Journal of Engineering and Applied Sciences 11 (7): 1545-1548, 2016
ISSN: 1816-949X

Inner Friction and Dynamic Modulus of Elasticity of Structural Concrete

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Abstract: The analysis of experimental data assessment of the coefficient of inner friction, the dynamic modulus of elasticity and their interrelation for structural concrete at a long time interval was carried out. It leads to the optimization of concrete structure at the micro and macro level.

Key words: Micro and macro-structure of concrete, structurization, the strength, the coefficient of inner friction, the dynamic modulus of elasticity, structural concrete, super plasticizer

INTRODUCTION

According to the modern views, the strength enhancement of concrete obtained by using the plasticizers is caused not only by the reduction of water in concrete mix and therefore it leads to the porosity contraction in the hardened cement paste. But also it is caused by the dispersion of the aggregate particles of cement, the change of electrical phenomena at the phase boundary of the cement particles and also by the conditions of hydration process, bringing to the formation of a higher content of gel component of hardened cement paste.

MATERIALS AND METHODS

We have shown (Makridin *et al*., 1995) the influence of concentration and the introduction of Super Plasticizer (SP) S-3 into the cement-water composition on submolecular heterogeneity of the hardened cement paste structure. By Mchedlov (1988), the amount of its L_d mosaic units was determined by means of the ionization x-ray patterns of hardened cement paste in the age range from 28 days to 4.5 years. It allows to judge about the granulometric homogeneity of the structure of the formed phases, about the degree of ordering of the crystals, the specific surface area of the formed phases and about the dislocation density in the structure that can ultimately determine the strength of the hardened cement paste as the matrix concrete basis of increased strength. However, all these known facts do not reveal the effect of SP S-3 on the kinetic dependence of elastic moment and inner friction of high-strength concrete.

This study presents the results of studying the influence of the additive SP S-3 on the real micro and macro-structure formation of the high-strength concrete by means of the kinetic coefficient of inner friction and the dynamic modulus of elasticity dependencies. As it is known, the inner friction of solids is called the property of this solid to irreversibly transform the mechanical energy into heat, given to it in the deformation process. The method of inner friction is a structure-sensitive method of studying the fine texture of solids. To measure the inner friction and the dynamic modulus of elasticity of the concrete the Inner Friction Coefficient Measurement Instrument (IFCM-2) was used. The coefficient of the inner friction and the modulus of elasticity are determined by resonance characteristics gained from the flexural vibrations of the prototype.

For the manufacture of the prototypes, the Portland cement M-400 was used, by Stary Oskol Plant, lime rock particles of the fraction from 5-10 mm, quartz fluviatile sand with the fineness modulus of 1.57 and SP S-3. Three types of samples were produced. The concrete mix of the first type without the use of SP S-3 and with W/C = 0.306 (water-to-cement ratio) is control. The concrete mix of the second type is also with W/C = 0.306 but with addition of SP C-3 in amounts of 1% by weight of cement. The concrete mix of the third type is also with addition of SP C-3 in amounts of 1% but with the reduced water flow, i.e. with W/C = 0.242. The estimated consumption of cement, fine and coarse aggregates for 1 m^3 of concrete in all types was equal and was as follows: cement and sand at 620 and 940 kg of crushed stone. The time of compression at formation of prototypes at the standard vibration parameters was as follows: for the first type 120 sec, for the second type 10 sec and for the third 70 sec. The density of the compacted concrete mix samples was for the first, second and third types 2300; 2360 and 2380 kg/m^3, respectively.

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After moulding the concrete samples were exposed to wet and heat processing in the steam curing room at a standard mode and then after demoulding operation they were prepared for testing according to the requirements of the instruction. The analysis of concrete samples, stored under normal laboratory conditions during 500 days, was involved in the researches. The following kinetic dependencies were studied: the coefficient of water yield, the coefficient of inner friction, the dynamic modulus of elasticity, the strength of axial compression and also the dependence between the dynamic modulus of elasticity and the coefficient of inner friction.

Figure 1 the experimental evidence on the kinetics of coefficient changes of inner friction of the given concrete samples is shown and also the estimated graphic dependencies are given. The regression analysis of the experimental data shows that the most optimal dependence has the following form:

$$k_{\underset{n}{fc}} = a+b\tau+\frac{c}{\tau^2}$$

Where:

a, b, c = Empirically determined coefficients

τ = The time of the observations

The values of the empirically determined coefficients are given in Table 1. It should be noted that the desiccation process of concrete prototypes is described by similar mathematical dependency, presented in Fig. 2 and the values of the empirically determined coefficients are shown in Table 2. The numbers of the curves in Fig. 2 and 3 and 4 correspond to the numbers of concrete composition types, shown in Fig. 1. The analysis of the experimental data and the ordering of the theoretical curves in Fig. 1 indicate that the cement particles adsorption of SP S-3 molecules in the concrete types 2 and 3 leads to the numerical value increasing of the inner friction, caused by the deteriorating conditions of the occurrence of coalescence contact of hydration products in hardened cement paste. At the same time, the application of the SP S-3 leads to the more precise dispersion of the aggregate particles of cement and to the more surgeless water distribution while cement gauging on the exposed surface of ultrafine particles, caused by physicochemical dispersion. As a result of that a greater amount of water has molecular adhesion by the solid surface. That is, probably, confirmed by the kinetic dependencies of desiccation process, shown in Fig. 2.

In Fig. 3, the experimental data and the mathematical dependencies of kinetics of changing the dynamic modulus of elasticity of the compared concrete types are presented. From solid-state physics it is known that the density of material structure has primary impact on the elastic modulus of disperse systems. As noted above, the introduction of the SP S-3 contributes to the densification of the cement composition and to the increasing of the coordination numbers of contact interaction, particularly at the fine-dispersed level of a cement component. So that leads to the numerical value increasing of the modulus of elasticity in cement compositions, containing SP S-3.

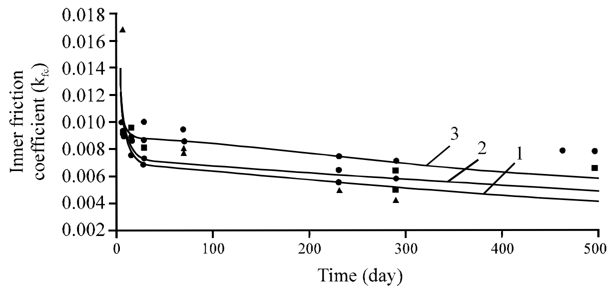

Fig. 1: The dependence of the inner friction coefficient of concrete on its age; 1) the control composition with W/C = 0.306; 2) the mixture with W/C = 0.306 and 1% of SP S-3; 3) the mixture with W/C = 0.242 and 1% of SP S-3

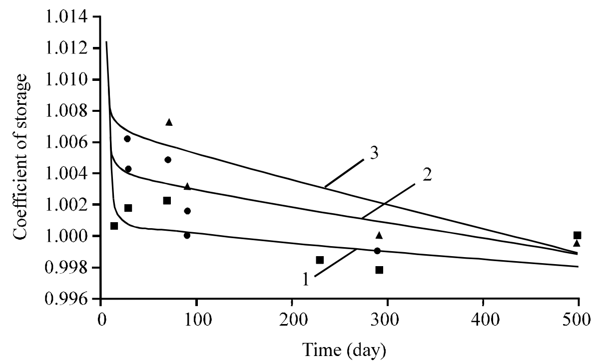

Fig. 2: The dependence of the water yield coefficient between its presteaming period

Table 1: The empirically determined coefficient

Concrete composition	The values of the empirically determined coefficients		
	a	b	c
1	0.006989	-5.86×10^{-6}	0.0949
2	0.007300	-5×10^{-6}	0.1040
3	0.008894	-6.4×10^{-6}	0.0183

Table 2: The empirically determined coefficient according to pre-estimating period

Concrete composition	The values of the empirically determined coefficients		
	a	b	c
1	1.0073	-5.46×10^{-6}	0.1680
2	1.0039	-1.03×10^{-5}	0.1190
3	1.0069	-1.613×10^{-5}	0.0089

RESULTS AND DISCUSSION

Mathematical processing of the experimental data presented in Fig. 3, allowed us to obtain the analytical dependence:

$$E_d = \frac{ab+c\tau^d}{b+\tau^d}$$

Where:

a, b, c = Empirically determined coefficients
τ = The time of the observations

The values of empirically determined coefficients are given in the Table 3. From the analysis of the types and values of the empirically determined coefficients of kinetic dependences, it follows that both constructive and destructive processes, taking place during the long-term hardening of concrete, have influence on the formation of the structure and numerical values of the modulus of elasticity. In our opinion, the numerator of this dependence characterizes constructive and the denominator-destructive processes in concrete. Constructive processes are determined by the lasting hydration of cement grains and destructive by the emergence of their own internal stresses. During long-term observing the structurization of hardening disperse systems, one can state the mutual influence of these processes, that results in prevailing either constructive or destructive basis. That is expressed in the saw-tooth nature of changes mechanical properties of these systems. This is confirmed by the researches of other authors (Akhverdov, 1981). During the early period of hardening, the constructive process of structurization is prevailing, the speed of which can be determined:

$$\frac{dy_c}{d\tau} = cd\tau^{d-1}$$

During the long-time period of hardening, along with the constructive process, the destructive process begins to develop, velocity of which can be expressed by the formula:

$$\frac{dy_\partial}{dt} = d\tau^{d-1}$$

The analysis of the velocities of these processes, determined by the calculation of the obtained models, shows that the process velocities of the comparison types of concrete have both significant qualitative and quantitative differences. From the data presented in the Table 4, it is seen that the velocities of constructive and destructive processes in concrete samples of the type have a fading effect which can be described by a hyperbolic function. At the same time in concrete samples of the types 2 and 3 prepared by using SP S-3, the process velocities are characterized by exponential dependence. In our opinion this exponential dependence is caused by steric factors, introducing into the constructive process of the cement strength synthesis with the chemical additive. In Fig. 4 the dynamic moment of elasticity dependencies on the coefficient of the inner friction are shown. They were obtained by mathematical processing of experimental data. A mathematical model of these dependencies is:

$$E_d = a + \frac{b}{k_{fcn}}$$

where a, b the empirically determined coefficients. The values of the empirically determined coefficients are shown in the Table 5. From the graphic dependencies,

Table 3: The empirically determined coefficient according to kinetic dependences

Concrete composition	The values of the empirically determined coefficients: a	b	c	d
1	32416.850	57.018	52980.64	0.5098
2	29700.564	4.073	41032.56	1.0014
3	40457.713	10.823	45106.26	1.3680

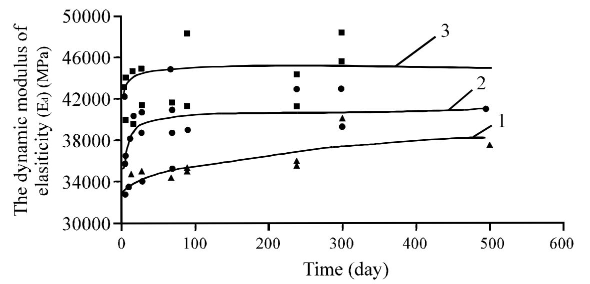

Fig. 3: The dependence of the dynamic modulus of elasticity on its age

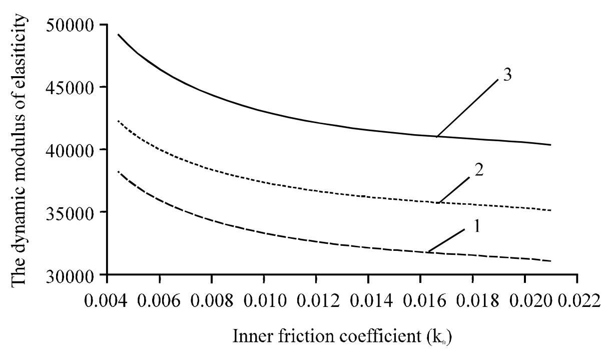

Fig. 4: Correlation dependence of the dynamic moment of elasticity on the coefficient of concrete inner friction

Table 4: The velocities of constructive and destructive processes

Composition	Process	Process velocities at a definite time period (day)				
		3	28	100	250	500
1	Constructive	15762.76	5273.758	2825.641	1803.212	1283.754
	Destructive	0.297519	0.099541	0.053333	0.034035	0.024231
2	Constructive	41153.25	41282.14	41355.78	41408.87	41449.07
	Destructive	1.002941	1.006083	1.007877	1.009171	1.010151
3	Constructive	92449.28	210318.3	335987.3	470722.4	607496.6
	Destructive	2.049589	4.66273	7.448796	10.43585	13.46812

Table 5: The empirically determined coefficient according to dynamic moments

Concrete composition	Values of the empirically determined coefficients	
	a	b
1	1.0073	-5.46×10^{-6}
2	1.0039	-1.03×10^{-5}
3	1.0069	-1.613×10^{-5}

presented in Fig. 4 and the physical nature of the mechanical properties of the cement composites formation, we can observe rather explicit interrelationship between the coefficient values of inner friction and the dynamic modulus of elasticity of the concrete samples. However, it should be noted that the use of the additive SP S-3, on the one hand, leads to improvement of the mechanical characteristics of the concrete and on the other hand to increasing its inner friction.

CONCLUSION

To explain the opposite effects of the additive SP S-3 on the properties of concrete, one should proceed from he notion that the strength and elasticity of hardened cement paste and concrete on its basis, is a porosity function, the nature of the supermolecular structure, the strength of the contacts in tobermorite gel, the properties of adhesive contacts, a structural factor, the morphology of new hydration formation (Sychev, 1981) and the inner friction is mainly the function of porosity and strength of the phase contacts in the matrix phase and the composite as a whole. In our opinion, the evaluation of the inner friction of concrete by non-destructive technique is an important prognostic criterion of quality and the optimization of concrete structure of increased strength.

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