Experimental investigation of selection of warm mode for high-performance self-stressing self-compacting concrete

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Abstract. The purpose of the present work is the search of the rational mode of thermal treatment of high-performance self-stressing self-compacting concrete. At the present time, only few of such investigations have been carried out by scientists. In the present paper, the results of scientific tests implemented by the authors for holding temperature 50°C and 60°C are outlined. Dependence between relative strength of concrete specimen cylindrical form and the total time of electrical curing at fixed duration of temperature rise and cooling has been figured out. The scientific experiments implemented have shown that the mode of thermal treatment 3+5+3 of high-performance self-stressing self-compacting concrete with the temperature of isothermal time 60°C allowed obtaining the value of relative strength at axial compression of 70%. Along with that, strength of concrete at 28 days corresponded to the concrete grade B80. The obtained data can be used to verify results of calculations.

1. General information

The modern reinforced concrete and steel-reinforced concrete structures are associated, in our account, with the term of ‘High Performance Concretes’ (HPC). This term comprises new generation of concretes which are distinguished by their high performance characteristics. The conception formed of HPC is based, in the first place, on the complex use of super plasticizing admixes and micro silica suspension [1-8].

It could be successfully realized provided that HPC keeps all its predominant features which made concrete the principal building material for construction; the technology of its manufacturing and concreting procedures are widely available and not labour-consuming.

Application of self-compacting concretes facilitates assurance of those requirements [9-11]. Quite often, achieving required performance characteristics could be possible due to use of self-stressing concrete [12, 13]. Steel-reinforced columns [14-16] could be regarded as the clear-cut example of structures required application of high-strength self-compacting self-stressing concretes.

From the other side, it’s widely known that the time of concrete strength development plays the crucial role at mass production of reinforced concrete and steel-reinforced concrete structures. During thermal treatment, hardening of concrete is intensified so much that it becomes possible to achieve the design strength 20-30 times faster than at the temperature of 20°C.
2. The relevance of research

In respect of this, the problem of investigation of thermal and moisture treatment modes for structures during the initial period of concrete hardening is of critical importance. The number of scientific papers touching this issue were published [17]. However, their analysis showed that many aspects require further consideration.

The researches of the chair of Design of Buildings and Structures of Nosov Magnitogorsk State Technical University implemented experimental investigation involving refinement of the warming mode with the use of electrical tubular heating elements for high-strength stressing self-compacting concrete.

The maximum heating up temperature of concrete mixture is usually set up according to the type and mineralogical composition of cement, the time required for achieving designed strength, intensity of mixture stiffening and some other factors and, as a rule, doesn’t exceed 80°C [17].

3. The essence of the study

Strength gain of concrete during the process of thermal treatment could achieve the maximum values in the first hours and fall dramatically subsequently. For this reason, it’s not worthwhile to carry out thermal treatment until the design strength is obtained. As a rule, thermal treatment is terminated when concrete acquires 70-80% of its threshold strength.

Thermal treatment mode of concrete has to result in obtaining the strength designed. In the present paper, the mode of thermal treatment which included temperature rise, isothermal warming up and cooling down was worked out (Figure 1). At such a mode of warming up, concrete acquires the strength designed cooled down. The present mode is usually applied at thermal treatment of structures with the surface module of 4÷10 [17].

The scheme of the system for warming up concrete is set out in Figure 2. Metal cast formwork in the shape of dismountable cylindrical outer shell with the height of 1000 mm and inner diameter of 100mm was installed in vertical position. Then a thin-walled stainless steel tube with the diameter of 12 mm was installed coaxially to the side walls of the cast formwork with the width of the wall 1 mm. A tubular heating electric element was inserted inside that tube.

Self-compacting concrete mixture was poured in the cast formwork assembled. Then via electric transformer and control board electric potential of 220 V was applied to a tubular heating element. In order to eliminate heat losses via outer surface, a metal sheath was covered by a heat-insulating jacket.

The warming up was started two hours later after having prepared concrete mixture. The control of temperature rise of warming up concrete was implemented with the use of six heat sensors; the location of heat sensors is set out in Figure 3.

Operation and control of standard conditions was carried out with the help of computer systems. The appropriate software product is designed for this purpose with the essence as follows. The special controller provided supply of electric circuit voltage to a heating element in accordance with the algorithm uploaded. Programming interface is designated for visual and digital display of readings of detecting devices as well as for mode setting of thermal heating element (Figure 4). The arrows in figure indicate the parameters that can be controlled in this program.

![Figure 1. Temperature rise, isothermal warming up and cooling down.](image-url)
Figure 2. System for provision of the required modes for warming up concrete.

Figure 3. Schematic arrangement of detecting devices, geometrical parameters of the outer sheath for warming up concrete with installed temperature detecting devices.
The maximum value of warming up temperature of concrete (50, 60°C) and its gradient is set by the researcher. At the initial stage, the gradient equal to 5-7°C is set as in freshly-mixed concrete there was a large amount of non-coherent water and concrete had high thermal conductivity. By the end of temperature rise (approx. in 2-2.5 hours) the maximum gradient equal to 12°C, have be set.

Concrete is heated with the gradient given of temperature rise during period of 2.5-3 hours. Throughout this time, temperature is rising up to 50 or 60°C (depending on the experiment). In the hours that followed, isothermal warming up is carried out.

Determination of optimal warming up time of concrete core is done in the range of 5 to 13 hours (the total time for 5, 8, 10, 12, and 13 hours).

Once the system is disconnected, the formwork around the specimen is stripped off and released from detecting devices, tubular heating elements and tube. With the help of stonecutting device, a concrete core is cut into cube concrete test specimen of cylindrical shape with the height of 100 mm (Figure 5).

Specimen testing for axial compression is implemented on the hydraulic press machine IP-2000 in compliance with All-Union State Standard 28570-90 (ST SEV 3978-83) ‘Concretes. Methods of Strength Evaluation on Cores Drilled from Structures’.

Figure 6 represents relationship between relative strength of concrete cylindrical specimen and time of warming up for the temperatures 50 and 60°C. The results of data approximation processed in MS Excel have allowed proposing the following equations:

- for the temperature 50°C
  \[ R_t / R_{28} = -0.0025 t^2 + 0.0701t; \]  

- for the temperature 60°C
  \[ R_t / R_{28} = -0.0044 t^2 + 0.114t, \]

where \( R_t \) is the concrete strength at hours \( t \); \( R_{28} \) is the concrete strength at 28 days.
Figure 5. Concrete core obtained after electric warming up and the concrete specimen designated for axial compression tests.

Figure 6. Relationship between relative strength of concrete specimen of cylindrical shape and the warming up time up to temperatures of 50°C and 60°C.

The obtained values of approximation quotient prove sufficiently high accuracy of these relationships. The results of experimental tests proved that for high-strength stressing self-compacting concrete, the values of its 74% relative strength at axial compression was reached at the temperature of isothermal holding at 60°C at the applied mode 3+7+3. Along with that, strength of concrete at 28 days corresponded to the grade B80. In order to reach 70% of concrete strength designed at the temperature of isothermal warming up of 60°C, thermal treatment for 11 hours was sufficient. The temperature of isothermal warming up of 50°C requires sufficiently longer time for obtaining the same concrete strength.
4. Conclusion
Application of thermal treatment to high strength self-compacting stressing concrete increased the rate of concrete strength development immensely. The most rational mode, providing 70% of strength designed, corresponds to three hours of temperature rise up to 60°C, five hours of isothermal warming up and three hours of consecutive cooling down.

References
[1] Radji F F, Bogen T, Sellevold E J and Loeland K E A Review of Experiences with Condensed Silica-Fume Concretes and Products Proc. CANMET/ACI Second International Conference Madrid, Spain, 1986 Vol 2 pp 1135-52
[2] Werner O R 1987 ACI Materials J 84 March-April 158-66
[3] Holland T C Working with silica fume in ready-mixed concrete - USA experience Proc. CANMET/ACI Third International Conference Trondheim, Norway, 1989 Vol 2 pp 763-81
[4] Kaprielov S 1995 The Common Factors of Structure Formation of Cement Stone and Concrete with Addition of Ultrafine Materials Concrete and Reinforced Concrete No 4 16-20
[5] Kaprielov S 2008 Application of High-Strength Concretes in Construction Capital Quality Construction No 4 30-35
[6] Kaprielov S, Sheinfeld A and Tarichev A 2013 Peculiarities of erection and holding construction of high-rise buildings made of high-strength concrete of grade b60-b100 during winter High Rise Buildings 13 No 3 104-9
[7] Kaprielov S, Sheynfeld A, Kardumian H and Dondukov V 2006 Characteristics of the structure and properties of high-strength concrete containing multicomponent modifiers including silica fume, fly ash and metakaolin Proc 16 IBAUSIL Weimar 20-23 Sept 2006 Vol 2 pp 77-84
[8] Kaprielov S, Travush V, Karpenko N, Sheinfeld A, Kardumayn G, Kiseleva Yu and Prigozhenko O 2008 Modified high-strength concretes of the grades B80 and B90 in cast-in-situ structures Building Materials No 3 9-13
[9] Kardumyan G 2008 Practical experience of application on new concrete in structures of high-rise buildings Construction Technologies No 7 54-57
[10] Kardumyan G 2009 Non-shrinkage low cement concrete of low permeability and exothermicity for crack resistant massive structures Proc 17 IBAUSIL Weimar 26-29 Sept 2009 Vol 2 pp 523-29
[11] Kaprielov S and Chilin A 2013 Ultra-high-strength self-compacting fiber-reinforced concrete for cast-in-situ structures Building Materials No 7 28-30
[12] Kardumyan G and Nesvetayev G 2012 Regarding designing composition of high-strength self-compacting concrete Concrete and Reinforced Concrete No 6 8-11
[13] Kaprielov S, Sheinfeld A and Kardumyan G 2013 Unique concretes and the experience of their application in modern construction Industrial and Civil Engineering No 1 42-44
[14] Krishan A, Gareev M and Sagadatov A 2004 Steel tube confined concrete columns with pre-hooped core Concrete and Reinforced Concrete No 6 9-13
[15] Krishan A L, Troskhina E A and Chernyshova E P 2016 Efficient design of concrete filled steel tube columns Procedia Engineering 150 1709-14
[16] Narkevich M Yu and Sagadatov A I 2017 Study of the work of centrally compressed steel-concrete elements with the core of high-strength concrete and thin-walled shell Bull. Civil Engineerin Technics No 11 14-15
[17] Guidance on Execution of Concrete Works in Winter Time in Regions of Far East, Siberia and High North 1982 Central Scientific Research Institute of Organization, Mechanization and Technical Assistance in Construction Gosstroy SSSR (Moscow: Stroyizdat) p 213