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# Forecasting the Compressive Strength of Thermal Treated Self-Compacting Concrete during Cast-in-Situ Construction

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**Abstract**

*Thermal treatment (TT) of concrete can significantly accelerate the strength growth during cast-in-situ construction. Forecasting the compressive strength of thermal treated self-compacting concrete (SCC) is one of the pillars of the technical safety of buildings. To this end we carried out a study of strength development issue of SCC during TT. For our study, we used SCC of grade C25. Test samples were cured with TT by infrared radiators for 7, 9, 11, 13, 16 and 24 hours. Then warmed samples were tested for compressive strength after 0.5, 4, 12 and 24 hours of cooling period. Study was carried out on the basis of analyzing, generalizing and evaluations of experimental data. A mathematical model for determining the compressive strength of SCC after one day of curing of SCC with TT is proposed, which allows to forecast the concrete behavior in a real cast-in-situ construction of SCC structures immediately after one day of curing with TT. This paper also presents a technology of TT of structures for cast-in-situ construction with SCC. The proposed technology can be used for mass cast-in-situ construction. Application of this technology allows to reduce the turnover of formwork, the labor costs for construction, and the construction period.*

**Keywords :** Self-Compacting Concrete, Thermal Treatment, Compressive Strength

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# I. Introduction

Self-compacting concrete (SCC) possesses enhanced qualities and improves productivity and working conditions due to the elimination of vibration and compaction. SCC is suitable for placing in structures with congested reinforcement without vibration and it helps in achieving higher quality of surface finishes.

Concrete that requires little vibration or compaction has been used in the defense industry of the USSR since the mid-1970s, with introduction of plasticizers, and subsequently superplasticizers in the concrete mixture. Introduction of these additives enables to liquefy the concrete mixture. Such compositions became known as the Molten Concrete Mixture. The emergence of new responsible projects, such as, the extended suspension bridges, large hydraulic complexes, runways for super-heavy aircrafts, increased the requirements for high-strength concrete. With the construction of such structures, the use of Molten Concrete Mixtures became the necessity for civil constructions. Then, in 1982, the first normative documents governing the use of Molten Concrete Mixture were published by the USSR government (Departmental Building Codes, 1982; Supplement to the Departmental Building Codes, 1982).

Later, in 1988, SCC was developed in Japan to achieve durable concrete structures (Hajime Okamura and Masahiro Ouchi, 2003). In Western Europe, SCC was first used in Sweden in construction works for transportation networks in the mid-1990s (Krishna Murthy N. et al. 2012). Since then, various studies have been carried out on SCC (Alexandrov Y.A., 2011; Benchaa Benabed et al., 2012; Khaleel O.R. et al., 2011; Kosmas K. Sideris et al., 2015; Krishna Murthy N. et al. 2012; Tomasz Ponikiewski and Jacek Gołaszewski, 2013). Almost all the researchers studied the physical and mechanical properties of SCC with different fillers. Bernardinus Herbudiman and Adhi Mulyawan Saptaji (2013) studied the effect of using the waste local building materials as the aggregates in SCC. The use of waste local building materials, in addition to other advantages of the use of such concrete, improve the environmental situation in the construction area.

Svintsov A.P. et al. (2012), Nikolenko Y.V. et al. (2014), Shesternin A.I. et al. (2015) and Kharun M. et al. (2017) describe the different applicable technologies for delivery and laying SCC which allow to get the optimization of expenditures for the construction by selecting the most optimal technology for cast-in-situ construction.

In recent years, some researchers are studying the effect of thermal treatment (TT) on the physical and mechanical properties of concrete. Girts Bumanis et al. (2015) studied the effect of TT on the ultra-high strength concrete. This study indicates that the early TT initiated high early strength. Sivathanu Pillai C. et al. (2016) studied the effect of TT on the neutron attenuation characteristics of concrete. The study was performed under 120 °C as in a sodium cooled reactor. The results indicate heavy moisture loss from concrete.

Some researchers studied different treatment methods, including the effect of TT, on the physical and mechanical properties of recycled aggregate concrete. Pandurangan K. et al. (2016) determined that TT is the most effective treatment method in improving the strength. Hanaa Khaleel Alwan Al-Bayati et al. (2016) established that TT has negative effects when done at very high temperatures, e.g. above 500 °C, however, TT at 350 °C followed by short mechanical treatment led to the best results. It is worth noting that the optimum temperature for TT of concrete is 80-95°C, otherwise can be the evaporation of moisture from the concrete mixture (Nikolenko Y.V. et al., 2014 and Svintsov A.P. et al., 2012). Zhonghe Shui et al. (2008) evaluated the rehydration of preheated concrete. During TT of concrete, it is important to take care against the evaporation of moisture from the concrete mixture.

Riad Derabla and Mohamed Larbi Benmalek (2014) studied the effect of TT on SCC. TT cycle was attained a maximum temperature of 60 °C. This study showed an overall gain in strength at early age. Many TT technologies of concrete structures were proposed by different researchers since the 1960s (Svintsov A.P. et al., 2012; Nikolenko Y.V. et al., 2014). However, all these technologies are related with high electrical energy cost, and the solutions for TT of structures with SCC is not proposed for cast-in-situ construction.

In the cast-in-situ slab construction, because of the rather slow strength growing of concrete, the formwork and the supporting stands have to keep for quite a long time up to 20 days depending on weather conditions. It complicates the production of other works and greatly increases the volume of complex of formwork, and hence leads to the higher construction cost and to a longer construction period.

The main aim of this paper is to present the result of our study of the issue of strength development of SCC during TT, and also to propose a technology of TT of structures for cast-in-situ construction with SCC which can significantly reduce the costs for construction.

## II. Materials and Methods of Research

For our study, we used SCC of grade C25. Total 78 test samples with dimensions of 100x100x100 mm were prepared in accordance with the plan of experiment.

72 samples, after 1.5 hours of setting, were covered with three-ply translucent screens, and TT was carried out by infrared radiators for 7, 9, 11, 13, 16 and 24 hours. Then warmed samples were tested for compressive strength after 0.5, 4, 12 and 24 hours of cooling period. Eighteen samples in each test, three from each series.

Another 6 samples were cured in air-humid condition in wet sawdust at the room temperature of 19-22 °C, which were tested after 28 days of curing.

Study was carried out on the basis of analyzing, generalizing and evaluations of experimental data. Mathematical processing of the experimental data was carried out on the basis of probability theory and mathematical statistics.

Patterns of changes in compressive strength were established using the regression analysis. The analyzed data was verified by the Spearman criterion of independence and Wilcoxon test of homogeneity in ensuring of $\alpha \approx 0.95$.

## III. Results and Discussion

The most important physical and mechanical characteristics of concrete is the compressive strength. During cast-in-situ construction, a considerable amount of time is spent on concreting of structures, and also on strength growing of concrete. For example, the minimum structural strength of the walls and columns can be assigned about 20% of the designed strength of concrete ($R_{28}$) at the time of concreting the overlying slab. When dismantling the forms from slab, all its supporting stands have to keep, if the strength of concrete is about 40% of the $R_{28}$. Upon reaching the concrete strength of 50% of the $R_{28}$, half of the supporting stands have to keep; at 60% of the $R_{28}$ – a fourth part of the supporting stands are keeping; at 70-80% of the $R_{28}$ – a fifth part of the supporting stands. To reduce the construction period, labor costs and turnover of formwork, it seems relevant to reduce the required setting time of SCC.

In framework of our study, we carried out an experimental determination of strength of SCC samples in axial compression. Fig. 1 shows the diagrams of changes in relative strength of SCC depending on the period of TT at different cooling period. We converted the unit of relative strength in the percentage to make it more understandable.

On the basis of experimental data, using the probability theory and mathematical statistics, a mathematical model for determining the compressive strength of SCC after one day of curing of SCC with TT was developed:

$$R_{SCC}^{1} = \frac{T_{th.tr.}(12.02 + 0.265 \cdot T_t)}{1 + 0.01 \cdot T_{th.tr.}(12.02 + 0.265 \cdot T_t)} \cdot R_{28}$$

where $R_{SCC}^{1}$– compressive strength of SCC after one day of TT, MPa; $R_{28}$– designed compressive strength of SCC, MPa; $T_{th.tr.}$ – period of TT, hrs.; $T_t$ – cooling time, elapsed after TT, hrs.

The proposed mathematical model allows to forecast the compressive strength of SCC after one day of TT with the accuracy of ±3-4% and the determination coefficient of $R^2 = 0.947$.

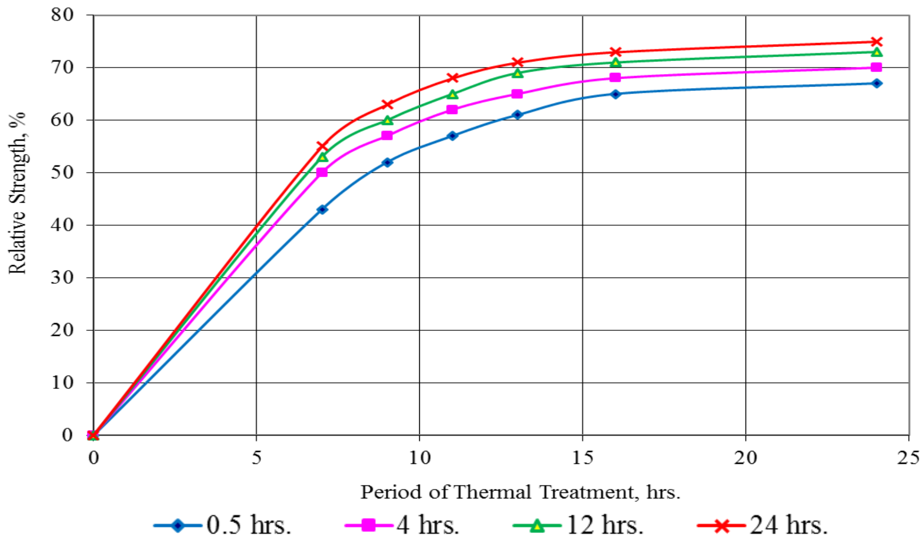


**Fig. 1:** Changes in the relative strength of SCC depending on the period of thermal treatment at 0.5, 4, 12 and 24 hours of cooling period

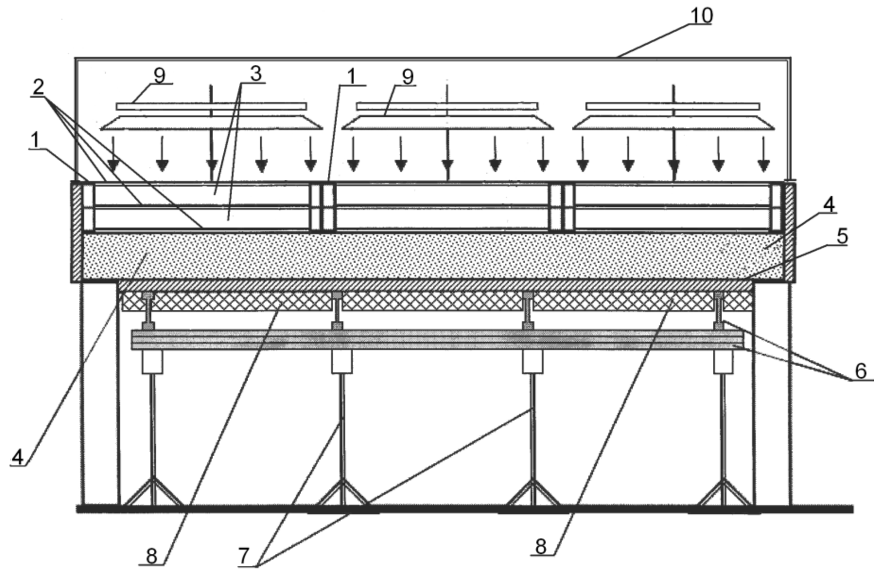


**Fig. 2:**Layout of TT of SCC of the horizontal structures by infrared ray for cast-in-situ construction

1 - clamps for fixing the translucent screens; 2 - transparent membranes translucent screens; 3 - airbags (clearances);

4 – concrete mix; 5 - deck panels; 6 - beams supporting the deck panels; 7 - telescopic racks; 8 - thermal insulation;
9 - infrared heaters; 10 - tent

**Technology of Thermal Treatment of SCC During Cast-in-Situ Construction**

One of the conditions for obtaining the high-quality cast-in-situ structures is the caring for fresh concrete mixture and subsequently for the concrete, i.e., the creation of favorable environment in the early stages of curing.

It is known that to ensure the rapid gaining of concrete strength in the factory, the thermal-humid treatment of concrete is carried out. The thermal-humid treatment mode, usually consist of the following operations:

- keeping the formed products in the formwork – 0.5 to 3 hours;
- placing these products into the thermal chamber, and rising the temperature up to a constant maximum duration – 3 to 3.5 hours (temperature rising rate is calculated);
- isothermal heating at maximum calculated temperature;
- reducing the temperature in the chamber within 2-3 hours.

The total duration of TT modes is 8 to 12 hours or more. The optimum temperature of warming is usually 80-95°C, wherein the strength of concrete after TT, depending on the overall cycle time, is 38 to 78% of the designed.In the cast-in-situ construction, concrete warming is carried out, in most cases, only at freezing ambient temperatures. In recent years, we carrying out some studies on TT of SCC in the laboratory, and had worked out a new way to warming the structures.

The following technology of warming the structures for cast-in-situ construction by SCC is proposed. After placing the SCC in the formwork, the open surface of structure should be covered by translucent screens. At the same time, the infrared gas burners are mounted on the structure in a such way that the rays, emitted by the burners, were directed at the concrete surface. The optimal distance between the surface of infrared appliance and the concrete surface is recommended 1.2 m (±15 cm). The optimum temperature for TT of SCC is 80-95°C. TT by the infrared radiators is possible both the open surface of concrete (e.g., slabs), and through the formwork of concrete structures (e.g., walls). For better absorption of infrared rays, the formwork panels should be metallic. Translucent screen transmits the infrared rays which at a meeting with concrete surface converted into thermal energy that absorbed by the concrete mixture. The translucent screens should be with three layers of membranes that forms two airbags. Such cover protects SCC mixture from the direct effect of external environment on the temperature of the laid mixture. Closed airbags serve as the heat insulators, restrain the outflow of heat from it into the atmosphere. Moreover, this cover prevents the evaporation of moisture from the concrete mix. The membranes, that allow to pass the infrared rays from the gas burners, partially perceive the thermal energy of infrared spectrum. During frosty weather, we recommend to insulate the opposite surface of formwork. Layout of TT of SCC of the horizontal structures by infrared ray for cast-in-situ construction during frosty weather is shown in fig. 2.

After the gaining of critical strength by SCC (not less than 50-60% of $R_{28}$), TT of concrete can be stopped. Our experiment showed that the strength of SCC after an eight-hours TT is 50-60% of the $R_{28}$. However, we recommend to keep the translucent screens for one or two days depending on the ambient temperature. After the removal of translucent screens, the structure is gaining strength close to the designed (80-100% of $R_{28}$). Therefore, the removal of formwork from the structure is possible just after one day of concreting, which significantly reduces the formwork turnover cycle and the volume of formwork sets, and also leads to reduce the construction period. We recommend to warm the structures with SCC by this technology, where the thickness of structure is up to 60 cm.

## IV. Conclusions

The proposed mathematical model allows to forecast the concrete behavior in a real cast-in-situ construction of SCC structures immediately after one day of curing with TT.

The proposed technology of warming the structures for cast-in-situ construction by SCC can be used for mass cast-in-situ construction. Application of this technology allows to reduce the turnover of formwork, the labor costs for construction, and the construction period.

## V. Acknowledgement

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