The Strength of Nanomodified Rapid Hardening Concretes at Elevated Temperature

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Abstract – This paper deals with investigation of nanomodified Rapid hardening concretes with ultrafine mineral additives, polycarboxylate type superplasticizer at elevated temperature. Ultrafine particles of supplementary cementations material relating to microheterogeneous systems are characterized by high values of specific interfacial area and "excess surface energy" and improved thermal stability of cement-based composites due to its high reactivity and particle packing effect.

Key words – elevated temperature, nanomodification, rapid hardening concrete, ultrafine supplementary material, superplasticizer, compressive strength.

I. Introduction

The technological operations associated with heating, heat treatment and burning or firing widely used in many fields of building industry in particular of Portland cement clinker and ceramic products manufacture. These processes take place in special thermal equipments, which lined by heat resistant materials with high thermal and mechanical properties. In addition, contemporary carrying out of lining works especially repair works sets high requirements concerning works time. Using of Rapid hardening concretes provides the ability of quality and quick repair, quick recovery technological processes, early structures loading.

Subjecting concrete to an elevated temperature leads to severe deterioration and it undergoes a number of transformations and reactions, thereby causing progressive breakdown of cement gel structure, reduced durability, increased tendency of drying shrinkage, and structural cracking [1]. The resistance of concrete exposure to elevated temperatures depends on the type of material used in the concrete. It is known [2], that the use of ordinary Portland cement for refractory concretes not gives positive results due to the decomposition calcium hydroxide at high temperatures with CaO formation and its second hydration.

It is important to binding $Ca(OH)_2$ into calcium hydroaluminates and hydrosilicates to prevent the destruction of cement stone during the heating, which is achieved by the adding of the active mineral additives and using of composite cements [3-5]. However, these binders are characterized by high water consumption, reduced early strength, low residual strength and heat resistance.

One of the innovative ways of obtaining of effective Rapid-hardening concretes with improved performances is the use of nanotechnology, which related to the directed process of structure formation by modifying of nanoscale elements [6, 7]. Several efforts have been made to enhance the thermal stability of paste matrix by adding ultrafine supplementary cementitious materials. The ultrafine particles less than 1 μm (nanostructure scale), which have defined a supply of free surface energy, increase the interface that can accelerate chemical reactions, detect catalytic activity and cause more substantial influence of superficial atoms on the synthesis of the cementitious systems strength [5, 8].

Cement pastes modified with nanosilica showed that nanosilica exhibited increased thermal stability however it is still disputative whether this effect can be attributed to improvement of thermal stability of calcium silicate hydrate gel (C-S-H) or only to a filler effect [5]. Due to the reactivity of nanosilica more high-density C-S-H was produced, and samples containing nanosilica had still higher residual compressive strength.

Most of the ultrafine materials, due to their high surface area exhibit high water demand which leads to significant reduction of fluidity and creating local agglomerates of nondispersed material [5, 6]. This can cause a problem with homogeneity dispersion of nanomaterial in the cement matrix, reducing of free water content for hydration process, achieving of desired workability, increasing of autogenously shrinkage. So, development of Rapid hardening concretes with high thermal resistance required complex nanomodification cement matrix by ultrafine supplementary material and high effective polycarboxylate superplasticizer.

The aim of this research is to investigate the strength kinetic of nanomodified Rapid hardening concrete in normal condition and influence of elevated temperature on its residual compressive strength.

II. Materials and methods

Ordinary Portland cement (OPC) CEM I 42,5 and CEM II/A-S 42,5 JSC "Ivano-Frankivskcement" based on Portland cement clinker with mineralogical composition, mass.%: C_3S – 64,20; C_2S – 12,88; C_3A – 5,65; C_4AF – 14,62 - was used in the investigations. Low calcium fly ash (FA) and silica fume (SF), methakaoline (MK) were used as ultrafine supplementary cementitious materials.

Natural sand of Zhovkva quarries (MF=2,1) and coarse aggregates fractions 2-5 mm were used for fine-grained concrete production. The dosages of polycarboxylate superplasticizer GLENIUM ACE 430 (PC) which incorporated into all mixes was 1.5% by weight of cement. Consistency of fresh concrete was determined by flow-table method conforming EN 1015-3 standard. The samples were cured in normal conditions for hardening of concrete (90-100% RH at 20±2°C). After 2 and 7 days some specimens kept in medium-temperature furnace with thermostat and were subjected to elevated temperatures 200°C and 350°C for 1 hour. After cooling samples were visually observed weeks to estimate the damage degree.

III. Results and discussion

Test results showed that fine-grained concrete based on the CEM II/A-S-42.5 modified with PC and ultrafine additives SF+MK characterize by significant increasing

of early strength R_{c2}=62.1 MPa and R_{c2}/R_{c28} = 58.8% (Fig. 1). Significant increasing of early strength of nanomodified concretes conditioned by optimization of particle packing system by ultrafine mineral additives, which determines the initial density system, availability energy active ultrafine particles in supplementary cementitious materials that interact with $Ca(OH)_2$ (early pozzolanic reaction) with additional formation of hydrate products in unclinker part of cement. Residual strength of fine-grained concrete exposed a 200°C increase up to 103.6-109.3 MPa compared to concrete cured in normal condition.

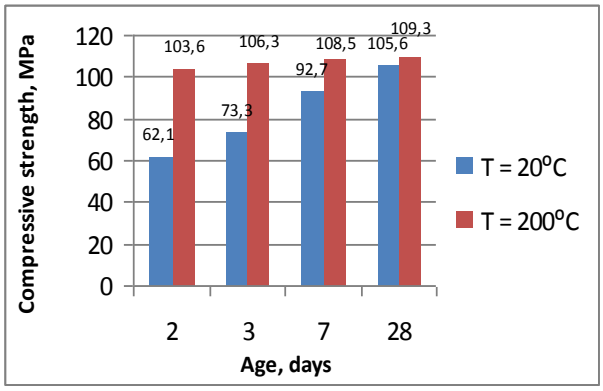

Fig.1 Compressive strength of fine-grained concrete based on the CEM II/A-S 42.5

Early strength of fine-grained concrete based on the CEM I 42.5 modified by PC+SF is 69.6 MPa and strength of fine-grained concrete modified by PC+SF+MK is 70.4 MPa (Fig. 2).

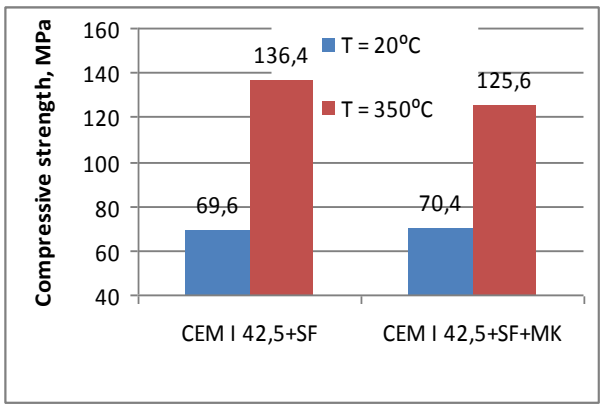

Fig. 2 Compressive strength of fine-grained concrete based on the CEM I 42.5 after 2 days

The compressive strength of fine-grained concrete with SF after 28 days hardening in normal conditions increases up to 104 MPa. For fine-grained concrete with SF+MK this parameter is 105 MPa. The parameters R_{c2}/R_{c28} of nanomodified concretes are 66.9% and 67.1%, which provides to attribute these concretes to Rapid hardening high strength concretes.

After exposure to 350°C and subsequent cooling to room temperature, there was a significant improvement in strength for samples of nanomodified fine-grained concrete based on the CEM I 42.5. Thus, concrete modified by PC+SF is 136.4 MPa and strength of fine-grained concrete modified by PC+SF+MK is 125.6 MPa The reason is that among a certain higher temperature range, the pore pressure in the hardened cement mortar is increased by the evaporation of internal water, forms a high-temperature autoclaving environment, so as to promote the unhydrated cement particles forming more hydration product, and enhances the compressive strength of specimens [2].

Conclusion

The nanomodified concretes with ultrafine mineral additives characterize by high early, standard strength and exhibit enhanced thermal stability mechanical properties. The possibility of obtaining Rapid hardening concretes with high thermal resistsnce is achieved by complex nanomodification with chemical admixture and ultrafine mineral additives, which provided by optimization of system particle packing, increasing of density of cement matrix, acceleration of hydration process and pozzolanic reaction with binding of $Ca(OH)_2$.

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