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PRODUCTION OF CONCRETE PAVEMENTS USING MIXED CEMENTS

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Abstract. This paper discusses the possibility of assessing the k-value of power plant fly ash using durability. Compressive strengths, activity indices, pressure water seepage depth and carbonation depth were determined for cement mortars with 10, 20 and 30 % cement replacement by fly ash for ages of 7, 28 and 60 days. The k-values for each cement substitute were determined for each age using the relationship between water/cement ratio and compressive strength. Using the results of the depth of pressurized water seepage and depth of carbonation, the determined k-values were assessed and k-values that are safe for use of power plant fly ash in aggressive XC and XD environments were determined.

Keywords: K-value, activity index, fly ash, concrete admixtures.

1. Introduction

The use of active admixtures in concrete, such as fly ash, finely ground granulated blast furnace slag, is nowadays desirable mainly due to the reduction of the use of Portland clinker, the production of which produces large amounts of CO_2, which subsequently escapes into the atmosphere [1].

Fly ash has an effect on both the properties of fresh concrete and hardened concrete. The initial strengths of concrete with fly ash are lower than those of the reference concrete. The strengths of this concrete reach the strengths of the reference concrete only at later ages (around 90 days) [2]. In terms of durability, fly ash has a slightly negative effect on frost resistance and fly ash has a positive effect when aggressive substances penetrate and corrode the steel reinforcement [3].

The use of active admixtures in concrete in the Czech Republic is addressed by the so-called k-value concept. The European standard EN 206+A2 mentions this concept, but this standard does not provide any possibility to determine the k-value for active admixtures and the concept itself is described in a very general way [4].

The effect of active admixtures on the properties of concrete depends on the nature of the individual materials, the age of the concrete, the external conditions, etc. To take all these influences into account when designing concrete, the k-value concept uses the relationship between the water/cement ratiot and the compressive strength. If the condition of equal compressive strength is satisfied, then relation (1) is valid [5]:

$$w_0 = \frac{v}{c + k \cdot p}\,. \qquad (1)$$

Where w_0 is the water/cement ratio of concrete without admixture, v is the water content of concrete with admixture in $\mathrm{kg\,m^{-3}}$, c is the cement content of concrete with admixture in $\mathrm{kg\,m^{-3}}$, p is the admixture content in $\mathrm{kg\,m^{-3}}$ and k is the k-value.

The procedure for determining the k-value is given in CEN/TR 16639. However, this document is not used in the Czech Republic. In this methodology, concretes with different water/cement ratios without and with active admixture are mixed. The k-value is determined from a comparison of the dependence of the compressive strength on the water/cement ratio. The result is not a single k-value for a given active admixture, but a set of k-values dependent on the water/cement ratio [6]. However, this method does not take into account the effect of the active admixture on the durability of the concrete.

2. Methodology

CEM I 42.5 R Mokrá cement and high temperature Opatovice fly ash were used in the experimental work. Cement mortars were mixed with 0, 10, 20 and 30 % cement replacement with Opatovice fly ash. A constant water/cement ratio of 0.5 was used in the cement mortars and the amount of cement used was the same as in EN 196-1: Methods of testing cement – Part 1: Determination of strength. The aggregate was composed of three fractions so that its grain size curve corresponded as closely as possible to that of standardised sand according to EN 196-1. The cement mortars were tested at ages 7, 28 and 60 days for compressive strength according to EN 196-1, determination of the depth of carbonation according to EN 13295: Products and systems for the protection and repair of concrete structures – Test methods – Determination of resistance to carbonation and resistance to pressure water seepage according to EN 12390-8: Testing of hardened concrete – Part 8: Depth of pressure water seepage.

Recipes [m^{-3}]	REF	A10	A20	A30
Cement	511	460	409	358
Water	254	254	254	254
Ash		51	102	153
Sand 0.1–0.6	443	443	443	443
Sand 0.6–1.2	517	517	517	517
Sand 1–4	572	572	572	572

Table 1. Recipes of cement mortars.

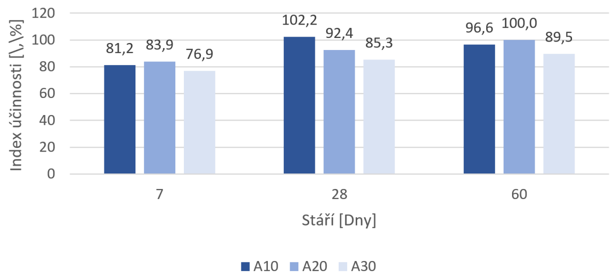

Figure 2. Activity index.

Using the determined compressive strengths, a k-value was determined based on the relationship between the water/cement ratio and compressive strength. The relationship between water/cement ratio and compressive strength is described by formula (2) [7].

$$f_c = K \cdot (\frac{1}{v/c} - a) \qquad (2)$$

where f_c is the compressive strength in MPa, K je coefficient dependent on the reference cement in MPa, c is the amount of cement in the concrete in $kg\,m^{-3}$, v is amount of water in the concrete in $kg\,m^{-3}$ and a is the coefficient depends on the age of the concrete.

Verification of the k-value by durability was carried out using the requirements of the "Concept of Equivalent Concrete Performance". In this concept, limiting values for the change in d (as a % difference from the reference concrete, which leads to the rejection of the use of Type II admixture with a 90 % probability) are given in terms of the durability aspect of the concrete. The change in d properties of cement mortar with fly ash shall not exceed the limit of 30 % deterioration.

3. Results

This section presents the result of the experimental part. In following figures are shown results of compressive strength, activity index, depth of carbonation, pressure water leakage and k-value for cement mortars with fly ash.

In Figure 1 we can see the results of compressive strength which are highest for reference mortars a with increasing amount of fly ashe were lower.

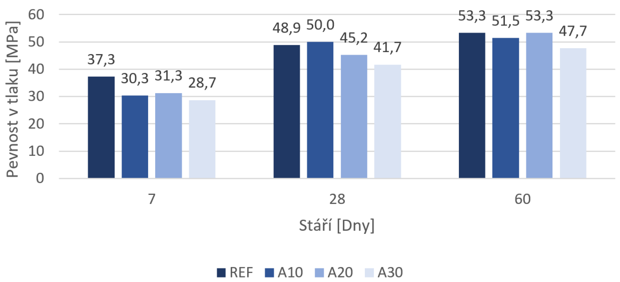

Figure 1. Compressive strength of cement mortars.

Activity indices are corresponding with compressive strengths of cement mortars. Highest activity index is for mortar with 10 % of fly ash after 28 days and for mortar with 20 % of fly ash after 60 days.

Figure 3 shows the depth of pressure water leakage. The highest depth of pressure water leakage is for mortars A20 and A30 after 7 days. This value decreases with increasing age of cement mortars.

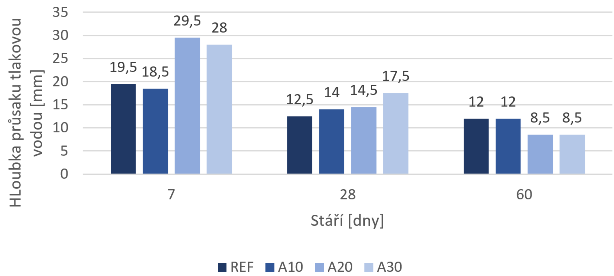

Figure 3. Depth of pressure water leakage.

In Figure 4 are shown result of depth of carbonation. As depth of pressure water leakage is the highest depth of carbonation for cement mortars A20 and A30 after 7 days.

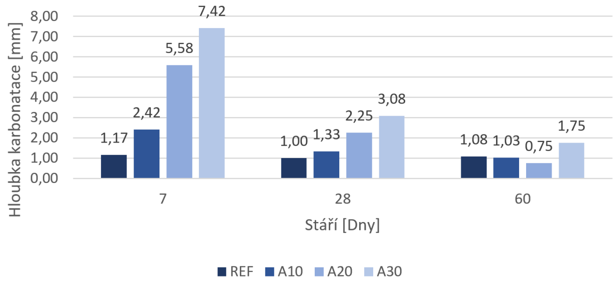

Figure 4. Depth of carbonation.

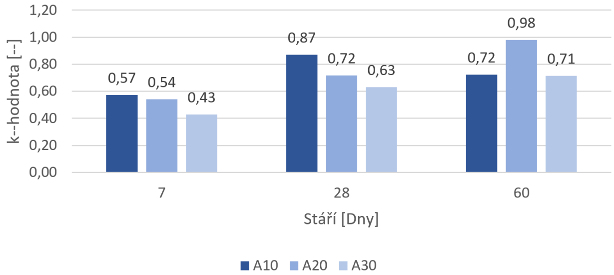

Figure 5. k-value for power plant ash.

Age [days]	Depth of pressure water leakage [mm]				Difference [mm]			Change d[%]		
	REF	A10	A20	A30	A10	A20	A30	A10	A20	A30
7	20	18.5	30	28	-1	10	8.5	-5.1	51.3	43.6
28	13	14	15	18	1.5	2	5	12.0	16.0	40.0
60	12	12	8.5	9	0	-4	-3.5	0.0	-29.2	-29.2

Table 2. Durability aspect for pressure water leakage.

Age [days]	Depth of carbonation [mm]				Difference [mm]			Change d[%]		
	REF	A10	A20	A30	A10	A20	A30	A10	A20	A30
7	1.2	2.4	5.6	7.4	1.2	4.4	6.2	100.0	366.7	516.7
28	1	1.3	2.3	3.1	0.3	1.3	2.1	30.0	130.0	210.0
60	1.1	1	1	1.8	-0.1	-0.1	0.7	-9.1	-9.1	63.6

Table 3. Durability aspect for pressure water leakage.

K-values in Figure 5 were determined using using the relationship between compressive strength and water/cement ratio of cement mortars. The course of the k-value corresponds to the course of the compressive strengths.

3.1. K-value assessment using durability

According to CEN/TR 16639 aspects of durability can be assessed by the following durability tests [6]:

- Carbonation resistance,
- Resistance to chloride penetration,
- Resistance to freezing and thawing,
- Resistance to the effects of seawater,
- Sulphate resistance.

According to the Czech supplementary standard ČSN P 73 2404 Concrete – Specification, properties, production and compliance Supplementary information, the k-value for fly ash cannot be used for exposure classes XF2-XF4. For this reason, the frost resistance tests were omitted and instead the depth of pressure water penetration was determined [8].

For each type of aggressive environment, limits of change are set from which the concrete must not deviate from the reference concrete. CEN/TR 16639 gives the limit values for the change in d as the percentage difference from the reference concrete that leads to the rejection of the use of a Type II admixture with a 90 % probability, in terms of the durability aspect. The change in d properties of the tested concrete with admixture shall not exceed 30 % [6]. Durability assessment using pressure water leakage is shown in Table 2 and durability assessment using carbonation depth is shown in Table 3.

4. Discussion

In Figure 2, we can see that the activity indices are lowest at 7 days of age, as expected, and increase with increasing age. This corresponds to the slower rate of pozzolanic reaction of fly ash compared to the hydration of cement. The slower pozzolanic reaction of fly ash also corresponds to the higher depth of pressure water seepage and carbonation.

In Figure 3 we can see that the depth of pressure water penetration at 7 days of age is significantly worse (by almost 50 %) than the reference mortar, especially for the formulations with 20 and 30 % fly ash. At the age of 28 days this difference decreases significantly, to 12 % for the recipe with 10 % fly ash, 16 % for the recipe with 20 % fly ash and 40 % for the recipe with 30 % fly ash. At the age of 60 days, the penetration depths of the fly ash formulations are already equal to or lower than the penetration depth of the reference mortar water pressure.

As we can see in Figure 4, at an age of 7 days, the depth of carbonation is significantly higher for mortars with fly ash (up to hundreds of percent) and the depth of carbonation for these mortars decreases with increasing age. However, in the case of formulation A30 with 30 % fly ash, there is a significant increase in the depth of carbonation even at 60 days of age. The K-values determined using the relationship between compressive strength and water/cement ratio of cement mortars at 7 days of age are 0.43–0.57. Already these k-values are higher than the recommended value in EN 206+A2, which is equal to 0.4 for fly ash with CEM I cement [4].

To verify the durability aspect, the depth of pressure water seepage and the depth of carbonation were determined. In the case of pressure water penetration depth, cement mortar A10 with 10 % fly ash meets the durability condition at all ages, formulation A20 only at ages 28 and 60 days and formulation A30 only at age 60 days. For the depth of carbonation, the durability aspect is met only for formulation A10 at ages 28 and 60 days and for formulation A20 at age 60 days.

5. Conclusion

The aim of this paper was to verify the possibility of determining the k-value of power plant fly ash in the replacement of 10, 20 and 30 % Portland cement using the aspect of durability.

The compressive strengths obtained were used to determine the activity indices, which were lowest at 7 days of age and highest at 60 days of age. Mortar A10 at 28 days of age achieved a higher activity index than 100 % and mortar A20 at 60 days of age achieved an activity index of 100 %.

For the depth of carbonation and the depth of seepage by pressure water, the waveforms were similar. In the case of pressure water seepage depth, the seepage depths at 60 days age were equal to or lower than the pressure water seepage depth.

The K-values determined from the relationship between water/cement ratio and compressive strength were highest for mortar with 10 % cement replacement with fly ash at 28 days of age. At the age of 60 days for mortar with 20 % cement replacement with fly ash.

In the case of pressure water seepage depth, mortar A10 is suitable already at 7 days of age, mortar A20 at 28 days of age and mortar A30 up to 60 days of age. The durability aspect for the depth of carbonation was only satisfied for mortar A10 at ages 28 and 60 days and for mortar A20 at age 60 days.

On the basis of the test results obtained and the assessment of the durability aspect, it can be said that for replacements and ages that satisfy the durability aspects, the values set for exposure classes XC and XD can be safely used. However, it should be taken into account that the requirements of EN 206+A2 for the exposure classes are given for concrete. It is therefore advisable to verify the k-values on concrete exposed to these aggressive environments.

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