PEAT FLY ASH AS A SUPPLEMENTARY CEMENTING MATERIAL IN CONCRETE

Ari Ipatti
Imatran Voima Oy
Concrete and Soils Laboratory
M.Sc.Eng., Research Engineer

SYNOPSIS

The study was performed as a comparison test on superplasticized peat and coal fly ash concretes with or without an air-entraining agent. Reference concretes with pure Portland cement were used. The fly ash contents varied between 20 - 60 % by mass of the total amount of binder.

The non-air-entrained concretes were used for studying the compressive strength, drying shrinkage, watertightness and water absorption properties. With the air-entrained concretes the frost-resistance properties were additionally studied by means of protective pore ratio, freezing dilation, freeze-thaw resistance and frost-salt resistance tests.

The test data indicate that with proper mix design and choice of admixtures peat fly ash can be used as a supplementary cementing material to produce a high-quality, frost-resistant concrete.

Key words: concretes; fly ashes; peat; supplementary cementing materials.

1. INTRODUCTION

It has been estimated that the peatland areas of Finland are roughly 10 % of the world's total peatland areas /1/. Thus peat is a potential energy source in Finland, where its large scale utilization, due to fluctuations of oil prices has recently been initiated. This is particularly true in Central and Northern Finland where transportation of coal is expensive, yet peat is available in great amount.

With several peat-fueled heat and power supply stations already in operation, under construction, or at planning stages, the production of peat fly ash has considerably increased. In 1984, the production of peat fly ashes in Finland approximated 180 000 tonnes /5/. About 7 500 tonnes were utilized in the cement and concrete industry /5/.

Peat fly ash has been found to improve the workability and cohesion of freshly mixed concrete as well as the impermeability of the hardened concrete /2, 4, 5/. High-quality peat fly ash is also more reactive than coal fly ash, which is due to the larger CaO-content of fly ash. However, the pozzolanic properties of the peat fly ash could only be utilized when the water demand of fresh concrete is stabilized. In addition, the chemical and physical properties of peat fly ash vary greatly depending on the bog and power plant used.

The practical problems involved in the utilization of peat fly ashes are: the varying production rate, due to seasonal fluctuations, insufficient storing capacities and the quality control arrangements /5/.

2. OBJECTIVES AND SCOPE

The main objective of the work described in this paper was to evaluate the suitability of the peat fly ash of the Joensuu power station for use as a supplementary cementing material in concrete. The comparable fly ash in the study was taken from the coal-fired power station of Lahden Lämpövoima. The fly ash contents used in this study varied between 20 - 59 % by mass of the total amount of binder.

The study on concretes was performed as a comparative experiment in which one half of the test mixtures were air-entrained, and the other half non-air-entrained. In addition, in concretes containing fly ash, both water reducer and superplasticizer were always used.

The non-air-entrained test concretes were used for studying the compressive strength, watertightness and drying shrinkage properties. With the air-entrained test concretes the frost resistance properties were additionally studied by means of protective pore ratio, freezing dilation, freeze-thaw resistance, frost-salt resistance and capillary degree of saturation tests.

The study was performed in collaboration with Imatran Voima and Lujabetoni. The test on freshly mixed concretes were conducted at the Siilinjärvi plant of Lujabetoni, as were also determined the early age strengths of the hardened concrete. Special tests on the hardened concrete were conducted at Imatran Voima's Concrete and Soils Laboratory.

3. EXPERIMENTAL

3.1 Materials

The cement used in the present study was rapid hardening Portland cement (RHPC) manufactured in Lappeenranta by Partek. The physical and chemical properties of this cement are presented in table 1 and figure 1.

Two different types of fly ashes originating from the peat-fired power plant of Joensuu and the coal-fired power plant of Lahti were chosen for this study. The results of the chemical and physical analyses of the peat fly ash are given in table 1 and figure 1 and compared with those of the coal fly ash.

Table 1. Chemical analyses and physical properties of cement and fly ashes.

BINDING AGENTS		CEMENT RHPC	COAL FLY ASH	PEAT FLY ASH
Chemical analyses:				
CaO	%	56.0	5.4	8.0
SiO_2	%	20.9	58.0	62.0
Al_2O_3	%	3.7	17.7	12.5
Fe_2O_3	%	1.5	7.7	6.4
Na_2O	%	0.7	0.9	2.2
K_2O	%	0.4	1.5	1.7
SO_3	%	3.3		
MgO	%	2.3	2.1	1.8
Cl	%	0.02	<0.01	<0.01
Loss on ignition	%	2.45	3.12	0.46
Physical properties:				
Vicat setting time				
Initial, h:min		1:50		
Final, h:min		2:50		
Blaine fineness	cm^2/g	4700	3460	2210
Density	kg/m^3	3140	2270	2540
Compressive strength				
3 d	MN/m^2	45		
7 d	"	51		
28 d	"	61		
91 d	"	67		

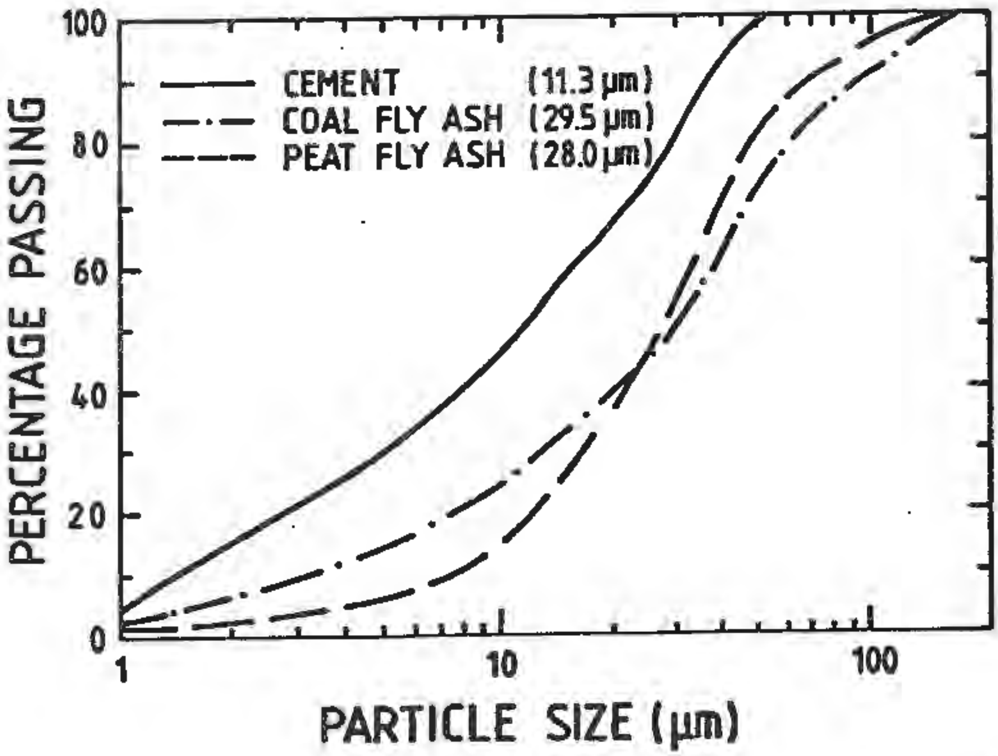

Figure 1. Particle size analyses (and median particel sizes) of cement and fly ashes.

The aggregate used in all the concrete mixtures was combined from three different fractions. Physical properties and gradings of the individual fractions and the combined aggregate are presented in table 2.

Table 2. Physical properties and gradings of the individual aggregate fractions.

Physical properties:		0 - 4 mm	0 - 8 mm	8 - 16 mm
Organic impurities colorimetric value		1	0	0
Silt content	%	10.1	4.2	-
Solid density	kg/m^3	2730	2720	2690
Cl^--content	%	0.008	0.010	0.006

Gradings (percentage passing): Sieve (mm #)	0 - 4 mm	0 - 8 mm	8 - 16 mm	Combined
0.063	2	0	0	0.5
0.125	6	1	0	2
0.25	16	3	0	5
0.5	32	11	0	11
1.0	51	32	0	21
2.0	66	62	0	33
4.0	78	90	4	45
8.0	95	100	7	53
16.0	100	100	84	92
32.0	100	100	100	100

A modified melamineformaldehyde-based superplasticizer and a lignosulfonate-based water reducer were used in all the concrete mixtures containing peat or coal fly ashes. In addition, an air-entraining agent based on tall oil acids sodium salt was used when frost resistance properties were evaluated.

Common tap water was used.

3.2 Mixtures

The strength, shrinkage, water tightness and frost-resistance properties of concretes were studied with six test mixtures of which the mix proportions and properties are given in table 3.

Table 3. Mix proportions and properties of fresh concrete mixtures.

MIXTURES		1	2	3	4	5	6
Proportions:							
Cement	1	1	0.41	0.63	1	0.76	0.80
Coal fly ash	1	-	0.59	-	-	0.24	-
Peat fly ash	1	-	-	0.37	-	-	0.20
Aggregate		5.43	5.47	5.88	5.23	4.86	5.30
Water		0.54	0.52	0.51	0.43	0.34	0.42
Superplasticizer		-	0.015	0.005	0.01	0.015	0.005
Water reducer		-	0.005	0.015	-	0.005	0.015
Air-entraining agent		-	-	-	0.0005	0.0007	0.0007
Properties 5-10 min:							
Temperature	°C	18	19	25	18	17	24
Slump	mm	65	110	160	70	95	160
Air content	l/m^3	16	21	14	42	50	41
Density	kg/m^3	2370	2400	2470	2390	2290	2390
Properties 60-75 min:							
Slump	mm	25	75	110	35	35	80
Air content	l/m^3	16	21	13	42	49	32
Density	kg/m^3	2400	2370	2470	-	2290	2410
Proportions:							
Cement	kg/m^3	344	137	205	356	289	280
Coal fly ash	"	-	195	-	-	91	-
Peat fly ash	"	-	-	119	-	-	72
Aggregate	"	1866	1815	1906	1862	1847	1862
Water	"	185	172	164	153	128	147
Admixtures	"	-	6.63	6.48	3.74	7.87	7.27
Air	l/m^3	16	21	14	42	50	41

3.3 Methods

The properties of the aggregate, fresh concrete and hardened concrete were determined in accordance with the Finnish SFS-Standards. (International test methods corresponding to the SFS-Standards are given in parentheses).

Aggregate properties
The organic impurities, silt contents, solid densities and gradings of the different aggregate fractions were tested in accordance with the Finnish Standards SFS 5277, 5278, 5280 and 5281 (NT BUILD 185 and 186, ISO 6274 and 7033).

Fresh concrete properties
Sampling and measurements of consistency, air content and density of the fresh concrete mixtures were conducted in accordance with the Finnish Standards SFS 5283, 5284, 5287 and 5288 (ISO 2736/1, 4109, 4848 and 6276).

Making and curing of test specimens
Unless otherwise stated, making and curing of test specimens and testing of densities were conducted in accordance with the Finnish Standards SFS 5341 and 5442 (ISO 2736/2 and 6275).

Compressive strength
For each concrete, seven sets of concrete cubes of 150 x 150 x 150 mm were cast in steel moulds. Concretes were tested at the ages of 1, 3, 7, 28, 56, 91 and 180 days in accordance with the Finnish Standard SFS 4474 (ISO 4012).

Drying shrinkage
For each concrete, two concrete prisms of 100 x 100 x 500 mm were cast in steel moulds. Prisms were initially cured in water at 20±2 °C for seven days and subsequently at RH 40±5 % and 20±2 °C. The shrinkage deformations were measured periodically during a period of six months.

Impermeability to water
The watertightness was measured at the age of 28 days according to the Finnish Standard SFS 4476. For each concrete, two 150 x 300 mm cylindrical test specimens were cast in steel moulds.

In the watertightness test the specimen is subjected to one-sided water pressure (1 Mpa) for a period of 24 hours. After this, the test specimen is split in half, and the maximum water penetration S_k is measured in millimeters from the cross-section. The test results are given in a water penetration factor obtained from the equation below

$$\text{water penetration factor} = S_k/100 \text{ mm}$$

In general, concrete is regarded as being impervious to water if the water penetration factor is less than 1.0.

Protective pore ratio
The protective pore ratio (Pr) was determined according to the Finnish Standard SFS 4475. For each concrete, two 150 x 300 mm cylindrical concrete specimens were cast in steel moulds.

The protective pore ratio indicates how large a proportion of the total pore volume remains filled with air, when dried concrete is stored in water under normal air pressure. The air-filled pore volume is determined by pressing water into the specimen at an overpressure of 15 MPa.

In Finnish Standards the protective pore ratio of frost-resistant concrete must meet the demand of Pr ≥ 0.20 in normal conditions.

Freezing dilation
The freezing dilation was determined in accordance with the Finnish Standard SFS 5448. For each concrete, two 150 x 300 mm cylindrical test specimens were cast in steel moulds.

The freezing dilation indicates the deviation of the relative change in length measured from water saturated concrete occuring during the cooling stage from the relative change in length by means of extrapolated coefficient of thermal expansion in temperature of -20 °C.

According to the Finnish Standards a negative dilation factor is the requirement to be met by frost-resistant concrete.

Feeze-thaw resistance
The freezing-and-thawing test was determined in accordance with procedures outlined in the Finnish Standard SFS 5447. For each concrete, 9 concrete prisms of 100 x 100 x 500 mm were cast in steel moulds.

The test comprises 150 freeze-thaw cycles in which the freezing takes place in air of -20 °C and the thawing in water of +20 °C. In estimating frost resistance the Hummel exponent (H) was used and is defined as follows:

$$F_{ctf} = (F_c)^H$$

where F_{ctf} is flexural tensile strength (MN/m^2)
F_c is compressive strength (MN/m^2)

Concrete is regarded as being frost-resistant if the Hummel exponent of the prisms in the freezing-and-thawing test is maximum 10 % smaller than that of the comparison test prisms kept in water.

Frost-salt resistance
The frost-salt resistance was determined in accordance with the Finnish Standard SFS 5449. For each concrete, six concrete cubes of 100 x 100 x 100 mm were cast in steel moulds.

The test specimens were initially cured in water at 20±2 °C for seven days and subsequently at RH 70±5 % and 20±2 °C. For the purpose of water saturation, these cubes were transferred to water at an age of 28 days or 91 days.

The freezing bath used was a saturated solution of sodium chloride. Its temperature was -15 °C. The thawing bath consisted of pure water of 20 °C. The disintegration was measured after 10 and 25 freeze-thaw cycles by measuring the change in volume.

In general, concrete is regarded as being frost resistant if the change in volume after 25 freezing-and -thawing cycles is less than 5 %.

Capillary degree of saturation
The capillary degree of saturation was determined according to the test method 358/86 of Technical Research Centre of Finland (VTT). For each concrete, three prisms of 100 x 100 x 100 mm were cast in steel moulds.

After initial drying at +50 °C, the specimens were allowed to absorb water under normal pressure. The absorption of water into concrete was measured by weighing the specimens at certain intervals during a period of two weeks.

4. RESULTS AND DISCUSSION

4.1 Materials

The Cl- and MgO-contents and loss on ignition of coal and peat fly ashes were below the maximum values set in the National Building Code of Finland. The SiO_2 and CaO-contents of peat fly ash were somewhat higher and the Al_2O_3-content somewhat lower than with coal fly ash.

The density of peat fly ash was slightly higher than that of coal fly ash. On the other hand, the Blaine fineness of peat fly ash was clearly smaller than that of coal fly ash. The percentage passing a 45 µm sieve was about 69 % with coal fly ash and about 77 % with peat fly ash.

4.2 Fresh concrete

The National Building Code of Finland states that the maximum amount of fly ash to be added in the manufacture of concrete shall be 60 % of the amount of Portland cement used. With air-entrained frost-resistant concrete, it is allowed to add fly ash, correspondingly, a maximum amount of 25 % of the amount of Portland cement used.

In the study, a total of six test mixtures were prepared, of which the mixtures 1-3 were non-air-entrained and 4-6 air-entrained. In the non-air-entrained peat and coal fly ash concretes the fly ash contents were 58 % and 142 % respectively of the amounts of Portland cement. In the air-entrained peat and coal fly ash concretes the fly ash contents were 26 % and 32 % respectively.

The slump values of the freshly mixed concretes were clearly higher with test mixtures containing peat fly ash than with comparative concretes. Part of this difference can, however, be explained by the higher temperatures of the freshly mixed peat fly ash concretes. The biggest change in the consistency during the first hour after mixing was found with the air-entrained fly ash concretes.

The air contents in the mixtures were 14-21 l/m^3 with the non-air-entrained concretes and 41-50 l/m^3 with the air-entrained concretes. The change in the air contents during the first hour was largest with the air-entrained peat fly ash concrete (mixture 6).

The density of freshly mixed peat fly ash concretes was slightly higher than with the coal fly ash concretes.

4.3 Hardened concrete

The compressive strengths of the non-air-entrained concretes are compared in figure 2. The early age strengths of the fly ash concretes (mixtures 2 and 3) were somewhat lower than the strengths of the control concrete (mixture 1). The peat fly ash concrete reached the strength level of the control concrete at the age of 56 days, and the final strengths of the two were about 57 MN/m^2. The final strength of the coal fly ash concrete was about 20 % lower than that of the control concrete.

The development of the compressive strengths of the air-entrained concretes can be seen in figure 3. The early age strengths of the peat fly ash concrete (mixture 6) were somewhat lower than those of the coal fly ash concrete (mixture 5) and those of the control concrete (mixture 4). However, at the age of about 7 days the peat fly ash concrete reached the strength level of the control concrete, and its final strength, 69 MN/m^2, was about 15 % higher than that of the control concrete.

The drying shrinkage of the non-air-entrained concretes are given in figure 4. The shrinkage-values of the peat fly ash concrete (mixture 3) at the age of 180 days were of the same magnitude than those of the control concrete (mixture 1). However, during the same period the coal fly ash concrete (mixture 2) had shrunk about 28 % more than the control concrete.

The development of the drying shrinkage of the air-entrained fly ash concretes are compared in figure 5. The shrinkage value of the peat fly ash concrete (mixture 6) at the age of 180 days was about 34 % lower than that of the corresponding coal fly ash concrete (mixture 5). The use of the air-entraining agent seems to reduce the drying shrinkage as the shrinkage values of the air-entrained coal and peat fly ash concretes (mixtures 5 and 6) at the age of 180 days were about 8 % respectively 19 % lower than those of the corresponding non-air-entrained fly ash concretes (mixtures 2 and 3).

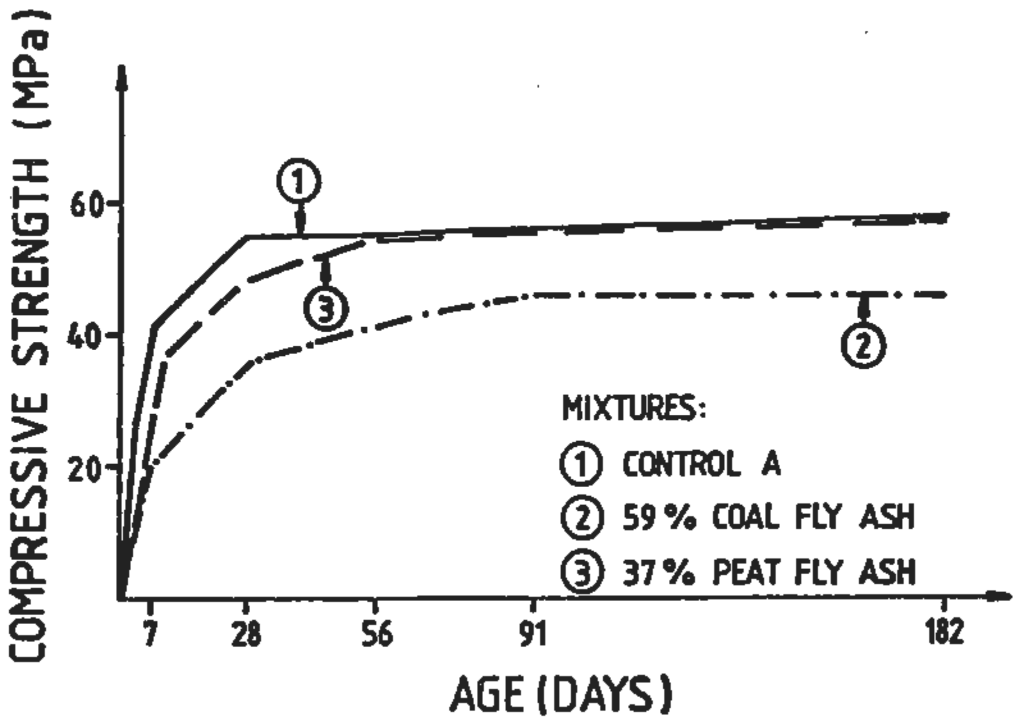

Figure 2. Mean compressive strengths for non-air-entrained concretes. Specimen size 150 x 150 x 150 mm.

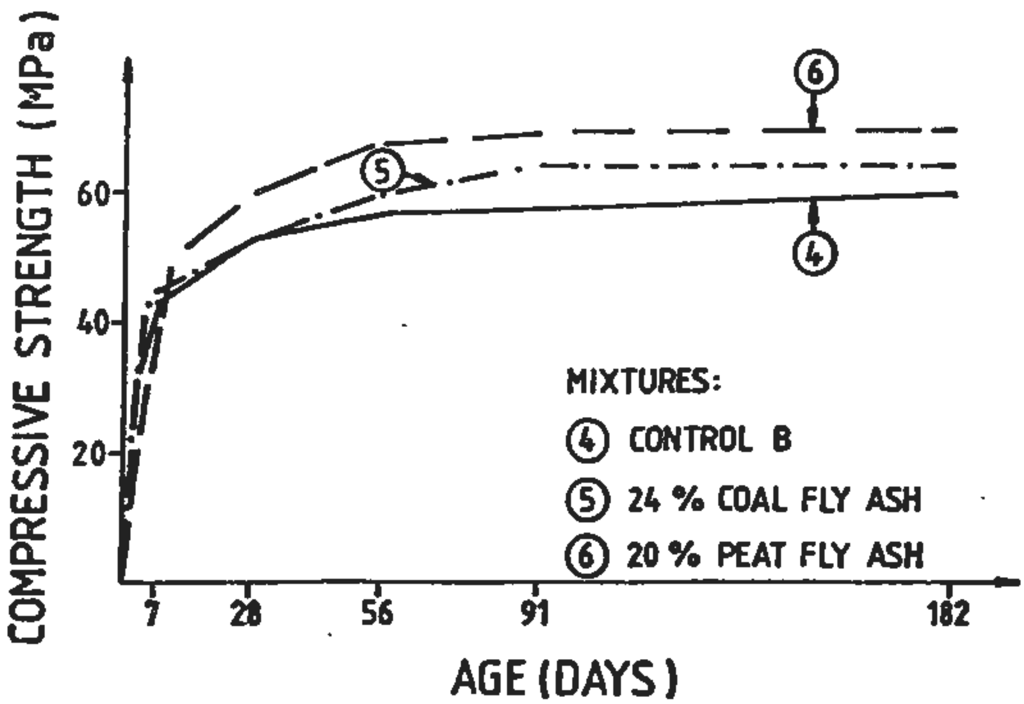

Figure 3. Mean compressive strengths for air-entrained concretes. Specimen size 150 x 150 x 150 mm.

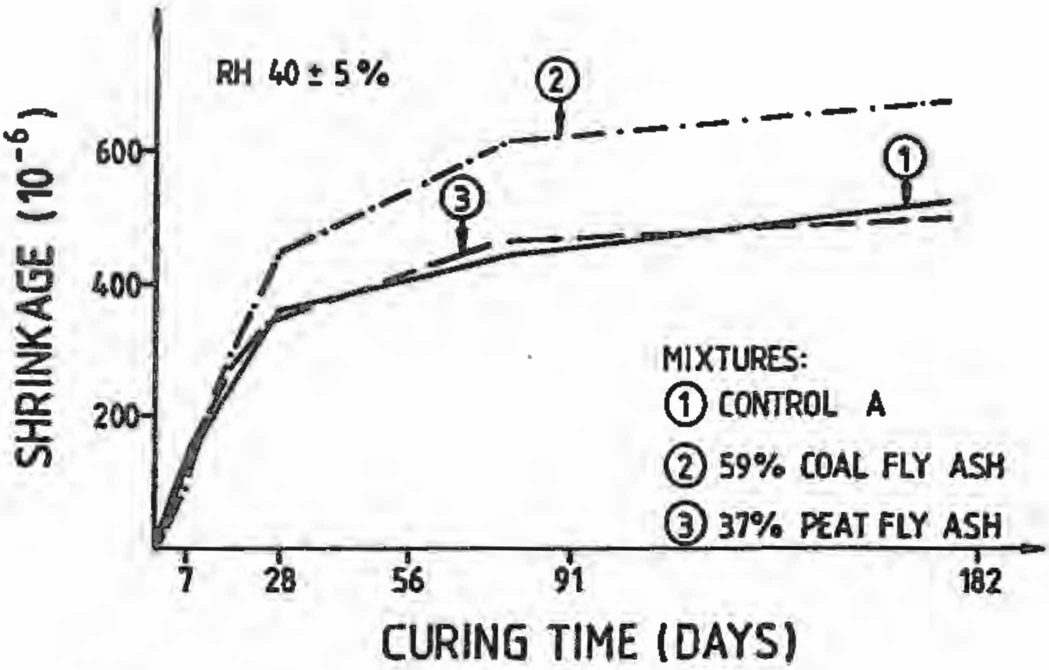

Figure 4. Mean drying shrinkage values for non-air-entrained concretes. Specimen size 100 x 100 x 500 mm.

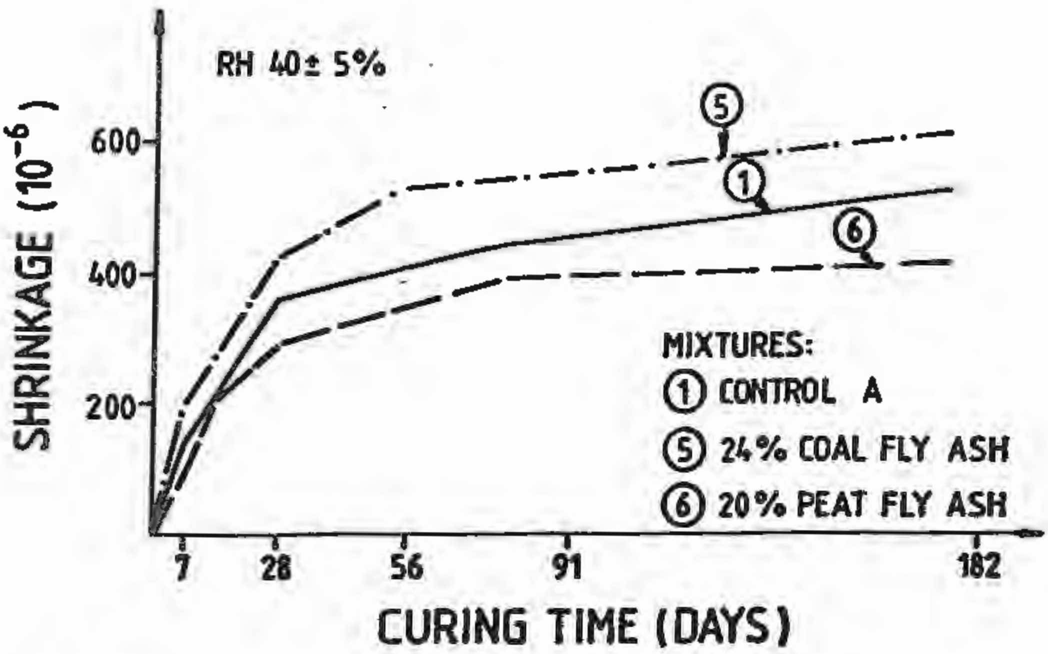

Figure 5. Mean drying shrinkage values for air-entrained concretes. Specimen size 100 x 100 x 500 mm.

The results of the watertightness tests are compared in table 4. The values of water penetration factors varied between 0.2 - 0.4 with non-air-entrained concretes and between 0.1 - 0.3 with air-entrained concretes respectively. The water penetration factor values of peat fly ash concretes were slightly lower than those of corresponding coal fly ash concretes. However, the differences were marginal.

Table 4. Watertightness properties of concrete mixtures.

MIXTURES	1	2	3	4	5	6
Density kg/m^3	2440	2370	2420	2400	2360	2410
Water penetration factor	0.3	0.4	0.2	0.3	0.2	0.1

The frost resistance of concrete was studied with a total of four different test mixtures of which the air-entrained ones were the mixtures 4-6 and the non-air-entrained one the mixture 1. The results of the various types of frost resistance tests are given in table 5 and in figures 6 and 7. Based on the test results we can say the following:

- All of the air-entrained concretes met the criteria set for the frost resistance in all tests performed. No notable differences were found in the frost resistance of the peat fly ash concrete (mixture 6) as compared with the coal fly ash concrete (mixture 5) and the control concrete (mixture 4).

- It is significant that the mixture 5, the fly ash content of which is clearly higher than that allowed in the National Building Code of Finland, was also frost-resistant based on all tests performed.

- The frost resistance of the non-air-entrained control concrete (mixture 1) was expectedly worse than that of the air-entrained test concretes 4-6. Even this test concrete met, however, the criteria set for frost resistance exclusive of the tests of protective pore ratio and frost-salt resistance.

- The total porosity of the peat fly ash concrete (mixture 6) was slightly lower than that of the coal fly ash concrete (mixture 5) and those of the control concretes (mixtures 1 and 4).

- In the water absorption test, the capillary pores of all the test concretes were water-filled by a time of 12.7 - 16.9 h. The use of the peat and coal fly ashes or an air-entraining agent did not essentially change the nick-point time. However, with the non-air-entrained control concrete (mixture 1) the degree of saturation at the nick-point was clearly higher than those of the air-entrained concretes (mixtures 4-6).

Table 5. Frost resistance properties of test mixtures.

MIXTURES		1	4	5	6
Test of protective pore ratio 28 d:					
Absorbed water	l/m³	120	116	104	96
Penetrated water	"	23	43	70	41
Total porosity	"	143	159	174	137
Protective pore ratio		0.16	0.27	0.40	0.30
Frost-salt resistance 28 d:					
Absorbed water	%	1.1	1.3	1.4	0.8
Volume change	"				
10 cycles		2.6	0.04	0.7	0.2
25 cycles		11.2	0.14	1.2	0.6
Frost-salt resistance 91 d:					
Absorbed water	%	2.4	2.0	1.9	1.3
Volume change	"				
10 cycles		4.8	0.3	0.5	0.4
25 cycles		24.2	0.8	1.1	0.4
Freezing dilation 28 d:					
Coeff. of thermal expansion	µm/mK	8.6	8.8	8.0	8.7
Dilation factor	µm/m	-25	-40	-60	-35
Freeze-thaw resistance, 150 cycles:					
- Initial strength specimens 28 d:					
Compressive strength	MN/m²	46.6	48.3	44.3	51.3
Flexural strength	"	5.2	5.8	5.4	5.1
- Freeze-thaw specimens 92 d:					
Compressive strength	MN/m²	51.3	54.3	58.9	64.5
Flexural strength	"	5.5	6.2	6.4	6.7
Hummel exponent		0.43	0.46	0.46	0.46
- Water-cured specimens 92 d:					
Compressive strength	MN/m²	52.1	55.8	58.7	63.4
Flexural strength	"	6.5	6.7	6.5	7.1
Hummel exponent		0.47	0.47	0.46	0.47
- Change in Hummel exponent %		-8.9	-3.7	-0.5	-3.7
Capillary degree of saturation, 28 d:					
Total porosity	l/m³	147	171	156	147
Nick-point time	h	13.0	16.9	15.7	14.2
Degree of saturation		0.78	0.63	0.61	0.62
Capillary degree of saturation, 91 d:					
Total porosity	l/m³	150	180	166	139
Nick-point time	h	12.7	12.9	15.7	15.1
Degree of saturation		0.86	0.65	0.63	0.66

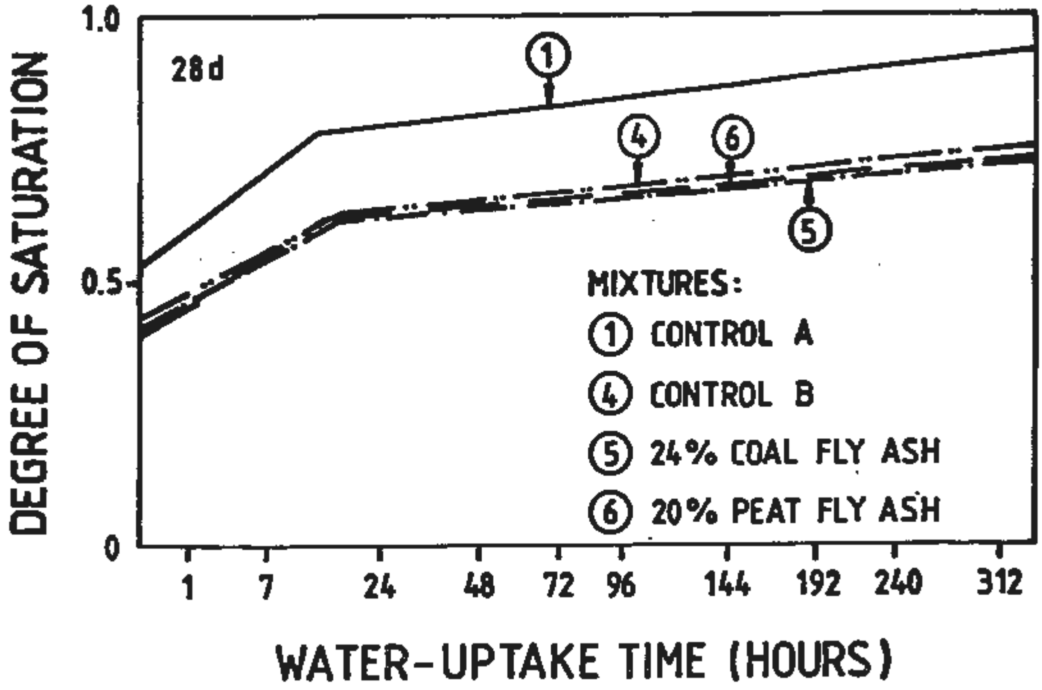

Figure 6. Mean values of the capillary degree of saturation versus time of water-uptake. Age of the specimens at the start of absorption 28 days.

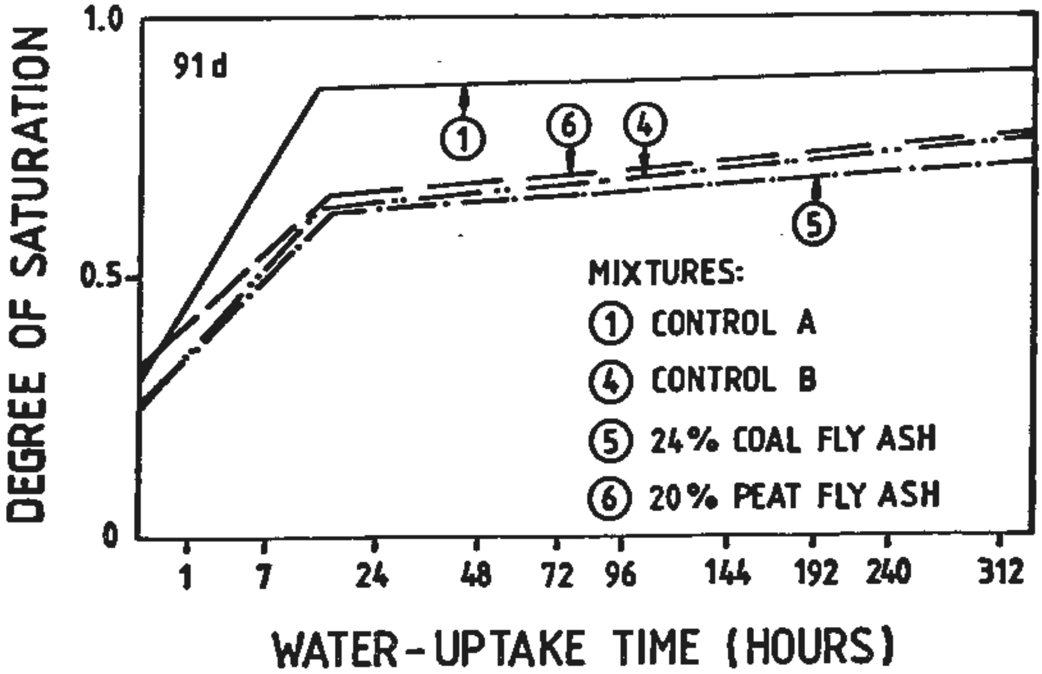

Figure 7. Mean values of the capillary degree of saturation versus time of water-uptake. Age of the specimens at the start of absorption 91 days.

5. CONCLUSIONS

Based on the study it can be said that the peat fly ash of the Joensuu power plant is suitable for use as a supplementary cementing material in concrete. Exclusive of the somewhat slower development of the early age strength, typical for concretes containing fly ash, the coal and peat fly ash mixtures compared in the study were high-quality, frost-resistant concretes.

The strength, impermeability and frost resistance properties of the peat fly ash concretes did not essentially differ from corresponding properties of the coal fly ash concretes. The drying shrinkage with the peat fly ash concretes was even somewhat lower than that of the concretes where coal fly ash was used.

In applying the test results it should be noticed, however, that the quality of the peat fly ash may vary, whereat the impact of the peat fly ash on the concrete properties may also differ from the test results presented in this study. The presented test results can, on the other hand, be regarded as being on the safe side, as the fly ash contents used have been in the study normally allowable maximum amounts, and in some mixtures even considerably larger.

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