strength properties of fly ash are affected by variations in relative density, moisture content, particle size distribution, chemical composition and level of unburnt coal content. Figure 4a shows the relationship between moisture content and the angle of internal friction for fly ash /Symposium 1973/. Usually the angle of internal friction is in the range $\phi=20\text{-}39^{\circ}$ /Table 1/. Values for the cohesive element for the shear strength equation vary from $c=0\text{-}44\ kN/m^2$ /Cowan 1986/. Figure 4b shows the relationship between shear strength and the number of blows for 10 cm penetration of standard vane performed at Przezchlebie lagoon.

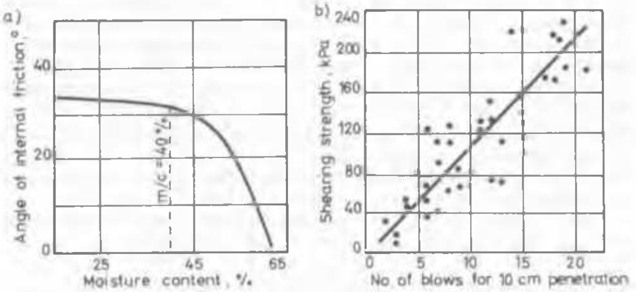

Figure 4. /a/ Variation of Angle of Internal Friction with Increasing Moisture Content /b/ Shear Strength v. Vane Resistance for Przezchlebie Lagoon Ash.

3 DISCUSSION

The ash deposited in Przezchlebie, and no doubt other lagoons, may be compared with cohesive natural sub-soils in that they are composed of essentially silty sized particles and have the added feature that the deposite comprise of alternative layers of silty sand and sandy silt particularly sensitive to variations in moisture content and consequently may exhibit excesive and differential settlements. The behaviour of these fly ash materials are difficult to predict especially when used for the construction of engineering structures. The use of sound engineering principles such preloading techniques,sand drains and stones columns would not only improve the material's behaviour but also make its performance more predictable.

The investigation of the ash deposit at Przezchlebie reinforced the importance, when considering the utilization of the lagoon material, of undertaking a thorough geotechnical investigation of the deposit since it would appear that:

1. Considerable differences exist in the nature, size and moisture content not only in the horizontal profile but also in relation to the distance and method of disposal from the discharge point.
2. Predicted settlement and variations with time are not necessarily compatible with procedure used for similar "soil" types.
3. No influence of ash lagoon seepage water on the quality of ground-water in the area adjacent to reservoir was observed in the years 1984 and 1985.

Notwithstanding the obvious difficulties in using fly ash or in predicting performance the material is being widely used in many countries and although the properties will be dependent not only on the geotechnical properties but also on coal origin, size, handling, utilization techniques, boiler size and of course ultimate ash disposal. There are many similarities and such investigations performed on different ashes can only lead to a more universal understanding of those diverse properties.

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