Time Progress of Compressive Strength of High Performance Concrete

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Abstract. Development in the field of concrete engineering is increasingly focused on the practical application of high performance concrete (HPC) or ultra- high performance concrete (UHPC) in construction practise. Newly developed kings of concrete are newly using in transport and building structures. The process of hydration of hydraulic binders based on Portland cement doesn´t stop after 28 days, when the test of compressive strength take place, but it´s a long time process that takes for many months. For design we use the values of strength of 28 days. This paper explorers how does the long-term development of compressive strength of HPC runs. The composition of HPC is significantly different from the common concrete lower strength classes. The question of the influence of additives, filler on microsilica based, silica flour to the time development of compressive strength is being explored in this paper. There is also recorded the influence of curing condition of the test specimens to the compressive strength. The age of testing samples starts at a very early ages 1, 3, 7, 21, 28, 45, 90 and 180 days. The strength in uniaxial compression was measured on cubes with dimension 100 mm.

Introduction

The hydration of Portland cement means a long-term process that has an effect of the resulting mechanical properties and their time development. Many studies have proved the significant influence of surrounding conditions and treatment of fresh concrete on the final properties according the long term properties and durability. In [1] was described the influence of temperature at early age to final compressive strength. The high temperature at early age concrete leads to lower final compressive strength but faster increase of initial strength. Equivalent knowledge has been achieved in [2]. Both authors have focused on determining the influence of temperature during treatment of the fresh concrete.

Many authors also examined the effects of boundary condition to the final properties of high-performance concrete or ultra-high performance concrete, in many cases reinforced by steel fibers. N. M. Hong in [3] dealt with the material properties of fiber reinforced ultra-high-performance concrete from early ages to 28 days. In this research was confirmed the rapid increase of compressive strength, when after 14 days the strength was at the level of 90 % of

28 days. The influence of curing condition on final compressive strength was investigated in [4]. Graybeal investigated the influence of hot steam and high humidity over 95 % on the final compressive and tensile strength and modulus of elasticity compared to laboratory condition samples. In all observation quantities the final values were about 30 % higher in case of hot steam and high humidity curing condition. In practical testing of materials we very often put the fresh samples to water to the age of 28 days. In the following article is presented a series of data results of the influence of water curing condition to mechanical properties in comparison with curing in laboratory condition. The research of literature showed that many authors describe the development of high-performance concrete mechanical properties at the age of 28 days and curing in laboratory condition or in hot steam and high humidity condition. The samples curing in laboratory condition showed a long-term increase of strength but the increase in case of curing in hot steam was very fast but soon terminated. In practical testing of mechanical properties in laboratory we usually store the samples in water condition. The issue of water curing influence during maturation of high-performance concrete on compressive strength is not fully described in literature, as well as long-term development of strength of high-performance concrete.

Experimental Program

The presented experimental program was focused on examination of time development of compressive strength of high-performance concrete designed at the Experimental Centre by Ing. Petr Máca. The uniaxial compressive strength was investigated on two series of cube specimens with dimension 100 mm. Two variants curing of fresh hardened concrete and their influence of the final mechanical properties represent the main topic of the experimental program. The foil covered the surface of fresh concrete in the steel forms due to the elimination of evaporation of water. After one day in steel forms all samples were removed and one half of specimens stored in laboratory conditions and the second one in water for next 27 days.

Used mixture of concrete. This work represents a part of complex experimental research focused on development of new type of high-performance concrete. Requirement for concrete was its composition available raw materials, low water-cement ratio and good workability. The approximately composition of used concrete is shown in Table 1.

Table 1 Concrete mixture composition

Components		Amount [kg/m^3]
Aggregates	01/08	1090
Fine Aggregates	Microsilica, Cement	1158
Water	Water supply	169
Plasticizer	Carboxyl-ether	38.4
Water-cement ratio		0.22

Experimental methods. The main aim of the presented experimental program is development of compressive strength detected on mechanical testing machine INOVA. The determining pore size distribution in the inner structure of high-performance concrete was measured by Thermo Pascal 140. The Loading was carried out by constant force increase at time corresponding to10 kN·s^{-1}. The construction of testing machine enables centric effect of load and correct break of sample. The samples after test we can see in Fig. 4 where the typical shape of specimen is shown.

The size and amount of the pores in the inner structure was carried out by measuring the mercury intrusion porosimetry machine Thermo Pascal 140. This method works on intrusion of mercury to pores of studied piece of material. Basic physical principle is intrusion of hydrophobic liquid to the pores. According to Washburn equation Eq. 1 the penetrated pore´s diameter is inversely proportional to applied pressure of liquid, in this case mercury. The applied pressure is gradually increasing during the experiment and thus mercury penetrates narrower pores [5]. The minimum accessible pore diameter is then given by the apparatus maximum operation pressure. The maximum pore size limit depends on the apparatus design as well, according to the mercury hydrostatic pressure. When one assumes the mercury surface tension to be 480 mNm^{-1} and contact angle 130°, the measurable pore diameter ranges from 3 nm to 100 μm.

$$r = -(2\cdot\gamma\cdot\cos\Theta)/(g\cdot\rho\cdot h) \qquad (1)$$

Where r …radius of a cylindrical capillary
- γ…surface tension of mercury
- Θ…contact angle between mercury and solid surface
- g…gravity acceleration constant
- ρ…density of used liquid (in this case mercury)
- h…high of mercury in a cylindrical capillary

Results

In the following text are shown all the results of test that were performed.

Mercury intrusion porosimetry. The pore distribution of testing concrete is shown in **Fig. 3**. In this chart we can see the dependence of pore diameter on pore volume contained in testing samples. Free bounded water contained in the pores structure can affect the resulting value of mercury porosimetry and distort the final results. Contained water comes from the surrounding environment, from technological process or from curing in water condition.

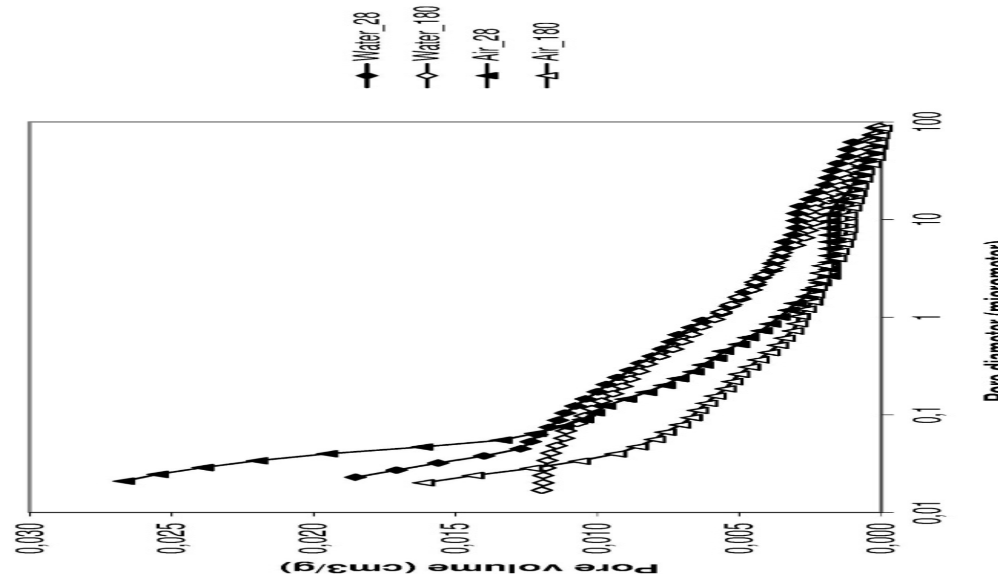

Figure 1 Pore distribution

Compressive strength and density. All tests were carried out according the standard CSN EN 73 1302 Testing hardened concrete – Part 3: Compressive strength of test specimens [6]. All results of compressive strength of specimens stored in laboratory condition and specimens stored for 27 days in water. The table also includes the values of density detected on the same specimens before testing the compressive strength. In achieving high strength of concrete the importance of completely centric effect of testing machine`s loading force without eccentricities increase. The samples curing in water condition had to be dry before testing, in this case the drying carried out in naturally in laboratory conditions.

Table 2 Final values of compressive strength

Time [days]	Compressive Strength [MPa]	
	Water Curing	Air Curing
1	-	89.99
3	-	106.58
7	117.16	98.87
14	118.38	127.31
21	124.38	131.37
28	137.15	149.63
35	144.05	151.83
45	145.04	149.25
90	148.52	152.33
180	154.88	168.27

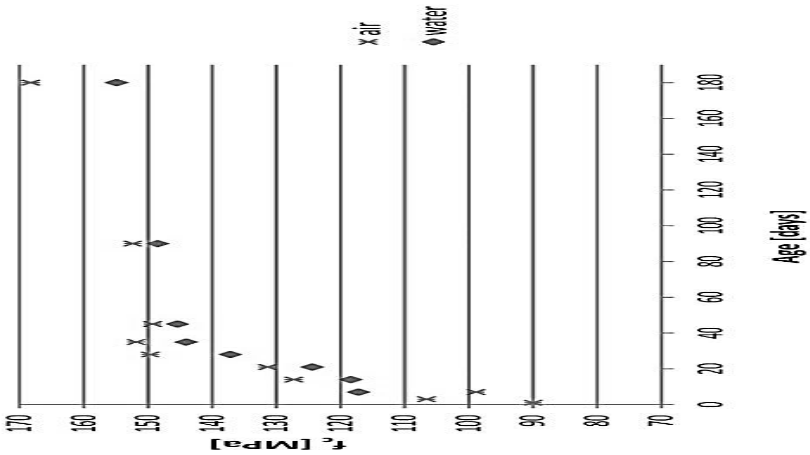

Figure 2 Time development of compressive strength

Table 3 Final values of density

Time [days]	Density [kg/m^3]	
	Water Curing	Air Curing
1	-	2293.53
3	-	2267.20
7	2299.56	2291.13
14	2276.54	2261.93
21	2273.46	2279.45
28	2277.84	2329.95
35	2283.00	2271.62
45	2281.94	2282.04
90	2277.06	2268.68
180	2265.36	2273.24

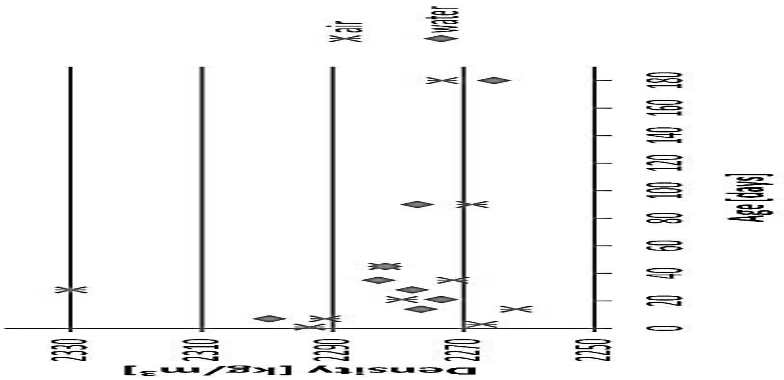

Figure 3 Time development of density

Figure 4 Typical shape of specimen after testing

Conclusion

In connection with the great progress in the development of modern types of silicate composites using advanced modern types of superplasticizers, special fine binders and fine fraction of aggregates new category of high-performance and ultra-high-performance concrete comes to the building structures practice. We can find the possible use in many types of structures, especially in highly exposed construction in bridges, high-rise building and in some special applications in safety barriers resists the effects of bullets and absorbing the energy of explosion. Due to the excellent mechanical properties and also sufficient ductility while using high strength steel fiber the final structures could be very subtle and effective in the same time. The basic premise for design of high-performance silica composite is properly designed mixture with continuous granulometric curve and low water-cement ratio. These types of mixture have their small problems with workability of fresh mixture and it´s placing to the forms [7]. Merely reduction of water-cement ration doesn´t guarantee higher strength but it leads to higher volume of air in concrete which is related with lower compressive strength. The addition of microsilica is necessary for ensuring appropriate granulometry and adequate workability [8].

The measurement of density show bigger values of samples curing in water conditions. This phenomenon could be caused by residual water in pore structure from the water storage because the drying before measurement of density and mechanical properties was carried out at laboratory condition.

The time progress of compressive strength of high-performance concrete is shown in Tab. 1 and Tab. 2 as well as in the Fig. 1. The measured values clearly show higher strength of samples curing in the laboratory condition in air. This described phenomenon affects all samples of different age except the age of seven days. This deviation could be caused technological aspects of production, where small difference in procedure leads to different outcome. The exact compliance with the procedure is necessary for an integral condition for ensuring consistent performance.

We can also see the rapid increase of strength in this type of concrete, when at the age one day the strength corresponding to 60% of the values at the age 28 days. Strength development continues throughout the whole observation time, however between 28 and 180 days the strength increased by 11 %.

Macroscopic properties, such as compressive strength, are the image of the internal structure of the material to its integral microstructure and micro composition. The mercury intrusion porosimetry clearly showed the decrease of porosity over time in both types of curing. This process is closely related to the still ongoing hydration of Portland cement. On the results is evident the influence of curing in water condition of the lower porosity for both times. The character of the pore system directly affects the rate of penetration of aggressive substances from the surrounding environment to the internal structure of the concrete. Both samples cured in air condition showed lower amount of capillary pores with are closely related to the transport of moisture or other substances to the inner structure.

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References

[1] J. K. Kim, X. H. Moon, S. H. Eo, Compressive strength development of concrete with different curing time and temperature, Cement and Concrete Research (1998) 1761 – 1773.

[2] A. Sterba, T. Sterba, The effect of the time or curing and temperature of concrete on its hardening speed, Concrete TKS (2007) 6 - 10.

[3] K. N. Hong, S. T. Kang, S. W. Kim, J. J. Park, S. H. Han, Material properties of air-cured ultra-high-performance steel-fiber-reinforced concrete at early ages, International Journal of the Physical Sciences, 5 (2010). ISSN-1992-1950

[4] B. A. Graybeal, Compressive Behavior of Ultra-High-Performance Fiber-Reinforced Concrete, Cement and Concrete Research, 36 (2006), ISSN-0008-8845

[5] R. Cerny, P. Rovnanikova: Transport processes in concrete, London Spon press (2002)

[6] Czech Standard CSN EN 12390-3 Testing hardened concrete – Part 3: Compressive strength of test specimens

[7] F. de Lerrard, T. Sedran, Optimization of ultra-high-performance concrete by the use of a packing model, Cement and Concrete Research (1994) 997 - 1009

[8] K. Wille, A. E. Naaman, S. El-Tawil, G. J. Parra-Montesinos, Ultra-high performance concrete and fiber reinforced concrete: achieving strength and ductility without heat curing, Materials and Structures, 45 (2011). ISSN-1871-6873