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EFFECT OF ULTRAFINE FLY ASH ON THE PROPERTIES OF HIGH PERFORMANCE CONCRETES

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The influence of the process of mechanical activation on the properties of fly ash was shown. The effect of ultrafine fly ash and chemical admixtures of polyfunctional action on the properties of fine grained concrete was investigated. It was observed that combination of such complex chemical admixtures and ultrafine fly ash provides the reaching of technical, technological and economical effects in High Performance Concretes.

Key words: ultrafine fly ash, porosity, surface activity coefficient, flowability, mechanical strength.

Наведено результати досліджень впливу механічної активації на властивості золи-винесення. Показано вплив ультрадисперсної золи-винесення та хімічних добавок поліфункціональної дії на властивості бетонів. Встановлено, що поєднання таких комплексних хімічних добавок та використання ультрадисперсної золи-винесення дозволяє забезпечити технічний, технологічний та економічний ефекти у високофункціональних бетонів.

Ключові слова: ультрадисперсна зола, пористість, коефіцієнт поверхневої активності, рухливість, міцність.

Introduction

Nowadays building with using High Performance Concretes (HPC) have become increasingly popular in world practice. However, the production of this types of concrete involves using high-quality binders and microfillers. The theoretical principles of strength synthesis and durability of High Performance Concretes are based on creating optimal microstructure of cement matrix, reducing porosity by the using chemical admixtures of polyfunctional action together with ultrafine supplementary cementitious materials and improving their production technology [1, 2].

Supplementary Cementitious Materials (SCM) – are widely used today in the technology of binding materials production. In most SCM are represented by industry waste products, such as fly ash, slag, silica fume or other natural materials such as quartz sand, limestone and others. The idea of creating High Performance Concretes involves optimization of micro- and mesostructure due to the high packing density of fine particles (physical optimization), hydraulic and pozzolanic reactions in supplementary cementitious materials (chemical optimization) and also to improving the transition zone between the cement matrix and aggregate (optimization of coupling) [2].

Formulation of the problem

Today most investigations of HPC are aimed at improving their properties, including high rheological properties of mixtures, high strength characteristics and durability. All this could be achieved in concretes by using supplementary cementitious materials, which increase the packing density of the cement matrix and interact with calcium hydroxide, which is appears during the hydration of Portland cement with future formation of calcium hydrosilicates. The most widely used SCM is fly ash, but the experience of its use in binders shows that sometimes there may be a slight deterioration in the performance of concrete. Therefore, to avoid these phenomena usually use the mechanical and chemical activation of fly ash. Investigation of hydration and structure formation of Portland cement with ultrafine fly ash and complex combination of chemical modifiers with polyfunctional action in the direction of formation necessary properties of mixes and concretes is extremely important.

Analysis of recent publications

According to Collepardi M., Aïtcin P., Jasiczak J., Zaychenko M. e. a., construction building with using High Performance Concretes continues to increase. The main difference between traditional and High Performance Concrete is lower water-cement ratio, reduced amount of coarse aggregate, the optimal grain structure and availability of using modern superplasticizer and fine supplementary cementitious materials (microsilica, fly ash, etc.) [1-5].

Fine supplementary cementitious materials could significantly influence on the building and technical properties of materials, the kinetics of hydration and hardening properties of binders. Considerable interest for the future investigations study is a byproduct of coal burning – fly ash [6]. Different studies have demonstrated technical and economic possibility of using fly ash as supplementary cementitious material in the manufacture of portland cement. By increasing the amount of fly ash to 30% the decreasing of cements activity was observed. For obtaining cements with fly ash without decreasing of strength and technical properties of concrete it is appropriate to use activated ash. Investigations show that the most effective and economical way is mechanical activation [7].

Previous studies have found that the particles of ash are characterized by spherical particles which sometimes can include some dislocations. Their surface is generally smooth and evidenced by the presence of vitreous membranes around. Such surface has obviously slowing effect of water during mixing Portland cement, which contains fly ash, and it removal can accelerate the interaction of ash particles with water [1, 7, 8].

During the process of mechanical activation energy wich influence directly on the crystal and molecular substructure of solids is the most effective way catalytic effect. This leads to an increasing of dislocations, the disclosure of the active surface amorphization of structural elements. Amorphization in its turn contributes to a significant increasing of active centers. Last decades of the century milling process was mainly improved by the increasing in the size of mills and their power. However, the use of modern mills today allows to reduce the cost of metal, grinding and to reduce energy consumption by 50-60% and to get ultrafine materials. They eliminate overheating of the material, reliable and easy in operating [7].

Ultrafine product – "superpucolana" consisting of spherical silica-alumina grains contain large amounts of alkali metals was proposed [9]. This material is obtained from fly ash by the process of mechanical activation. The dispersion of "superpucolana" expressed through the residue 45 μm sieve is 1-2%, and the content of fractions ≤20 μm is more than 90%, and large amount of particles smaller than 1 μm. The additive has high pozzolanic activity, more than 120% after 90 days. Using "superpucolana" even after replacing 25 mass.% of the cement significantly influence on the reduction of early strength, but increases strength after 28 days. The basic properties of "superpucolana" is low water demand, which increases the rheological parameters of concrete mix and by reducing water-cement ratio influence on the increasing of concrete strength characteristics. Due to its properties "superpucolana" can be used in the manufacture of binders and concrete as high pozzolanic supplementary cementitious material. The use of ultrafine fly ash with more high specific surface than cement creates different opportunities for the production of new types of concrete [2, 8-10].

The purpose of work is the investigation of ultrafine fly ash and the properties of High Performance Concretes containing this additive together with superplasticizers of polyfunctional action.

Materials and methods

Ordinary Portland cement (OPC) CEM I – 42,5 R JSC "Ivano-Frankivskcement" with specific surface of 380 m^2/kg was used in the investigations.

Fly ash (FA) from Burshtyn power plant activated mechanically in was used as supplementary cementitious material. Polycarboxylate type superplasticizer (PC) was included in cementitious systems as modifier.

Results and discussion

According to particle size distribution analysis CEM I – 42,5 R contains 10, 50 and 90 vol. % of particles smaller than 5,75; 19,42 and 56,29 μm respectively. Chemical and phase composition of fly ash quality is determined by its dispersion, form of particles surface, its activation should provide the destruction of the surface of spherical particles of ash and dispersion of large particles with increasing its share of the total surface. Curves with particle size distribution of materials are shown in Fig. 1. It is observed that ultrafine fly ash is characterized by 34 vol. % of particles smaller than 1 μm, which is in 3.1 times higher compared with ash.

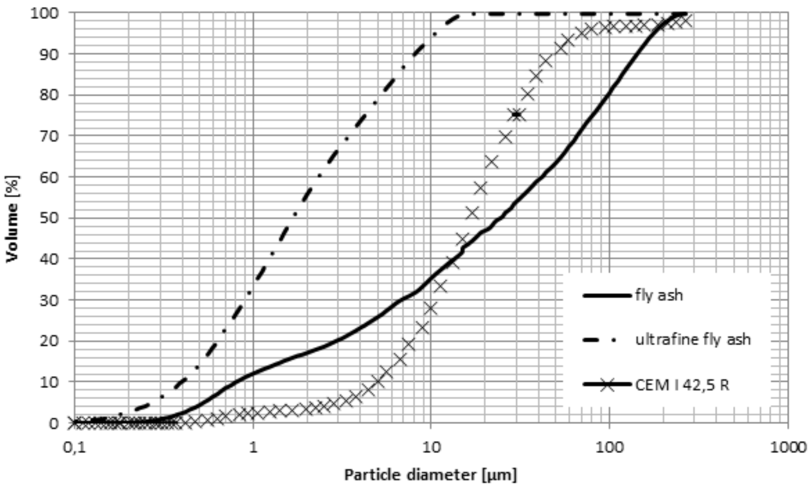
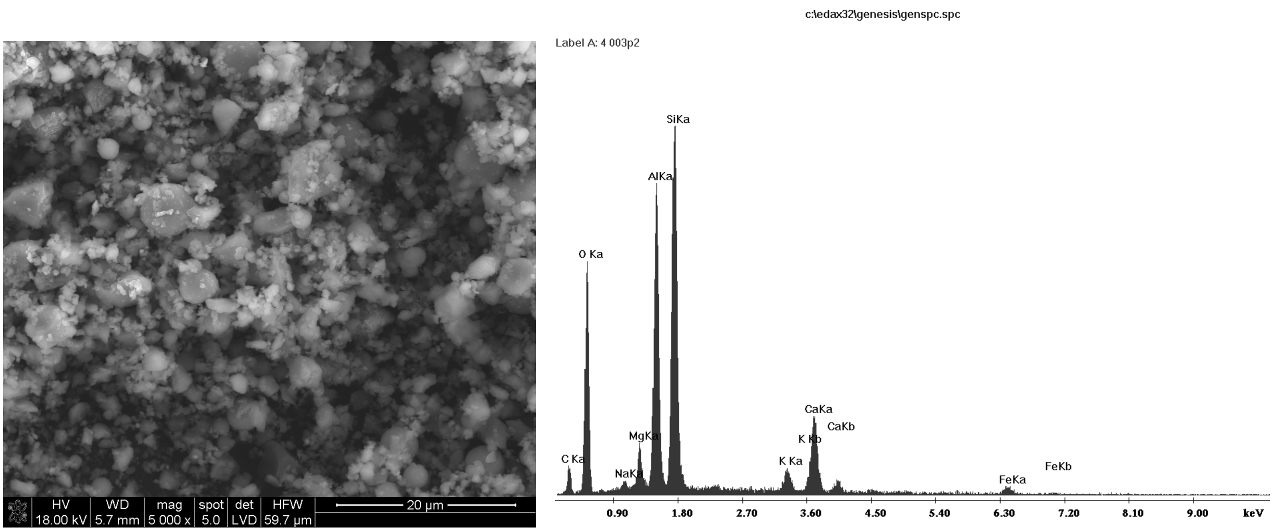


Fig. 1. Characteristics of partical size distribution of materials

According to the electron microscopy data (Fig. 2), the main component of ultrafine fly ash is crushed silica-alumina phase and grains in the form of balls with average diameter of 10 μm. According to EDAX analysis of the composition of particles activated fly ash is presented in oxides, mass. %: Al_2O_3 – 26,96; SiO_2 – 40,27; CaO – 2,58; K_2O – 2,19; FeO – 4,79.



a *b*

Fig. 2. Microstructure (a) and EDAX spectrum in spot EDX3 (b) of ultrafine fly ash

Differential coefficient of surface activity K_{dsa} that shows the effect of the content fractions of particles in the total volume was obtained as the product of the coefficient surface activity and the content of each fraction (Fig. 3). It is shown that K_{dsa} for particles 0,2–0,5 μm in ultrafine ash two times higher compared with fly ash, which shows the significant impact of ultrafine particles from 0,1 to 1 μm.

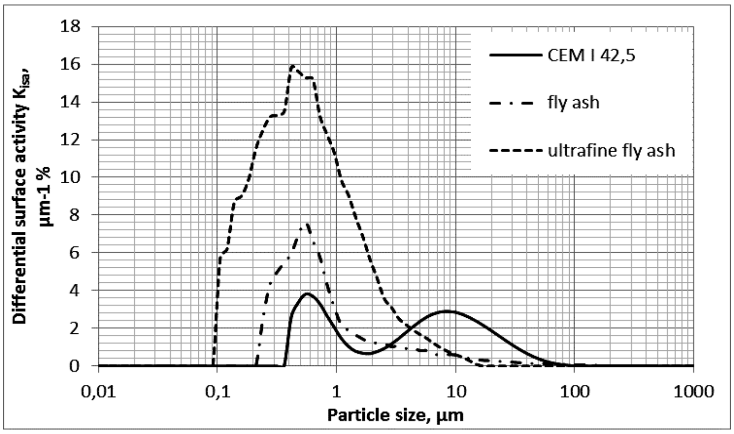
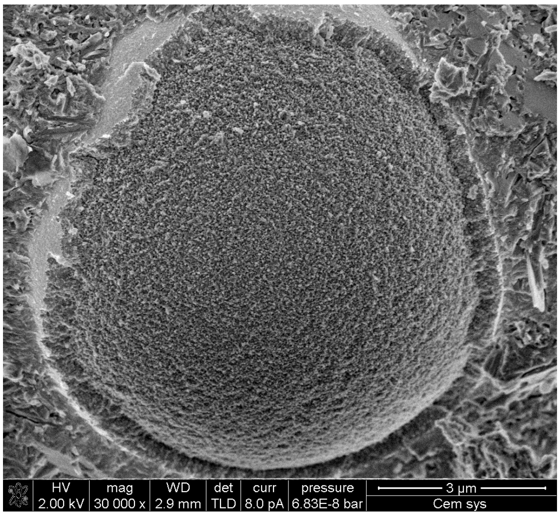


Fig. 3. Coefficient of differential surface activity Kisa of materials

Addition of ultrafine fly ash may improve the structure of the interfacial transition zone (ITZ) between additive and cement matrix (Fig. 4 a, b) further; the ultrafine fly ash acting first as a fine filler and later reacting with the portlandite in the ITZ to form C-S-H. Mechanical activation of fly ash can significantly improve its structure-forming properties by increasing the active surface in 2-3 times.



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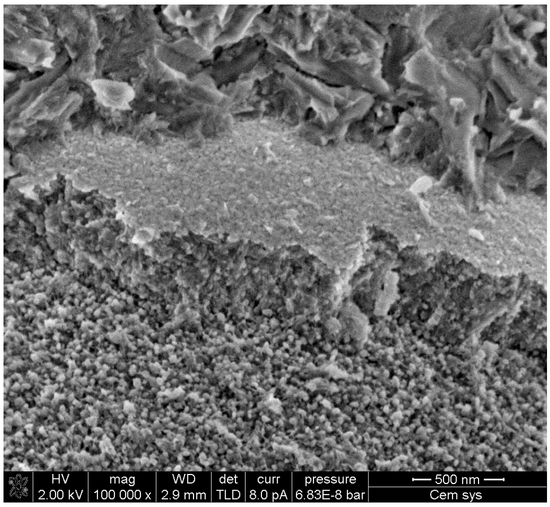

b

Fig. 4. Microstructure of cementitious system with ultrafine ground fly ash after 28 days of hardening

To investigate the influence of fly ash additives on the properties of concrete the following concrete compositions were designed (Table 1). Fly ash was involved in the concrete mixture instead of cement and aggregates. Calculation of concrete modified by the addition of fly ash was shown [3].

Table 1

Concrete compositions

Concrete	Composition of mixture, kg/m^3				
	cement	fly ash	water	aggregates	admixture
Control	385	-	192,5	1812	2,7
1	362,2	119,5	192,5	1688	2,7
2	372,2	61,5	192,5	1749	2,7

3	385	119,5	192,5	1669	2,7

Test the consistency of concrete mixture were carried out according to standart procedures. The test results are given in Table 2.

Table 2

Consistency of concrete mixture

	Concrete			
	Control	1	2	3
Slump, mm	110	118	114	95
Consistency	S3	S3	S3	S2/S3

Physical and mechanical properties of concrete compositions above are shown in Table 3. Investigations showed that the introduction concrete which contains fly ash (3) increases the strength of concrete after 2, 28 and 56 days respectively on 2.6; 9.4 and 13.5% compared to control composition.

Table 3

Physical and mechanical properties of concretes

Concrete	Compressive strength f_{cm} MPa, after days		
	2	28	56
Control	18,8	37,9	41,5
1	16,1	34,5	43,1
2	17,5	37,0	43,6
3	19,3	41,5	47,1

Investigations of fine concretes properties with the addition of ultrafine fly ash showed that the replacement of 10 and 20 mass. % portland cement increases concrete strength during all period of hardening (Table 4). Using 20 mass. % of ultrafine fly ash provides increasing of strength on 17% compared to concrete without additives. It should be noted that due to the high pozzolanic activity of ultrafine fly ash finegrained concrete strength increases to 57.5 MPa after 90 days of hardening.

Table 4

The properties of fine-grained concretes (cement : sand = 1:2)

Cement	W/C	Flowability, mm	Compressive strength, MPa, after days			
			2	7	28	90
cement (100%)	0,39	110	15,9	24,8	37,1	39,5
cement (90%) ultrafine fly ash (10%)	0,39	112	16,2	25,0	38,5	53,1
cement (80%) ultrafine fly ash (20%)	0,39	114	20,7	29,2	43,5	57,5
cement (70%) ultrafine fly ash (30%)	0,39	115	14,8	20,5	35,5	53,2

Testing of fine concrete containing 20 mass. % of ultrafine fly ash and chemical admixture PC (polycarboxylate superplasticizer) showed (Table 5) that the flowability of finegrained concrete mixtures increases to 240 mm (technological effect ΔF = 114%). In the same time concrete strength increased from 37.4 to 60.7 MPa (ΔR_{28} = 62%).

Table 5

The properties of fine-grained concretes (cement : sand = 1:2)

Concrete	W/C	Flowability, mm	Compressive strength, MPa, after days			
			2	7	28	90
cement (100%)	0,39	112	17,9	25,5	37,4	39,3
cement (80%) ultrafine fly ash (20%)	0,39	118	22,7	27,4	42,7	59,4
cement (80%) ultrafine fly ash (20%) + 1,2 mass.% PC	0,39	240	14,3	40,1	60,7	65,7

It should be noted that the use of ultrafine fly ash with polycarboxylate type superplasticizer gives a possibility to obtain High Performance Concretes with high building and technical properties. Thus, increasing the energy content of ultrafine active fractions in ultrafine fly ash provides the increasing efficiency of superplasticizers action in the mixture, density and strength of concrete.

Conclusion

Ultrafine fly ash due to the big amount of active fractions more intensively reacts with calcium hydroxide during hydration process. The use of ultrafine supplementary cementitious systems improve the efficiency of chemical admixtures based on polycarboxylates and their combination is characterized by synergetic action. This gives the possibility to obtain High Performance Concretes which can be used for repair and renovation of reinforced concrete constructions with providing next effects: technological effect – the flowability of the concrete mix increases to 240 mm without strength loss (ΔF = 114%), technical effect – compressive strength is higher (ΔR_{28} = 62%), the economic effect – gives the possibility to reduce costs by reducing the cement content (ΔC = 20%). The new challenges in construction materials mean that such sustainable, efficient, High Performance Concretes will have even more benefits in the future.

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