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Application of fly ash from fluidized bed combustion as addition for underwater concrete

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Abstract

The paper presents the method of using fly ash from the combustion of solid fuels in fluidized bed as valuable constituents of cement concretes. The research was conducted in two directions. The first one was to obtain such consistency of a concrete mix, modified with fluidized ash, to ensure the required consistence for underwater concreting, while the second direction included the study of basic physico-mechanical features of hardened underwater concretes with the addition of fluidized ashes and theirs development in time. Underwater concretes with fluidized bed ash content, used as a cement substitute in the quantities of 10, 20, 30, 40 and 50% of cement weight, were subject to testing. The measurements of consistence, determinations of viscosity and flow ability through the reinforcement as well as the air content were carried out for the concrete mixes. The tests of the hardened underwater concretes included determination of compressive strength and tensile strength as well as water absorbability and depth of water penetration under pressure; the concretes were tested after 28 days of curing. The tests confirmed the possibility of using fluidized ashes as a substitute for cement in concretes placed under water. A mix with a content of 30% of fluidized ashes was selected for the further tests as a cement substitute. The development of strength over time after 7, 14, 28, 56 and 90 days was tested and an attempt was made to determine the efficiency coefficient k for the tested fluidized ashes.

Keywords: Circulating Fluidized Bed Combustion Ash, Mechanical Properties, Underwater Concrete

1. INTRODUCTION

Fly ashes, as the by-products of coal combustion, are important and valuable raw materials for the building materials industry, particularly for the producers of cement and concrete. This is reflected in the valid standards, which give precise requirements for the fly ash used as an addition to cement (EN 197-1:2012 [1]) or concrete (EN 450-1:2012 [2]). The physico-chemical properties of the fly ashes, and thus the possibilities of their use in the cement concretes, depend on many factors, like: type of the combusted material, type of the installation, including conditions of burning and rate of cooling, and technology of gases desulfurization. Besides the typical fly ashes, which are the by-products of combustion of the black or brown coal in the so-called conventional combustion beds, new types of ashes are also created in the form of the mixture of the products of simultaneous combustion of the coal and desulfurization of the gases (the ashes connected with the products of dry methods of desulfurization and the ashes from the fluidized bed combustion). The fly ashes from the fluidized beds are the mixture of the products of ash removal from the exhausts and the residues of the sorbent. Thus, they often contain high amount of SO_3 and CaO and show high loss on ignition [3]. The fluidized ashes do not meet the rigorous requirements of European Standards for the mineral additions to cement and concrete. For this reason they are often considered unuseful for traditional technologies of cement production. According to the requirements of the standard EN 450-1 [2], the fly ashes from fluidized bed combustion may be used in the cement production in the amount up to 5%, as the secondary mineral addition, and as an addition for concrete they are presently used on the basis of Technical Approvals.

As a consequence of the strict requirements referring to the emission of CO_2, SO_3 and NO_x, introduced by the European Union, the growing number of combustion systems with fluidized beds is installed in the Polish energy plants as a part of their modernisation. Therefore, the amount of the conventional siliceous fly ashes, produced by the Polish energy industry, is decreasing. The interest in use of the fly ash from the fluidized beds to the production of building materials, including cement composites, has rapidly grew [4-7].

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The results of testing of the underwater concretes (UWC), made with the use of the ashes from the fluidized beds, are presented in the paper. The fly ashes were used in UWC as a partial substitute of cement in the range 20-50% with a 10% step.

2. PROGRAM AND RANGE OF TESTING

All UWC mixes have been made of the Portland cement CEM I 42.5 R, river sand 0/2 mm and natural gravel with the maximum grain size 16 mm. The fluidized ashes from Zeran (Poland) electric plant have been used as the mineral addition in the amount 10 to 50% of the cement mass (referring to the reference concrete C0). The chemical composition of the ash is presented in the Table 1. The constant value of w/b = 0.4 has been used. The admixture for the underwater concretes has been also introduced in the amount 4 kg/m^3 of concrete (7.5 g/kg of cement). The composition of the concrete mixes is presented in the table 2.

The tests of the concrete mixes, carried out according to the valid standards and recommendations, included determinations of the following properties:

- consistence (slump) after mixing and after 60 minutes from completion of mixing;
- mixing time by the V-funnel;
- ability to flow through the reinforcement by the J-ring;

For the hardened UWC, the 28-day compressive strength has been determined in the air-dry conditions, as well as the mass absorbability and the depth of water penetration under pressure. The results of testing of the concrete mixes and hardened UWC are presented in the Table 3. On the basis of the obtained results, the concrete C30 has been selected for the further testing, as it has met the requirements regarding to the consistence and demonstrated good strength parameters; the concrete C0 without the ash has served as a reference concrete.

Table 1.Chemical composition of fly ash from fluidized combustion beds [wt. %]

LOI	S_iO_2	Al_2O_3	Fe_2O_3	CaO	MgO	Na_2O	K_2O	SO_3	TiO_2	P_2O_5
10.31	39.06	21.01	5.55	10.74	1.87	0.54	1.98	6.83	0.80	0.64

Table 2.Mix proportioning of underwater concrete [kg/m^3]

Concrete	Cement	Fluidized ashes kg/m^3	Fluidized ashes % of cement mass	Water	Sand	Gravel	Super-plasticizer	AWA admixture
C0	530	0	0	212	593	1028	4.0	4
C10	477	53	10	212	593	1028	5,2	4
C20	424	106	20	212	593	1028	7.5	4
C30	371	159	30	212	593	1028	10.0	4
C40	318	212	40	212	593	1028	12.5	4
C50	265	265	50	212	593	1028	15.0	4

Testing of the concrete C30 covered the following properties:

- compressive strength development over time after 7, 14, 28, 56 and 90 days of curing in the water;
- compressive strength development over time after 7, 14, 28, 56 and 90 days of curing in the air;
- splitting tensile strength development over time after 7, 14, 28, 56 and 90 days of curing in water.

The compressive strength of UWC was determined on the specimens made and cured in two different environments: water and air. The specimens made and cured under water were prepared in the following way [8]. The steel mould with dimensions 30 x 50 x 15 cm was placed at the bottom of the container. The container was filled with water in such a way that the level of the water was at least 20 cm above the upper edge of the mould. The concrete mix was then placed directly over the water level. The manufactured concrete plate was demoulded after two days and stored in water until testing. Immediately before the strength testing, the concrete plate was cut in the cubes with the side 10 cm. There were 6 cubes prepared to testing in every time. The obtained values of compressive strength were re-calculated for cubes with the side 15 cm. The tests of splitting tensile strength of underwater concretes stored under water were performed similarly.

Table 3 Results of UWC testing

Mix	Consistence slump [mm]		Consistence flow [mm]		V-funnel	J-ring		Compressive strength after 28 days
	t=0 min	t=60 min	t=0 min	t=60 min	Time [s]	Flow [mm]	B_J [mm]	$f_{c,uw}$ [MPa]
C0	230	145	450	370	5.3	315	32.7	50.2
C10	230	150	450	300	4.7	325	30.4	47.6
C20	235	160	445	270	3.9	347	29.0	42.4
C30	270	170	600	365	7.3	600	15.2	45.8
C40	260	200	525	310	16.1	515	18.7	43.2
C50	289	230	545	350	19.4	455	28.7	33.9

The specimens cured in the air were prepared in the cubic moulds with the side 15 cm, without compacting. After two days of storing in the room with the relative humidity 95% and temperature 20±2 °C the specimens were demoulded and stored in the same room until testing.

3. TEST RESULTS AND THEIR ANALYSIS

Analysis of the development of compressive strength (Fig. 1) and splitting tensile strength (Fig. 2) of the tested concretes showed that regardless of the age of the concretes, the concretes with addition of the fluidized ashes (C30) had in every case the lower compressive and tensile strength than the reference concrete (C0).

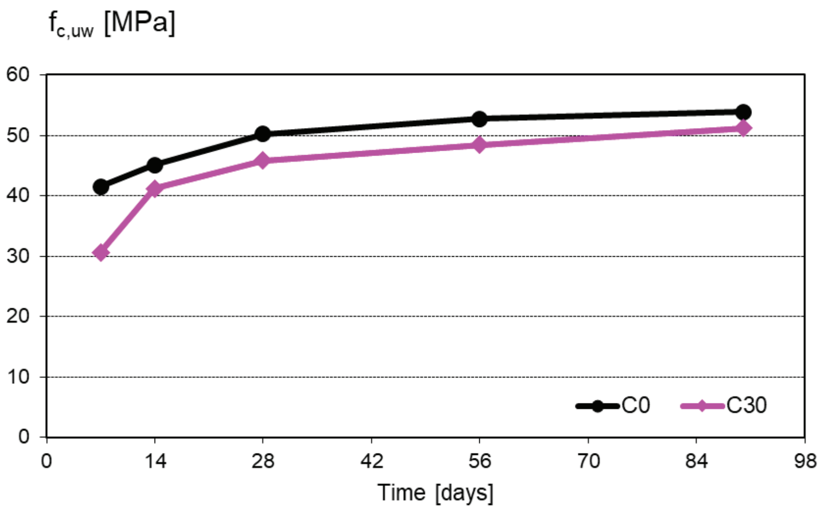

Figure 1.Development of the compressive strength of the tested concretes made in the underwater conditions

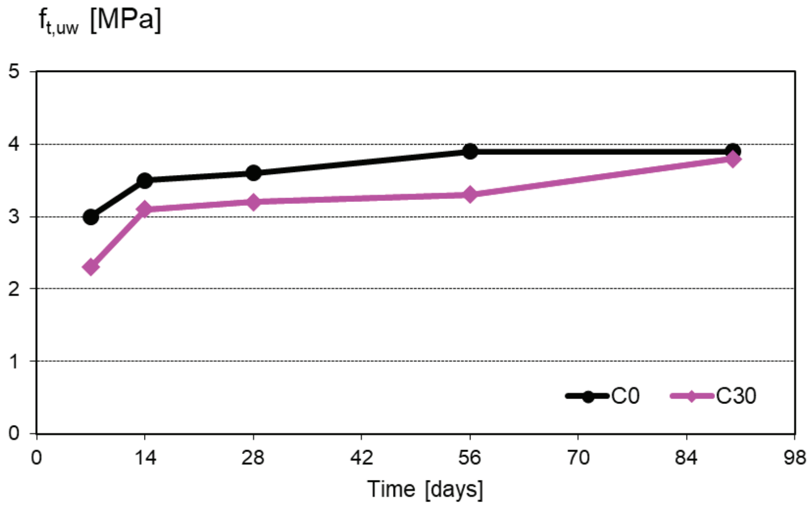

Figure 1. Development of the splitting tensile strength of the tested concretes made in the underwater conditions

The ratio of compressive strength of the concrete specimens prepared and cured under water, $f_{c,uw}$, to compressive strength of the concrete specimens prepared and cured in the air, $f_{c,air}$, may be an indicator for the evaluation of correctness of designing the UWC mixes regarding to compressive strength. According to the requirements given in [9], this indicator should be not less than 0.8.

Figure 3 presents the indicator $f_{c,uw}/f_{c,air}$ as a function of curing time for the tested concretes. The reference concrete (C0) has achieved the value of the indicator $f_{c,uw}/f_{c,}$air equal to 0.8 after just 7 days, while the concrete containing 30% of the fluidized ash (C30) after 14 days.

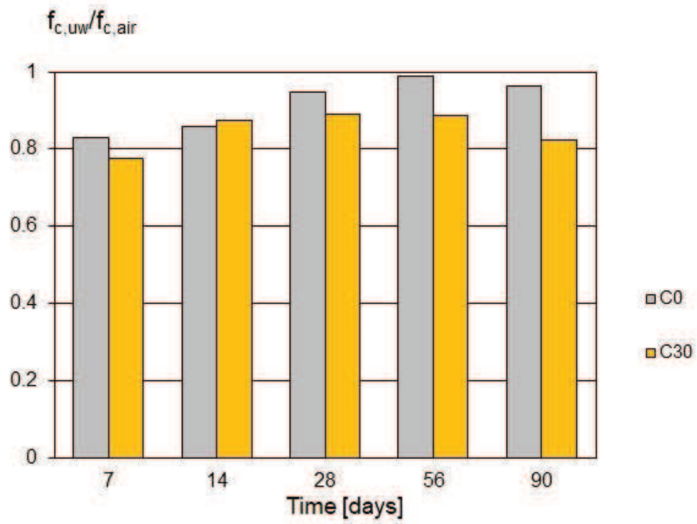

Figure 3. The indicator $f_{c,uw}/f_{c,air}$ as a function of curing time for the tested concretes

For determining the value of the efficiency coefficient *k*, the concept by Atis [10] was employed. The value of coefficient *k* was calculated for various times of concrete curing *t* on the basis of the following formula:

$$k(t) = \frac{c}{p}\left(\frac{f_c(t)_p}{f_c(t)_c} - 1\right) + 1 \qquad (1)$$

where: $f_c(t)_c$ is compressive strength of the concrete made only of cement, in MPa, $f_c(t)_p$ is compressive strength of the concrete made of the cement and fly ashes, in MPa, *c* and *p* are the contents of cement and ash in the concrete, in kg/m^3. The calculated values of the coefficient *k* are presented in the Figure 4.

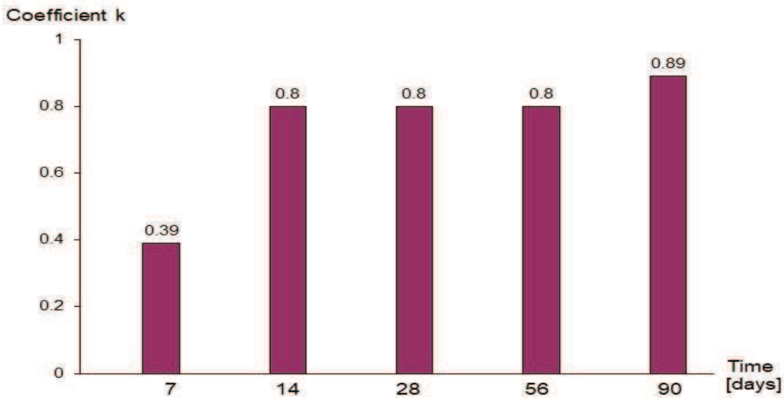

Figure 4. Coefficient k for C30 concrete

It can be noted that the value of coefficient *k* depends on the c/p ratio and the time of curing. According to Atis [10], the stabilization of the value of coefficient *k* is observed only after about 100 days of concretes curing, when the compressive strength is stabilising. In the case of the tested concretes, the stabilization of the coefficient *k* was visible after just 14 days. The coefficient *k* for the concrete C30 is twice higher than for the concretes containing siliceous fly ashes.

4. CONCLUSIONS

The carried out investigation shows the possibility of using the fly ashes from the fluidized combustion beds for the underwater concrete, however, development of the detailed recommendation for their use requires still a lot of studies with the wide range. The serious disadvantage of the underwater concretes with fluidized ashes is a rapid fall of workability of UWC mixes with time. As it was shown in the research [11], even at the maximum content of superplasticizer the difficulties with achieving the necessary mix workability occur after one hour. The research should be continued, taking into consideration the change of w/b ratio and longer time of concrete curing, for instance 360 days, as well as higher content of the fluidized fly ash in the binder.

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