Jarosław Rajczyk, Jacek Halbiniak

THE ANALYSIS OF THE INFLUENCE OF FLY ASH ON THE CONCRETE DURABILITY AND FROST-RESISTANCE GROWTH RATE

1. Influence of fly ash on the properties of concrete

Fly ash is a fine dust, composed of mainly spherical, hyalinized grains, being a product of pulverised coal combustion. It has puzzolanic properties. Addition of fly ash to concrete modifies its structure because of its filling effect and puzzolanic properties. While introducing fly ash to concrete it is important to be aware of different effects the component may have on the properties of the concrete mix and hardened concrete.

Addition of fly ash may improve fluidity of the concrete mix and its workability. Improvements in workability and simplicity in administration of the concrete mix by concrete pumps is connected with the "bearing effect" connected with almost ideal sphericity of the ash grains and their fineness. Liquefaction of concrete mix by using fly ash may cause reduction in the amount of batcher water and reduction of the water-binder ratio. The result of this phenomenon is the increase in concrete composite durability. Addition of fly ash may cause increase in water demand and workability decrease in case of using ashes with high loss on ignition. It is caused by irregularity in shape of the ash grains and their porosity in case of increase in the amount of unburned carbon in fly ash.

Addition of fly ash causes limitation of concrete shrinkage and increase in its resistance to influence of chemicals. The use of fly ash in massive elements is a very good solution, because it allows to reduce the rate and amount of heat generated in a hydratation process, which is connected with reduction of the risk of cracks in concrete structure. Fly ash significantly increases the concrete resistance in an aggressive kraft environment. The use of fly ash may cause decrease in concrete frost-resistance, especially with use of de-icing substances. It is commonly known that a component of frost-resistant concrete is air-entraining admixture in order to receive required pores structure in concrete. Addition of fly ash to such type of admixtures causes significant impediment in concrete mix aeration. Simultaneously, together with increase in the amount of fly ash in concrete mix it is necessary to use greater amount of air-entraining admixture. Fly ash also causes delays in concrete early strength growth in natural conditions, more significant in winter period. Moreover, while using fly ash with blast-furnace cement, fastened concrete carbonation should be taken into account.

Results of the research by Heinz and others show that alkalis from fly ash and some alkalis from cement become permanently attached to hydrated phases and do not cause alkalis product expansion- reactive silica.

Apart from some negative aspects of the use of fly ash, it became the most commonly used waste for the production of concrete composites. It is used as a partial cement substitute, and, more rarely, as an additional concrete component [1-4].

Fly ash may be included to the minimum amount of cement on concrete and to equivalent ratio water-cement with the use of "k" factor, the value of which is dependent on the cement category and its type:

– maximum amount of fly ash, taken into account in factor "k" should meet the requirement: fly ash (P) / cement (C) $\leq$ 0.33 (mass).

Ratio value P/C $\leq$ 0.33 refers to Portland cement CEM I and cements CEM II: slag cement, slate cement, lime cement and types of cement CEM II containing secondary components, such as puzzolan and silica ash. In case of cement types containing main components, e.g. puzzolan and fly ash, the ratio value P/C $\leq$ 0.25. For cement type in which additional component is silica ash ratio value is equal to P/C $\leq$ 0.15.

In case of using greater amount of fly ash, the excessive value should not be taken into account while calculating the ratio W/[C+k x fly ash], and minimum cement amount:

- For concrete types containing cement CEM I and CEM II/A (apart from CEM II/A-V) the following values of k factor may be allowed:
  - for strength category CEM 32,5 k value = 0.2
  - for strength category CEM 42,5 and 52,5 k value = 0.4

Minimum cement content required in a given exposure category may be reduced maximally by the amount: k x (min. cement content in a given exposure category - 200) kg/m^3 [5, 6].

2. Composition of the analyzed concrete types

In preparation of the concrete samples for analysis there were used: cement CEM I 32,5R and mixture of natural aggregate with a sand point PP = 37% with continuous particle size included in the area of limit curves [7]. Control series concrete mix characterized by ratio C/W = 2.0 without addition of fly ash was classified to the consistency category marked as S2. Control concrete composition in 1 m^3 included: cement 385 kg; water 192.5 l; aggregate 1812 kg, air-entraining admixture in the amount of 0.6% cement weight.

Control concrete type (series K) was modified by adding the maximum permissible amount of fly ash as a component (concrete series P_1) [1], using half of the permissible amount of the fly ash (concrete series P_2) and as an additional concrete component - without reducing the amount of cement, making correction in the amount of aggregate only (concrete series P_3).

Modifications in the control concrete series

Control concrete series was modified by using: maximum fly ash content in its composition (series P_1), half of its permissible amount (series P_2) and using fly ash as an additional concrete component, without reducing of the concrete amount (series P_3).

Basic control concrete composition:

– Cement: C = 385 kg/m^3
– Water: W = 192.5 l/m^3
– Aggregate: K = 1812 kg/m^3

Cement-water ratio is equal C/W = 2.0. For cement CEM I 32,5R the value of factor k = 0.2. Cement density $\rho_C = 3.1$ g/cm^3. Fly ash density $\rho_P = 2.2$ g/cm^3. Aggregate mix density $\rho_k = 2.65$ g/cm^3. Maximum flu ash content $P/C \leq 0.33$.

Concrete series P_1: for CEM I 32,5R → k = 0.2

Maximum fly ash content: $P/C \leq 0.33 \rightarrow P \leq 0.33 \cdot C$

Identical water demand of the concrete mix was presumed: $\frac{W}{C} = \frac{W}{C + k \cdot P}$

k = 0.2 (for CEM I 32,5R); W/C = 0.5 (in accordance with the basic composition of concrete);

P = 0.33 C

$$\frac{\mathrm{W}}{\mathrm{C}} = \frac{\mathrm{W}}{\mathrm{C} + \mathrm{k} \cdot 0.33\mathrm{C}} \Rightarrow 0.5 = \frac{192.5}{\mathrm{C} + 0.2 \cdot 0.33 \cdot \mathrm{C}} \rightarrow \mathrm{C} = 362.2\,\mathrm{kg}$$

Amount of cement m_c = 362.2 kg/m^3

Amount of fly ash P = 0.33C → P = 0,33 · 362.2 = 119.5 kg/m^3

Calculation of binder volume (cement and fly ash) in concrete V:

Fly ash density $\rho_P = 2.2$ kg/dm^3;

Cement density $\rho_C = 3.1$ kg/dm^3

$$\mathrm{V_{C+P}} = \frac{\mathrm{C}}{\rho_\mathrm{C}} + \frac{\mathrm{P}}{\rho_\mathrm{P}} = \frac{362.2}{3.1} + \frac{119.5}{2.2} = 171.1\,\mathrm{dm}^3$$

Concrete volume according to the basic composition was equal to V_C:

$$\mathrm{V_C} = \frac{\mathrm{C}}{\rho_\mathrm{C}} = \frac{385}{3.1} = 124.2\,\mathrm{dm}^3$$

- Because total volume of cement and fly ash (V_{C+P}) is greater than the volume of concrete V_C in the basic composition, it is required to reduce the volume of aggregate for the same volume ($V_{Korekta}$).

$$V_{Korekta} = 171.1 - 124.2 = 46.9 \text{ dm}^3$$

Aggregate volume according to the basic composition V_K:

$$V_K = \frac{K}{\rho_K} = \frac{1812}{2.65} = 684 \text{ dm}^3$$

Aggregate volume after correction $V_{korekta}$:

$$V_{korekta} = V_K - V_{Korekta} = 684 - 46.9 = 637.1 \text{ dm}^3$$

which allows to calculate total amount of aggregate in concrete mix.

$$637.1 \cdot 2.65 = 1688 \text{ kg/m}^3$$

Water-cement ratio after adding fly ash to concrete:

$$\frac{W}{C} = \frac{W}{C + k \cdot P} = \frac{192.5}{362.2 + 0.2 \cdot 0.33 \cdot 362.2} = 0.5$$

W/C ratio is the same as in case of basic project.

In an analogical way concrete series P_2 was created, by addition to control concrete series (K) half of the permissible amount of fly ash, which is P/C = 0.15. Composition of the concrete type series P_2 was presented in table 1.

In concrete type series P_3 fly ash was treated as an additional component. It means that the amount of cement was not reduced, the only correction was made in the aggregate amount. Composition of the concrete type series P_3 was presented in Table 1.

TABLE 1

Composition of the analyzed concrete series

Concrete series	Admixture composition [kg/m^3]				
	Cement	Fly ash	Water	Aggregate	Admixture
Control K	385	–	192.5	1812	2.7
P_1	362.2	119.5	192.5	1688	2.7
P_2	372.2	61.5	192.5	1749	2.7
P_3	385	119.5	192.5	1667	2.7

For all concrete series there were analyzed: concrete mix consistency, air content, compression strength after 2, 28 and 56 days of maturation and frost-resistance (150 cycles of freezing and thawing). Frost-resistance examination was started in the 28th and the 56th day of concrete maturation.

References

[1] Glinicki M.A., Dąbrowski M., Rajczyk J., Wpływ dodatku popiołu lotnego wapiennego na napowietrzenie mieszanki betonowej i charakterystykę porów w betonie. Popioły z energetyki, Warszawa 24-26 października 2010, Polska Unia Ubocznych Produktów Spalania, Warszawa 2010.

[2] Rajczyk J., Halbiniak J., Langier B., Technologia kompozytów betonowych w laboratorium i w praktyce, Wydawnictwa Politechniki Częstochowskiej, Częstochowa 2012.

[3] Lutze D., Berg W., Popiół lotny w betonie, Polska Unia Ubocznych Produktów Spalania, Warszawa 2010.

[4] Heinz D., Schmidt K., Urbonas L., Einsatz von Steinkohlflugasche (SFA) als Beton - Zusatzstoff zur Vermeidung einer schädigenden Alkali - Kieselsäure - Reaktion (AKR) bei alkaliempfindlichen Gesteinskörnungen, Schlussbericht zum VGB - Forschungsvorhaben P245 (AiF - Nr 13605N), 2006.

[5] PN-EN 206-1 Beton, część 1: Wymagania, właściwości, produkcja i zgodność.

[6] PN-EN 450 Popiół lotny do betonu.

[7] PN-88/B-06250 Beton zwykły.

Abstract

The article presents the analysis of the influence of different content of fly ash on concrete durability and frost-resistance growth rate. Durability research was conducted after 2, 28 and 56 days of concrete maturation. Frost-resistance examination was conducted for 150 cycles of freezing and thawing. Frost-resistance was examined for concrete samples after 28 and 56 days.

Analiza wpływu popiołów lotnych na tempo przyrostu wytrzymałości i mrozoodporność betonów

Streszczenie

W pracy przedstawiono analizę wpływu różnej zawartości popiołów lotnych na tempo przyrostu wytrzymałości betonów oraz ich mrozoodporność. Badanie wytrzymałości wykonano po 2, 28 i 56 dniach dojrzewania. Badania mrozoodporności wykonano dla 150 cykli zamrożeń i rozmrożeń. Mrozoodporność badano dla betonów w wieku 28 i 56 dni.