

Effect of Nano Admixture of CSH on Selected Strength Parameters of Concrete Including Fly Ash

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Abstract. Nowadays, various mineral additives and chemical admixtures are more and more frequently used in concrete mixtures. It is done in order to improve specific parameters of concrete. One of the most frequently used additives are siliceous fly ash (FA). These material are by-products of hard coal combustion processes. Utilization of FA has an ecological aspect (due to reducing the deposit areas of troublesome industrial wastes) as well as the economic aspect (a possibility to replace part of cement binder in the concrete mixture). Research, that carried out so far indicates a significant decrease in strength parameters of concrete with the addition of FA in early ages of curing. On the other hand, numerous experiments prove that using Calcium Silicate Hydrate (CSH) seeds causes an increase in mechanical features of composites with cement matrix. Therefore, it seems possible to strengthen the weakened structure of concrete containing FA through the use of a mixture of active modifiers included in the admixture. Based on the above, the authors of the study decided to carry out laboratory tests on concrete mixtures with the addition of FA and nano admixture of CSH. This study presents the results of tests on concrete with the addition of FA and CSH nanocrystals used as an admixture. Mixtures with 0 and 20% of FA and 4% admixture of CSH were prepared. All experiments were carried out after: 4, 8, 12, 24, 72h, and 7,28 days of curing.

1. Introduction

In recent years, the area of nanotechnology in the field of concrete technology has been developed considerably, e.g., [1-6]. In order to improve the physical and mechanical parameters of concretes, a modification occurs not only on the macro or micro scale but also on the nano scale.

The necessity of producing concretes with new and improved parameters is caused by a huge amount of investments in the area of construction and a fast rate of their growth. Currently, prefabricated elements are used more and more often during buildings' erection. This solution has many advantages, including:

- significant shortening of technological breaks,
- a limitation of the "wet processes" performed on the construction site,
- independence from weather conditions,
- the possibility of obtaining concrete composites with better parameters in the production process of precast products,



- the ability to reduce production costs as a result of a careful care of the concrete mixture, and the use of mineral additives and chemical admixtures.

The basic binder of the cementitious concrete, i.e., Portland cement, is replaced with various mineral additives, e.g., [7-10]. Such treatments are referred to as the green concrete technology in civil engineering, e.g., [11-13]. One of the most popular cement substitutes are siliceous fly ash (FA). These materials are industrial wastes produced as a result of the combustion of hard coal in power plants or combined heat and power plants, and they are safe from the radiological point of view [14]. Nevertheless, the storage of FA is costly and burdensome for the natural environment, so the use of this waste is important both from the economic [15] and ecological [16] point of view. In addition, FA used in an amount of up to 20% of cement mass significantly improve the mechanical parameters of concrete, including their fracture toughness after 28 days and in longer periods of curing [11, 17-21]. The disadvantage of this solution, however, is the reduction of an early concrete strength, e.g., [22], which plays a key role in prefabrication.

Due to the appropriate strength in the first hours of maturation and the faster, than traditional, hardening process of the concrete mixture, the efficiency of the prefabrication plant increases considerably. For this purpose, manufacturers decide on technological treatments such as autoclaving, low pressure steam curing, electro-heating, and/or using chemical admixtures.

The paper presents test results presenting an attempt to accelerate the binding processes in a concrete mixture with the FA addition, using a chemical admixture – the Calcium Silicate Hydrate (CSH). This admixture is an aqueous suspension of nucleuses in the form of nanoparticles. Thanks to nucleation, the growth of CSH crystals is definitely accelerated. The use of nucleuses as activators leads to the construction of a microstructure with improved physical and mechanical properties, e.g., [23,24]. This means increasing the initial strength and the possibility of earlier demoulding and transporting of prefabricates.

2. Experimental program

2.1. Scope of the studies

The tests were carried out for mixtures with the FA addition and the CSH nano-admixture. Concretes' compressive strength (fcm) was tested after: 4, 8, 12, 24 and 72 hours as well as 7 and 28 days of curing. All tests were carried out in accordance with the EN 12390 series standards.

2.2. Materials

The following materials were used to prepare the cubic test samples:

- CEM I 32.5R Portland cement from Ożarów - OPC
- Siliceous fly ash - from Puławy, combined heat and power plant
- CSH nanoparticles - Master X-SEED 100
- Water - from the municipal water supply
- Sandof 0 – 2 mm fraction - from the sand mine in Niemce
- Gravel of 0 – 8 mm fraction - from the Rokitno deposit
- Plasticizer – Stacheplast 125
- Superplasticizer – MasterGlenium ACE 430

2.3. Methodology

The tests were carried out for the following mixtures:

- 0% FA + 0% CSH (FA-0+CSH-0),
- 0% FA + 4% CSH (FA-0+CSH-4),
- 20% FA + 0% CSH (FA-20+CSH-0),

- 20% FA + 4% CSH (FA-20+CSH-4).

The composition of the mixtures tested and their designations are presented in Table 1. They were selected in such a way as to be able to compare the CSH modified concretes (FA-0+CSH-4, FA-20+CSH-4) with reference concrete (FA-0+CSH-0, FA-20+CSH-0).

Table 1. Details of concrete mixtures (kg/m³)

Constituent	Mixtures			
	FA-0 CSH-0	FA-0 CSH-4	FA-20 CSH-0	FA-20 CSH-4
Opc	352	352	282	282
Siliceous Fly Ash	0	0	70	70
Csh Nanoparticles	0	14	0	14
Water	141	127	141	127
SAND OF 0 – 2 Mm FRACTION	676	676	676	676
GRAVEL OF 0 – 8 Mm FRACTION	1205	1205	1205	1205
Plasticizer	2	–	2	–
Superplasticizer	-	2	-	2

When composing concrete mixtures, it was assumed that in each case a constant value of the water-binder ratio will be maintained – $w/b = 0.4$. The use of this proportion of water to the binder reduces the pore content in the cement matrix structure, which reduces the subsequent impact of the cement matrix on the damage processes in the concrete.



Figure 1. Preparing cubic samples

42 cubic samples with 150 mm side (6 samples for each maturing period) were made for all types of the mixtures. After 15 minutes from mixing the ingredients, a consistency test was carried out for each mixture according to the Vebe method, in accordance with [25]. All mixtures were made with the V2 consistency class. The highest Vebe time in seconds was observed for the FA-0+CSH-0 mixture (17 s.), while the lowest for the FA-20+CSH-4 mixture (13 s.).

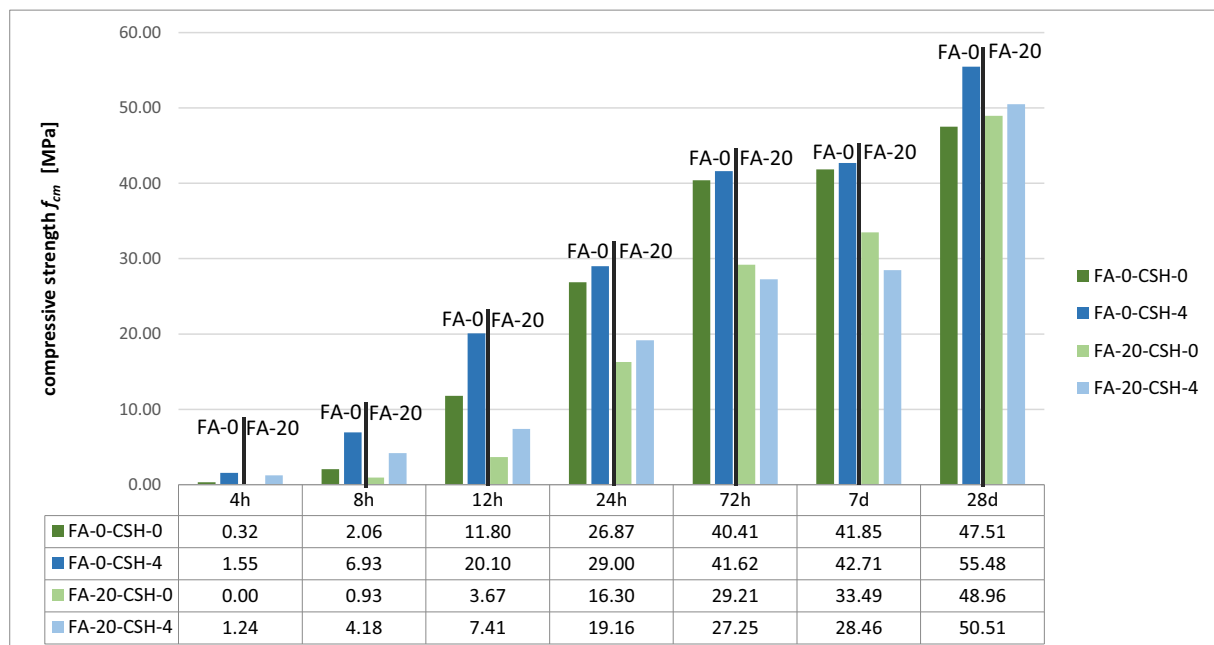
Compressive strength tests were carried out in the laboratory on the Controls Advantest 9 hydraulic press. The load increase was set at a level of 0.5 MPa/s.

**Figure 2.** Test stand – Control Advantest 9**Figure 3.** Specimen during the test.

All samples, tested up to 24 hours, were demoulded immediately before the test. Samples tested after 3, 7 and 28 days were demoulded after 24 hours and then cured in water at 20°C. The cubes were removed from the water one hour before the test. For the study after 28 days, the samples matured in a full immersion for 14 days.

3. Research results and their analysis

Fig. 4 shows the average strength f_{cm} of concretes from each series determined on the basis of results from 6 samples tested.

**Figure 4.** The results of the compressive strength (f_{cm})

On the basis of the tests conducted, a significant increase in the strength of concrete in the early curing periods (up to 24 hours) and after 28 days was noted. After 4 hours in the reference concretes, without FA additive, the admixture caused over 4 times the strength increase. In concretes with FA (FA-20-CSH-0), without the admixture, it was not possible to demould the mixture after 4 hours. After 8

hours, the increase in strength was over 3 times in both sets compared. With each subsequent study, the differences in the strength of the reference mixtures and mixtures with the CSH were significantly reduced. After 24 hours from the execution of the mixtures, the strength parameters of the mixtures compared were very similar to each other. However, after 3 and 7 days in the case of concretes with a 20% addition of FA (FA-20) the f_{cm} parameter was larger in the reference mixture, without the admixture used. After 28 days, an increase in the concrete compressive strength was observed for all concretes with the CSH nano-admixture. The concretes modified were characterized by higher compressive strength than reference concretes (not modified with admixture).

Based on the tests conducted, it can be concluded that the significant influence of the admixture is visible in the first 24 hours of the mixture's aging. Between 24 hours and 28 days, concretes with the admixture may obtain lower values of mechanical parameters, however their strength after 28 days is similar to the reference concretes and according to [26] the concretes would be marked with the same strength class.

4. Conclusions

After analyzing the results obtained from the research, the following conclusions can be drawn:

- 1) Modification of concretes in the nano-structure due to admixtures is a favorable solution during the production of prefabricated elements.
- 2) The use of the admixture significantly improves the early parameters of concretes both with and without the addition of FA. Thanks to this, there is a chance to shorten the process of prefabrication of elements and increase its efficiency.
- 3) Using the admixture, there is a chance to improve the parameters of concrete mixtures with the addition of FA both in early periods (up to 24 hours) and later periods (28 days). In the case of all mixtures compared after 4 hours, the strength increase was over 4 times, and after 8 hours more than 3 times. In research periods of over 8 hours, the impact of the CSH nano-admixture is insignificant, and after 3 days it disappears completely.
- 4) An increase in the strength of the CSH modified concretes after 28 days in relation to concretes without the nano-admixture was noted. Compressive strength results for the CSH modified mixtures without FA were more than 15% higher, while with the addition of FA increased by nearly 3%.
- 5) According to the [26] standard, all mixtures after 28 days receive the same class of the concrete strength.

5. References

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