ISSN 1313-2539

RELATIONSHIP BETWEEN THE MICROHARDNESS AND SOME MECHANICAL PROPERTIES OF DIFFERENT COMPOSITIONS OF FINE-GRAINED CONCRETES

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Abstract

Several standard methods are used for determining some mechanical properties of two groups of fine-grained concretes (ordinary – OPC and composite CPC) as a function of the pore volume (Vp). The latter varies within a broad range of the investigated water/cement ratios. It has been shown that both compressive strength logarithm (CC) and microhardness logarithm (MHV) are interrelated with the changes of pore volume and depend strongly on its size. The higher values of CC and MHV for CPC are due to the combined participation of the active additive and the acidic granulated slag. Their contribution to the enhanced hydration and dense cement structure formation is analyzed and the character of the CC=f(MHV dependence is determined. Microhardness measurements can be used for express indirect assessment of basic mechanical parameters of different composite construction elements.

Key words: *active additive, acidic granulated slag, composite Portland cement concrete, pore volume, compressive strength, microhardness.*

1. INTRODUCTION

Lately the modern microhardness methods are applied in building practice. They play a special role in the investigation and control of the composite cement materials and concretes [1-7]. Their advantages are related not only with the simple measurements, but also with the fact that microhardness properties give more complete information for their mechanical properties and structure. This important position of microhardness among the shown basic characteristics ensues from the very physical essence of the concept of microhardness – it appears to be an intrinsic characteristic depending on the essential mechanical properties of the silicate compositions. In this context the standard methods for microhardness measurement may be used for complex characterization of the "mechanical properties – microhardness – structure" relationship.

Microhardness tests are popular and have very good prospects. They have a number of advantages compared to other mechanical tests:

- The methods are express and easy to perform. No expensive devices or specially trained personnel are required. Restricted amounts of the initial materials are necessary for the preparation of small volume cement samples;

- The tests allow to determine the mechanical properties of composite construction materials and elements, as well as to take under consideration the contribution of their individual components (cement stone, aggregates and interfacial transition zone).

- The possibility has been provided for drawing conclusions about the character of the proceeding physico-chemical interactions, as well as about the magnitude of the adhesive strength, which has its reflection on the strength of silicate materials [8, 9].

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2. MATERIALS AND METHODS

2.1. Initial materials

The plan of the experimental part comprises the study of two groups of fine-grained concretes with composition 1:3 ratio – ordinary Portland cement concrete (OPC) and composite Portland cement concrete (CPC). The first sample contains natural aggregates as an initial component, in contrast to the CPC series, in which this component has been replaced by modified artificial aggregates (granulated slag). Its silicate matrix consists of: Portland cement amount reduced with 15 wt % from a new active additive (AA) and acidic slag. The composite possesses low exothermy, good adhesive strength and deformation properties, as well as high strength parameters, including at the early stage of hardening, without application of thermal or autoclave processing, [9-11], in contrast to some known compositions [12, 13]. The analysis is made with different water/cement ratio values (W/C=0.40, W/C=0.45 and W/C=0.50).

Portland cement CEM I 42.5 R produced in "Devnya" SA is used as a binding substance. Its mineral composition is: C_3S=56.0 %, C_2S=18.5 %, C_3A= 7.0 % and C_4AF=13.0 %. The grinding fineness is 0.5 % and the normal consistency – 23.5 %. The beginning and end of setting time are respectively 1 h 55 min and 9 h 35 min. The specific gravity is 2910 kg.m^{-3} and the bulk gravity – 1160 kg.m^{-3}. The Blaine specific surface is 4200 cm^2.g^{-1}.

The ground acidic granulated slag has graphite-black color and porous structure. The chemical composition is: CaO = 23.0 %, SiO_2 = 24.0 %, Al_2O_3 = 5.0 %, MgO = 1.5 %, Fe_2O_3 = 36.0 %, CuO = 0.5 %, ZnO = 2.0 %, MnO = 0.9 %, Na_2O = 1.0 %, K_2O = 1.0 % with M_0=0.84. The basic mineral phases have been recorded in it [14]. The presence of melilite {solid solution of gehlenite (C_2AS) and okermanite (C_2MS_2)}, monticellite (CMS), CaO, wuestite (FeO) and $FeO.Fe_2O_3$ has been proved. Slag glass represents the basic mass. The specific gravity of the granulated slag is 3730 kg.m $^{-3}$ and the dispersity determined by the Blaine specific surface is 3800 cm^2.g^{-1}. The slag was produced according to the wet method of granulation. Its basic physico-mechanical parameters are measured using the standard test methods, its chemical activity – by measuring the swelling when treated in alkaline solutions and the released heat of hydration – by differential calorimetry method [15, 16].

The new active additive (AA) is a waste product from the building industry with high CaO content (CaO = 76.8 %). It represents unexpensive secondary silicate product with sufficient availability. The bulk gravity is 1062 kg.m^{-3} and the specific gravity – 2340 kg.m^{-3}. The Blaine specific surface is 3100 cm^2.g^{-1}. The utilization of different quantitative combinations of AA allow to create various composite mortars and concretes with good strength properties. It reduces the amount of the binding substance and decreases the W/C ratio, [17].

2.2 Technology of concrete mixture preparation

The composite Portland cement mixture was prepared according to a two-stage technology. The accent was laid on a preliminary technological method for obtaining high-strength construction concrete, consisting in grain-size composition regulation and optimization of the slag filler content, as well as in its mechano-chemical activation together with the active additive with subsequent sojourn for a certain time period. The slag grains are additionally crushed due to the high velocity in the course of the rotational mixing of the composition. New surfaces are formed for chemical interactions with the dispersed additive particles. As a result of the occurring hydrolysis processes the solubility of the slag particles in the surface layers is enhanced, their sizes diminish and gel phase is formed [14, 17]. In this way the preliminary activation contributes to the intensification of the binding substance hydration processes. The basic technological stage includes mixing of the components and their homogenization with the Portland cement in a laboratory mixer.

2.3. Methods

2.3.1. Mechanical testing

ISSN 1313-2539

The compressive strength was determined using prismatic test specimens with dimensions 4x4x16 cm. After removing the moulds at the 24th hour the samples were placed in standard conditions – under water whit temperature T = 20 ± 3^{0}C till the corresponding age of testing – 28 days. The results were obtained as the mean arithmetic value from the single data of three prisms.

2.3.2. X-Ray diffraction method

The X-ray examination was used for determining the basic phases of the silicate material compositions. The X-ray data were registered by a DRON 2.0 computer-controlled powder diffractometer with filtered CoK_α radiation. The angle interval of registration varied between 5 $^0\Theta$ and 50 $^0\Theta$. The samples subjected to X- ray studies were tested after drying, grinding, sifting and pressing in a holder at room temperature.

2.3.3. Mercury porosimetry method

The changes of porosity were determined by the mercury porosimetry method using a Carlo Erba mercury porosimeter with a pore range from 5 nm to 750 nm.

2.3.4. Microhardness method

The microhardness was determined by means of a standard device for microhardness measurement according to Vickers 160 mhp – accessories to the NU-2 microscope. The penetrating body is a regular rectangular diamond pyramid. The maximal loading for this device of 160 g was applied.

Test samples with dimensions 20/20/10 mm were prepared from the above described concretes. They were grinded (polished), so that the necessary for microhardness determination smoothness could be achieved. Ten measurements were made for each sample in different sections. The obtained results were averaged. They include the contribution of all components participating in the composite cement system.

The standard microhardness according to Vickers (MHV) is calculated by the formula:

$$MHV = \frac{kP}{d^2},$$ where

P – The applied maximal loading (160 g);

d – the diagonal of the impression measured after the pyramid removal;

k – a constant depending on the indentor geometry for the Vickers' pyramid.

Defined in this way, standard microhardness represents a measure for the local plastic resistance of the material against penetration. It is correlated with the plastic component of deformation.

3. RESULTS AND DISCUSSION

The dependence of the compressive strength logarithm (CC) on porosity (pore volume Vp) is shown graphically in Fig. 1. The plot shows linear relationships for both formulations. Higher compressive strength values are recorded for the composite CPC concrete – on the average from 68 % to 78 % compared to the CPC reference sample. At the same time the CPC sample gives a narrower interval of Vp alteration (from 0.072 $cm^3.g^{-1}$ to 0.126 $cm^3.g^{-1}$) in comparison with the respective broader range of Vp for OPC (from 0.088 $cm^3.g^{-1}$ to 0.149 $cm^3.g^{-1}$). When extrapolated the two lines intercept in the point of 0 pore volume, i.e. these strengths may be equal for an ideal solid body [4].

ISSN 1313-2539

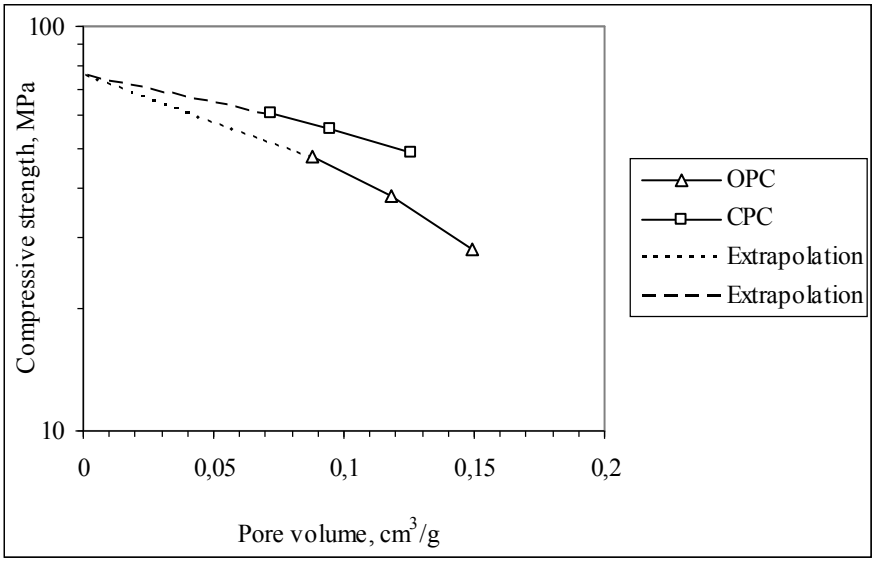


Fig 1 Logarithms of compressive strength versus pore volume for OPC and CPC containing AA=15 wt. %

The high compressive strength values for CPC are due to the simultaneous use of two secondary waste products – active additive and acidic granulated slag. As a result of the mechano-chemical activation in the presence of an alkaline activator additive the solubility of slag glass is increased. The calcium ions of the additive interact with the Al and Si ions situated on the surface of the slag grains, envelopes of gel products with high specific surface and binding capacity being formed on top of them. They deform the slag lattice and increase its activity. The slag grains start swelling. After the subsequent addition of Portland cement accelerated hydration takes place with portlandite (CH) formation in liquid phase. It crystallizes rapidly in the form of coarse hexagonal plates. Its positive role consists in the fact that it affects significantly pH of the medium and the stability of the crystal hydrate compounds. In this way the gel phase is rapidly transformed in calcium hydrosilicates and continuous access of water is ensured to the slag. A new phase is recorded – calcium hydroaluminoferrites $C_3(A, F)H_6$, as well as a higher amount of calcium hydrosilicates of the C-S-H type, Fig. 2 in contrast to the reference OPC series, Fig. 3. The same hydrate phases are formed under constricted conditions in the contact zone of the slag with the Portland cement stone, [18]. At the same time the lower water/cement ration restricts their growth. The calcium hydrosilicate and calcium hydroaluminoferrite phases with smaller size, recorded according to this mechanism, have a significant share in the formation of strong and compact bonds in the Portland cement structure, as well as in the high strength development of the composite CPC concrete, [19].

ISSN 1313-2539

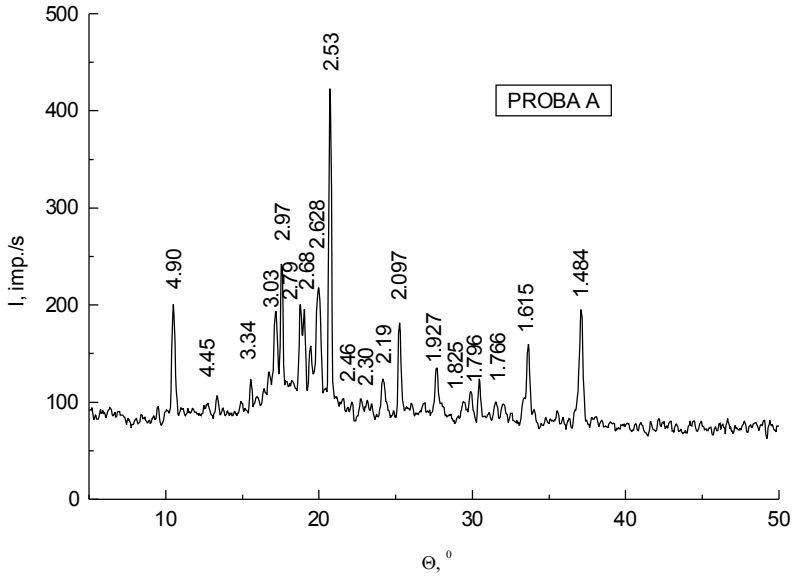


Fig. 2 X-ray pattern of hydrated Portland cement stone of composite concrete CPC, W/C=0.40

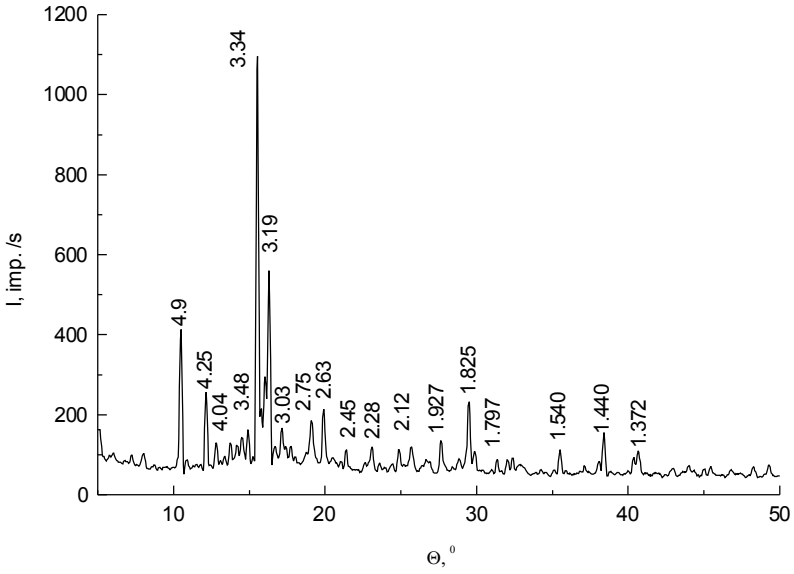


Fig. 3 X-ray pattern of hydrated Portland cement stone concrete OPC, W/C=0.40

The analysis of the experimental data for the log microhardness according to Vickers as a function of pore volume in the measured range of its alteration, exhibits analogous linear functional dependence

ISSN 1313-2539

as in the case of the compressive study, Fig. 4. Together with the already pointed out advantages of the application of both waste products, slag porosity also exerts impact on the MHV magnitude. Porosity increases the surface entering into chemical interactions with AA and Portland cement. The microhardness of CPC is on the average 34 % higher from the respective characteristic of the reference OPC. In addition the slopes of the MHV=f (Vp) relationship are almost equal for both concrete compositions. In the case of extrapolation the lines do not intersect. The reasons for this are complex. The values of microhardness are closely related with the plastic component of deformation. At the same time other factors are also involved – the elastic component of deformation, pore geometry and sizes, presence of micro-defects in cement stone, etc.

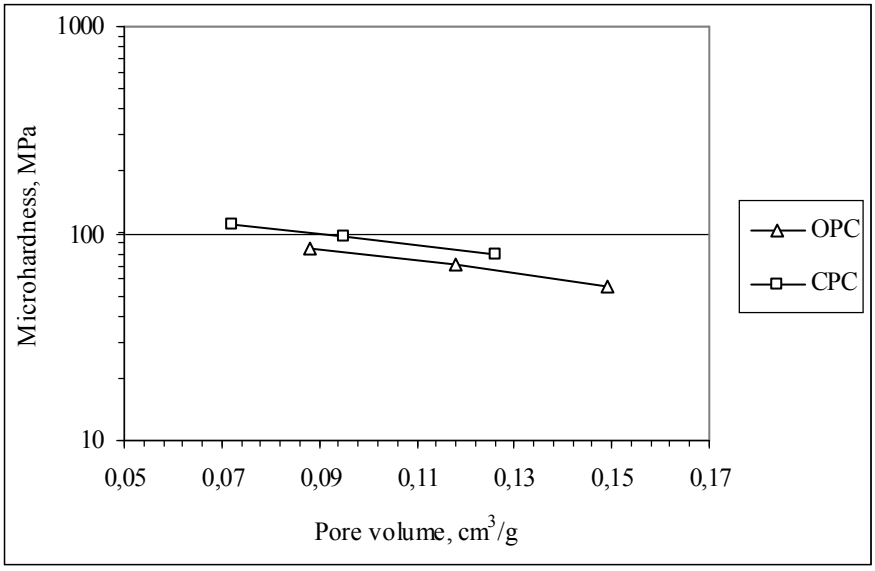


Fig 4 Logarithms of microhardness according to Vickers versus pore volume for OPC and CPC containing AA=15 wt. %

The microhardness according to Vickers versus compressive strength for OPC and high-performance composite concrete containing 15 wt. % of active additive is shown in Fig. 5. The experimental results show that CPC has the highest values of microhardness and compressive strength, but OPC – the lowest, [3]. It is also seen that with strength growth MHV is also increased proportionally for both concretes.

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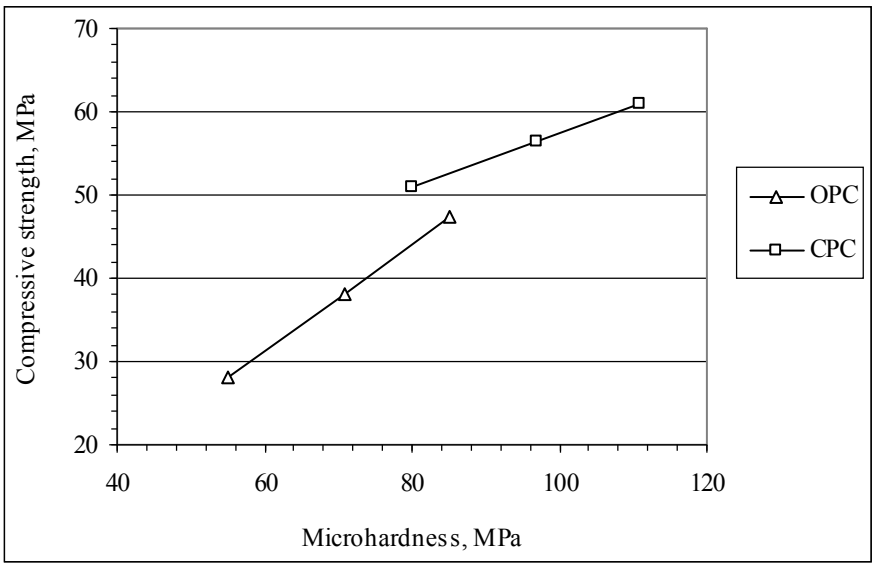


Fig 5 Compressive strength versus microhardness according to Vickers for OPC and CPC containing AA=15 wt. %

4. CONCLUDING REMARKS

Some mechanical properties (CC, MHV) have been investigated as a function of pore volume, varying within a wide range, for two different compositions of fine-grained concretes. It is shown for each of them that log compressive strength and log of microhardness are proportional to the measured pore volume and depend strongly on its magnitude. The higher values of compressive strength and microhardness of the composite concrete composition are connected with the occurring enhanced hydrolysis and hydration processes and with the formation of denser fine-grained Portland cement structure, containing smaller pore volume. The relationship between compressive strength and standard microhardness according to Vickers is graphically presented for both concretes. The analysis of the results shows that the microhardness methods may be rapidly and easily applied for obtaining express indirect assessment of basic mechanical characteristics of different composite construction materials and elements.

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