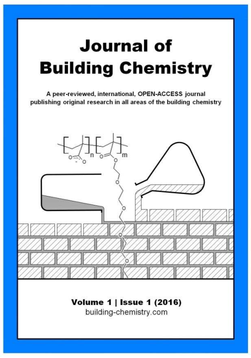

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Influence of addition of fluidal fly ashes on the mechanical properties of underwater concretes

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Abstract

The paper deals with possibility of utilization of the fly ash from fluidal beds as the component of underwater concrete. The concrete mixes contained various amounts of the fly ash, made and cured in different conditions, including underwater environment, were tested. The rheological characteristics of the concrete mixes has covered the flow table consistence and wash-out losses after immersion in water. The compressive strength of the concrete was also determined after various time of curing. It has been found out that, under certain conditions, the fluidal fly ashes can be valuable addition to underwater concrete mixes.

Keywords: Consistence; fluidal fly ash; underwater concrete; wash-out losses

1. Introduction

Technology of underwater concreting with using of special concrete mixes is relatively new issue in Poland. The concrete mixes used under water are highly flowable, yet still resistant to wash-out of the cement paste. This increased resistance to wash-out is usually provided by the admixtures controlling the viscosity (VMA, viscosity modifying admixtures according to EN 934-2 standard). The sufficiently high fluidity of the concrete mix requires the superplasticizer, acting – generally – in an opposite way to VMA. The role of admixtures in shaping the properties of the underwater concrete mixes was discussed in a number of papers (Horszczaruk 2009; Horszczaruk and Brzozowski 2014). A new factor in the considered field is new type of fly ashes, which appeared during recent years, namely the ashes from the fluidal beds (briefly referred to as fluidal fly ashes). The possibility of their utilization in construction is under investigation, including the use for cement and concrete production (Glinicki et al. 2011). The considered range of application covers also the underwater concretes.

The fluidal fly ashes are basically different from the conventional siliceous fly ashes. The latter consist mainly of the spherical, glassy grains. The fluidal ashes contain no glass phase (Fig. 1). Burning the coal in the fluidal beds, with simultaneous desulfurization of the exhausted gases, leads to significant lowering of amounts of SO_2 and NOx emitted to the atmosphere. However, this process also changes the characteristics of the ashes regarding to the physico-chemical properties as compared to the conventional fly ashes (Giergiczny and Pużak 2008).

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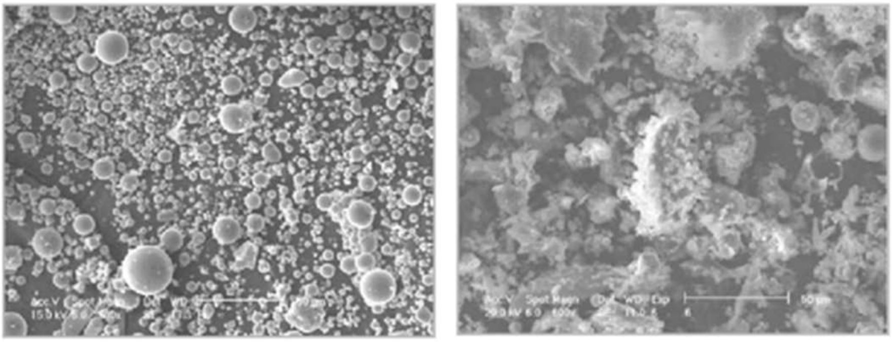

Fig. 1. Microscopic images of fly ashes: siliceous fly ash (left), fluidal fly ash (right) (Giergiczny and Gawlicki 2004).

The performance of the fly ashes depends mainly on the factors like:

- type of the burnt fuel (anthracite, lignite, bituminous coal, wood wastes, etc.),
- type of sorbent, its properties and granulation as well as the Ca/S ratio in the process of desulfurization,
- degree of oxidation of the products of desulfurization process,
- method of burning and the furnace's structure (e.g. the size of installation, the exhausted gases stream, time of staying of the sorbent in the desulfurization zone, changes of SO_2 concentration in the gases, burning temperature, etc.) (Giergiczny 2013).

In the state of delivery, the fly ashes from the fluidal beds do not meet the requirements of the European Standard EN 450-1, defining the performance of the fly ashes used in concrete production. Utilization of the fluidal fly ash is possible after its mechanical activation and usually requires adding the plasticizers or superplasticizers to the mix. However, obtaining of the Technical Approval for the particular application is necessary.

The main danger, caused by introduction of the fluidal fly ash to the cement concrete, is involved with the high amount of desulfurization product in some of the ashes. This product is the anhydrite – a carrier for the sulfate ions. The Standard EN 450-1 limits the allowable content of SO_3 in the cement to maximum 4%, depending to the strength class of the cement. The fluidal ashes produced in the given installation show substantial variability of SO_3 content. Therefore, the verification of chemical composition of the ash is necessary every time when its use for the cement concrete is considered. The SO_3 content in the fly ashes from the fluidal beds can vary from 3 to even 20% (Giergiczny and Pużak 2008), depending on the type of installation and burnt coal. Another danger, connected to the use of fluidal ash as an addition to the concrete mix, is increasing water demand of the mix, which can negatively affect the mechanical and/or durability performance of the concrete (Łagosz et al. 2008).

This paper presents the results of the tests on the influence of fluidal fly ash on the rheological properties of the concrete mix used under water.

2. Program of experiment

The rheological properties of four underwater concrete mixes were tested. The content of the fluidal fly ash in the mixes was 0, 10, 15 and 20% of the cement mass. The fluidal fly ash was derived from burning of the coal in Żerań (Warsaw) electric plant. Table 1 presents the chemical composition of the ash.

Testing of the concrete mix has covered determination of consistency by flow table method according to EN 12350-5 standard and determination of wash-out losses using American method according to the instruction CRD-C61-89A.

Testing of the hardened concretes has covered determination of the compressive strength on the cubic specimens (size 100 mm), made on the air conditions as well as made and cured under water for 7, 28 and 56 days. Casting of the specimens under water has consisted first in placing of the mould inside the vessel with water; the thickness of water layer above the top edge of the mould was about 20 cm. Then, the concrete mix was placed in the mould by pouring from just above the water table and the upper surface of the mix was levelled using the float. The specimens were demoulded after 24 hours and after demoulding they were stored in water until the time of testing.

The concrete mixes for testing were made of Portland cement CEM I 42,5N-HSR/NA. The aggregate was the natural sand 0÷2 mm and fractioned gravel 2÷8 mm and 8÷16 mm. The following admixtures were used:

viscosity modifying admixture, VMA (based on the natural and synthetic polymers) and superplasticizer, SP (based on polycarboxylic ethers). The compositions of the tested concrete mixes is presented in the Table 2.

Table 1. Chemical composition of the fluidal fly ash.

Component	Content [mass %]
SiO_2	39.06
Al_2O_3	21.01
Fe_2O_3	5.55
CaO	10.74
MgO	1.87
Na_2O	0.54
K_2O	1.98
SO_3	6.83
TiO_2	0.80
P_2O_4	0.64
Mn_3O_4	0.04
Loss on ignition	10.31

Table 2. Compositions of the concrete mixes.

Symbol of the mix	Cement [kg/m³]	Water [l/m³]	Aggregate			Admixtures		Fluidal fly ash [kg/m³]	Fluidal fly ash [% of the cement mass]
			Sand 0/2 mm [kg/m³]	Gravel 2/8 mm [kg/m³]	Gravel 8/16 mm [kg/m³]	VMA [kg/m³]	SP [kg/m³]		
M0	490	238	882	508.2	1144	2.45	4.90	0	0
M10	490	251	792	456	1026	2.45	4.90	49	10
M15	490	255	837	482	1085	2.45	4.90	74	15
M20	490	260	822	473	1065	2.45	4.90	98	20

3. Results and discussion

3.1. Mixes consistence and wash-out losses

Figure 2 presents the average results of the consistence tests using the flow table method, depending on the fluidal fly ash content. The consistence was measured after 30 and 60 minutes from the mixing of the components. The biggest flow was obtained in the case of 10% content of the fluidal fly ash (acc. to cement mass) after 30 minutes. However, the consistence of this mix worsened significantly after 60 minutes. In the case of the reference mix (without the fly ash), the flow is also high. For other mixes the flow did not exceed 40 cm, with no significant differences between the mixes.

The analysis of the wash-out losses from the concrete mixes has been performed using the method according the instruction CRD-C61-89A. The method consists in placing of the concrete mix sample in perforated container, and then immersion of this container in the cylindrical pipe filled with water. The immersion is repeated 3 times and the loss of weight of the sample is measured; the result is the loss of weight after the third immersion, according to the following equation:

$$D = \frac{(M_i - M_f)}{M_f} \cdot 100\% \quad (1)$$

where:
D – loss of mass of the sample [%],
M_i – mass of the sample before testing [g],
M_f – mass of the sample after testing [g].

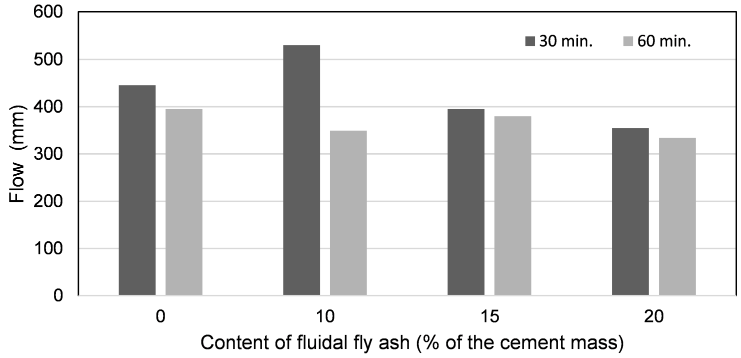

Fig. 2. Influence of the content of fluidal fly ash on the consistence of concrete mix after 30 and 60 minutes from the mixing of components.

The results of the wash-out losses determination are presented on the Figure 3.

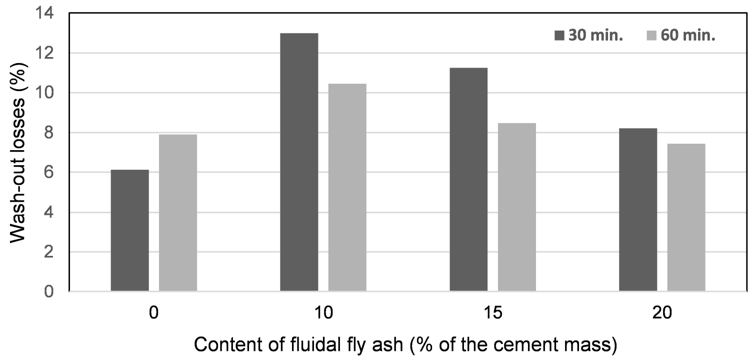

Fig. 3. Influence of the content of fluidal fly ash on the wash-out losses of concrete mix after 30 and 60 minutes from the mixing of components.

The addition of the fluidal fly ashes has caused the increase of the wash-out losses regarding to the reference mix after 30 minutes from the mixing of the components. However, after 60 minutes the wash-out losses of the mixes with 15 and 20% of the fluidal fly ashes (according to the cement mass) are similar to these of the reference mix. This can be attributed to the significant decrease of workability of the tested mixes.

3.2. Compressive strength

The compressive strength was determined on the specimens made in laboratory (air-dry) conditions and under water (Fig. 4). In the case of air-dry conditions, the addition of the fluidal fly ash has caused the increase of the compressive strength. The best results were obtained for 15% addition of the fly ash (according to the cement mass), however, they are only slightly higher than these measured for 20% of the fly ash.

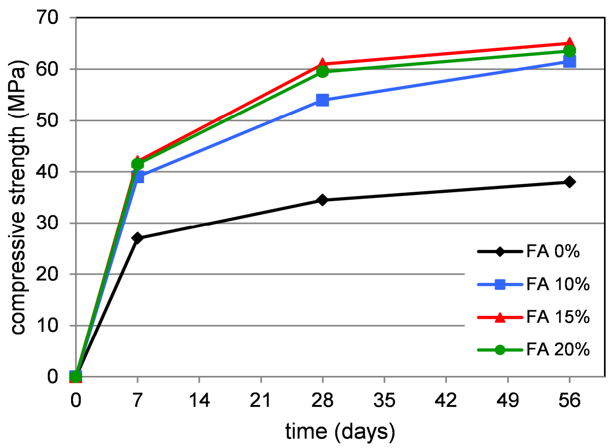

Fig. 4. Development of the compressive strength of the tested concretes made in the air-dry conditions, with various contents of fluidal fly ash (FA).

The concretes made and cured under water had lower compressive strength as compared to the air-dry made concretes. The relative loss of strength are presented on the Fig. 5, expressed as the ratio: strength on the air to strength under water.

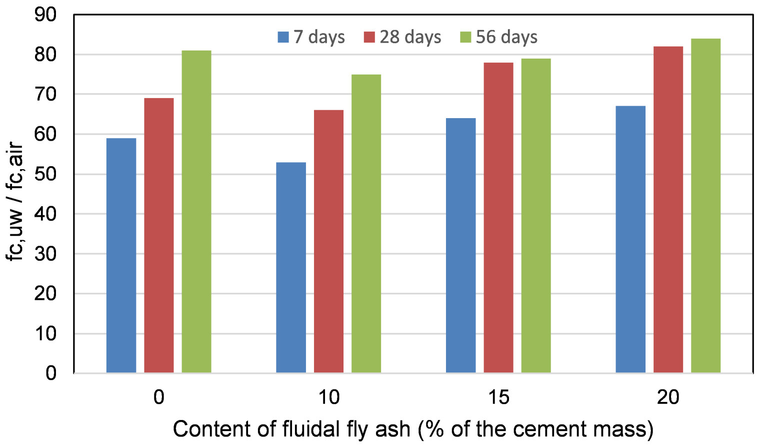

Fig. 5. Influence of the conditions of making and curing of the concrete on the development of the compressive strength, expressed as the ratio of the strength of concrete made and cured under water (f_c, uw) to the strength of air-dry made concrete (f_c, air).

The biggest falls of the compressive strength for the specimens made under water are determined after 7 days of curing; the aforementioned ratio of strength (air-dry to underwater) is increasing with time. Addition of the fluidal fly ash can improve the compressive strength of underwater concrete, at least in the case of 20% content of the fly ash in the binder. The biggest value of the strength ratio between air-dry and underwater concrete was observed for the specimens containing 20% of the fluidal fly ash after 56 days of curing and was equal to 81%, which is quite satisfactory from the economical point of view.

4. Conclusions

It has been found out that the addition of the fluidal fly ashes to the underwater concrete mixes can improve the compressive strength of the concrete. This is due to the limitation of the wash-out losses observed when the content of the ash in the mix is increasing. The optimum range of content of the fluidal fly ash, not causing the significant worsening of the mix workability, is 15-20% (according to the cement mass); in such case the concrete mix should be placed within an hour after the mixing of the components. Taking into consideration that the underwater structures usually contain small amount of reinforcement, the increased amount of CaO in the fluidal fly ashes will not affect the possible corrosion. The fluidal ashes seem to be a promising mineral addition, improving the mechanical properties of the underwater concretes.

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