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Technology for Preparing and Thermal Treatment of High Strength Concretes

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Abstract: High strength concretes, without which initially stressed members and high-rise buildings are inconceivable today, can be obtained with great technology and economic efforts. From among and technical parameters contributing in meeting this desideration, the main ones refer to the quality and dosage of cement types and nature of aggregate surface, as well as the concrete preparing placing and subsequent curing. As in numerous situations the high strength concretes are used in creating precast members. In order to accelerate the hardening of this material, in most countries, worldwide, thermal procedures are being used. Besides the beneficial effect of intensifying the chemical reactions in the water-cement system "with immediate consequences for the hardening kinetics", temperature rise brings about major, destructive modifications in the hardened concrete structure. As a consequence, thermally treat concretes exhibit, in all cases, at 28 days' age and beyond it, strength and durability coefficients that are sensibly lower than in the concretes hardened under normal conditions. At the some time, even at normal temperatures the cement binding energy is insufficiently used and the affect is the more remarkable when the binder batching is higher. The authors propose a technology of high strength concrete preparing and thermal treating, which allows for the optimal use of the cement quantity introduced in the mixture, concomitantly with severely limiting the destructive effects on concrete structures, at high temperatures.

Key words: Concrete, thermal treatment, preheated components

INTRODUCTION

It is established the fact that because of some destructive effects which are imposed in the cement-water-aggregates system, the quantity of binder introduced in the mix not rationally used. The main cause which act in this sense is determined by the "screening" effect of the cement grains by the first hydration products which cover its. Its density increase with the temperature and, so, the isolation effect is such greater. The partial solving of this impediment is obtained by removing those pellicles and re-distribution in the liquid containing mass.

As we know, high strength concretes are necessary mainly in making initially stressed members as well as in high-rise buildings.

The efficiency of prestressing depends on the quality of the active reinforcing used, as well as on the strength of the associating concrete. In the high and very high buildings the use of reinforced concrete structures is justified only when the primary material-concrete has a higher compressive strength. Therefore, the researchers' and manufactures' concern for concretes with higher mechanical characteristics is wholly justified.

The high strength concretes are obtained with substantial technologic and financial efforts. Beside larger quantities of high quality cement, strong aggregates which can adhere to the cement store, as low as possible water-cement ratios and special technologies of placing and subsequent treatment are compulsory.

There are, however, numerous parameters which intervene, to a lower or greater extent, in meeting this purpose irrespective of the binder quantity introduced in the mixture, the hardening of concrete is a slow process if we relate it to its compressive strength obtained after 28 days' hardening in normal ambient conditions. This is a disadvantage both for the in-situ and the prefabricated elements.

As temperature rise is an activating factor of cement and water reactions, with favorable effects on the evolution of strengths in the initial hardening (Giuşcã and Corobceanu, 2005; Corobceanu *et al.*, 2005; Anonymous, 1999), the prefabs industry uses thermal treatment in order to shorten the manufacturing cycle.

Concrete temperature rise, under atmospheric pressure conditions, besides favorably accelerating this material hardening, brings about other disadvantages connected mainly with the decrease of compared to the

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same concrete mixture which benefited of normal ambient conditions.

Experimental studies as well as results form prefabricating practice show that strength losses at 28 days' age or at longer terms can range between 18 and 35% as compared to the strength of the witness members, hardened under normal conditions.

Furthermore, the durability characteristics of the thermally treated concretes are definitely lower than those of the concrete hardened under normal or sub-normal regime.

Another aspect which easts doubts on the acceleration of concrete hardening, besides the large energy consumption with immediate effect on costs, is the unreasonable use of binders. Even at conventionally normal temperatures, a part of the cement quantity remains inert, without combining with water and as this parameter increases, the percentage becomes a source of concern. Under such conditions, the use of excessive cement batches does not justify at all.

In what follows we will plead for the use of some technologies which favor the optimal use of the quantity of cement introduced in the concrete mixture, associated with moderate thermal treatment which should limit the destructive effects that temperature rise brings about in the complex physico-chemical process of concrete hardening.

THERMAL EFFECT IN CONCRETE HARDENING

The rise of temperature in excess to the normally accepted one (20±5°C), under atmospheric pressure conditions, results in the intensifying of water and cement reactions, without sensibly modifying the chemical structure of the hydrating products.

Thus, it was estimated that at 80°C, the water-cement system amplifies its reactions six times in comparison with reaction rate at 20°C and near 100°C these increase ten times as much (Giuşcã and Corobceanu, 2005).

The concrete hardening rate does not increase to the same extent and this is due not to the modification of the chemical structure of the modification of the chemical structure of the hydration products, but to the physical transformations which occur in the concrete mass when temperature rises. These are destructive transformations and can be classified in 4 categories:

1. Differentiated dilating of concrete components of which water, the entrapped air and gases have the highest dilation coefficient and which cause the occurrence of a stress state while the concrete mixture loses its free displacement characteristics.

As the material is in its incipient structural development stages, it does not have' sufficiently strong bonds in order to take over the tensions which appear. As a consequence, a grid of micro cracks will develop in the concrete mass and they will merge, at a certain development stage, into macroscopic cracks.

Under such conditions, the mechanical and durability characteristics of concrete will be ostensibly affected the prefabricated members being sometimes rejected.

The slow increase of concrete temperature and the introduction of a waiting period in the thermal cycle at normal and subnormal temperature can diminish this effect.

2. Premature dehydration is another source of structural defects in concrete, which originates in the first part of the isothermal treatment period and goes on in prefabs cooling one. During the waiting period the concrete mixture has practically the same temperature as that of the environment. As source temperature rises and in the initial stage of the isothermal period, because of the thermal inertia of the material, it has a lower temperature than the environment and the interior pressure of vapors is lower than that of the curing premises.

As a consequence, concrete absorbs the moisture form the environment which results in meliorated hydrating conditions.

Soon, a temperature balance is being reached, which is quickly upturned by the cement exothermic reaction which manes the concrete temperature exceed that of the environment (Fig. 1). The interior pressure of the vapors increases as compared with that of the thermal treatment premises, which leads to an intense migration of moisture within concrete mass.

Initially, the condensed water evaporates from the free surface of the members, after which it moves form inside to the outside. For this reason thermally treated concretes are characterized by an oriented porosity that, associated with above mentioned destructive effect trebles the quantity and dimensions of structural defects as compared the occurring in the normal hardening.

The loss of an important amount of free water (Fig. 2), which is commonly 20…40 %, is unfavorably reflected in the subsequent hydration of cement grains in the normal temperature hardening.

The essential parameter which influences the extension of the phenomenon is the magnitude of the isothermal treatment temperature, associated, however, with the mineralogical nature of cement and the temperature decrease rate during cooling time.

3. Cement grain screening due to hydrating products determines the removal form the chemical process of an important amount of cement, which thus, remains inert.

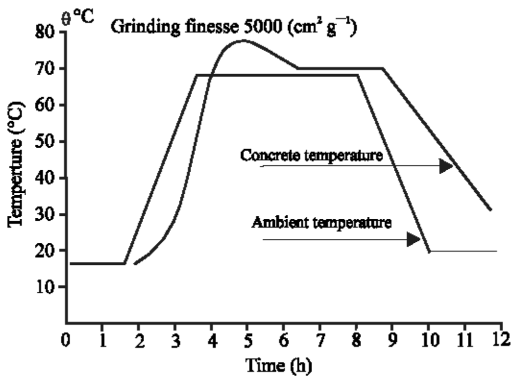

Fig. 1: Variation of concrete temperature depending on the ambient one

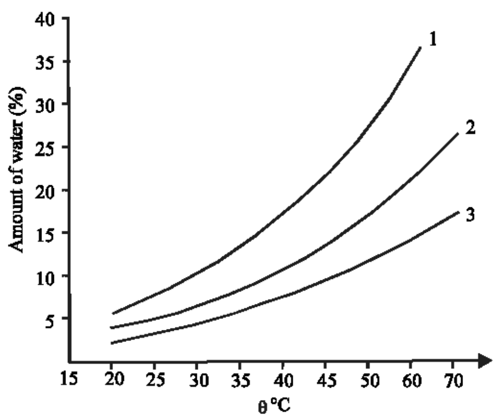

Fig. 2: Water loss in percentage out of total amount during the first 36 h

Microscope investigations (Giuşcã and Corobceanu, 2005; Corobceanu *et al*., 2005) have shown that the new hydrates formations increase proportionally to temperature and thermal treatment time, which leads to the modification of the gel properties as compared to normal hardening.

Thus, the density of hydrating products, created at high temperatures is at least 15…20% higher than in the case of the same products created at 20°C.

Consequently, thermally treated concretes gain an important strength during their initial hardening, but as the dense gel pellicles prevent water form moving towards the nonhydrated nuclei of the cement grains, in the subsequent hardening the strengths will increase only very slowly.

The large cement batches which characterize high strength concrete amplify the phenomenon due to the tendency of cement grains to agglomerate and thus, the amount of binder which is removed form the hydration process is larger.

4. Non-uniform spreading of temperature with concrete mass from exterior towards interior produces thermal resistances, which lead to sensible temperature differences between the various layers of the members.

At their deformation is partially confined, a new state of stress occurs, which, alongside that caused by the differential dilating of concrete components, will increase the micro-ani macro-cracks system with well-known consequences.

PREHEATING OF CONCRETE COMPONENTS

Using preheated components (CEB/FIB, 1993; Anonymous, 1989) in concrete preparation may be a solution as it eliminates some structural defects, which occur when the material is thermally treated. The differential dilating of the concrete mixture components appears while it is still in free displacement and this eliminates the destructive tensions occurring when temperature rises during the first stage of the isothermal period. At the same time, the spreading of temperature within the concrete mass is more uniform and the cement exothermal reactions preserve this quality, diminishing the unfavorable effect of thermal resistances.

At the same time, in industrial conditions the thermal cycle duration is 15…20 % lower as it practically comprises two stages: isothermal treatment and prefabs cooling. Productivity increases while costs decrease, if compared to classic technologies.

Analyzing comparatively the variation of compressive strength at different times (Table 1 and Fig. 3) in the commonly treated concretes and those hardened in normal conditions, one can see that the strength losses are lower.

One should not forget that the concrete hardened with thermal accelerations requires a supplementary amount of cement, its role being to compensate, at least partially, for the reductions which occur.

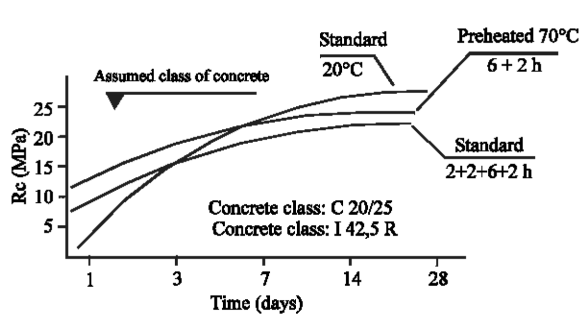

Fig. 3: Variation of compressive strength depending on temperature spreading

Table 1: Influence of concrete component preheated on compressive strength at different times (C 20/25)

	Average compressive strength on cube specimens R (MPa)				Standard R_{28} (%)	
Concrete heating procedure	24 h*	3 days	7 days	28 days	7 days	28 days
Standard 20°C	3.3	7.6	13.3	27.0	49.3	100
Thermal treatment 2+2+6+6 h	7.8	11.9	16.0	21.1	59.3	78.1
Preheated 6+2 h	12.3	14.8	18.5	23.6	68.5	87.4

* 24 h time refers only to the concretes hardened under normal temperature conditions. For the thermally treated ones, the tests were made at the end of the cycle

If large cement batches are used to obtain high strength concrete, the tendency of cement grains to agglomerate is higher than in the case of average batches and the proposed procedure does not reduce the screening effect of cement nuclei; on the contrary, it heightens it.

The advantage of preheating, besides the above-mentioned aspects, consists in shortening the thermal cycle and the choice of a 70°C temperature enables an optimal use of water characteristics, among which viscosity and specific heat are extremely important.

It is true that the strength coefficients obtained by applying this technology are, for all analyzed times, higher those obtained by applying a common thermal treatment, but the amount of binder introduced remains unused at least with the some percentage.

CEMENT HYDRATION INTENSIFYING

Knowing the elements which concur to the structural make-up of the cement stone hardened at high temperatures, we had in view the requirements of a more uniform and penetrating hydration of the cement grains, of their separation and homogenous dispersion in the mixture, an imposed water-grain contact and a reduced screening effect.

In this respect we made concrete experimentally (CEB/FIB, 1993; Anonymous, 1989; Corobceanu, 1985) by mixing the aggregate with cement slurry, which, in turn, was made by forcibly mixing it in a revolving mixer with at least 18000 revolutions per minute. The forced mixing was done both at normal temperature and at 65…70°C; the preliminary results are presented in Table 2.

After mixing the aggregate with the cement slurry in order to ensure a better hydrating of the cement grains, the concrete was 1 h, after which it was heated in one hour, after which it was heated in the hopper (electrically or with steam) where form it was placed into heated forms. In case of premixing at high temperatures, the concrete will be poured directly into hot moulds, after which it will be compacted by vibration, while it is warm.

It is desirable to use high frequency vibrations because, when heating the fresh concrete, the negative effect of the first tricalcic hydro-aluminate compounds on the compacting degree is felt to a lesser extent, as these loosen up.

It is worth mentioned that the water loss during heating, placing and vibration on cubic meter of concrete amounts to approximately 38…50 L, which should be taken into account when the concrete recipe is designed.

TECHNOLOGY FOR PREPARING AND THERMAL TREATMENT OF HIGH STRENGTH CONCRETES

The research represent the resuming (at a higher level) of some concerning of the Reinforced Concrete Department collective from the Civil Engineering Faculty Iasi which was solved in the proper laboratories. The first researches was started in 1985 and restarted in 2004-2005 by the solicitation of precast elements producers from our country. In the last researchers program was associated the principle of the initial hydration of a cement quantity introduced in the mix with the cement paste preparation by forced mixed-up with increased revolution. It is combine so the profound penetration effect of the water to the cement grain nucleus with the removing effect of the pellicles's hydration products.

High strength concretes have specific characteristics as compared to the average class concretes. The high cement batching, as well as the low water-cement ratio imposes that the intensification of cement hydration be done somewhat differently.

After selecting the desired concrete recipe, the total amount of cement to be used in mixture is divided as follows: 65% of the envisaged batching, together with 85…90% of mixing water are introduced in the mixer, so that the cement slurry attains on ever lows viscosity.

Depending on the type of cement we use (with fast or normal setting), the cement slurry is kept in the vessel for 60…90 min while a forced mixing is ensured in three rounds of 90 sec each. This operation is done at normal temperature and its role is to detach the first pellicles of hydrating products form the grain surface and direct them to the face liquid are.

Thus, the hydration goes deep down and the binder is optimally used with direct effects on the initial and final strengths of the material.

Table 2: Influence of concrete preparation procedure on its compressive strength up to 28 days' ages (C 20/25)

	Average compressive strength on cube specimens R in Mpa				Standard R_{28} (%)	
Concrete heating procedure	24 h*	3 days	7 days	28 days	7 days	28 days
Standard 20°C	3.3	7.6	13.3	27.0	49.3	100
Forced mixing at 20°C and thermal treatment for 0.5 + 6 + 2 h	14.8	16.9	19.3	26.1	54.8	96.6
Forced mixing at 20°C and thermal treatment for 6 + 2 h	17.1	18.9	20.7	25.1	63.3	92.6

*24 h time refers only to the concretes hardened under normal temperature conditions. For the thermally treated ones, the tests were made at the end of the cycle

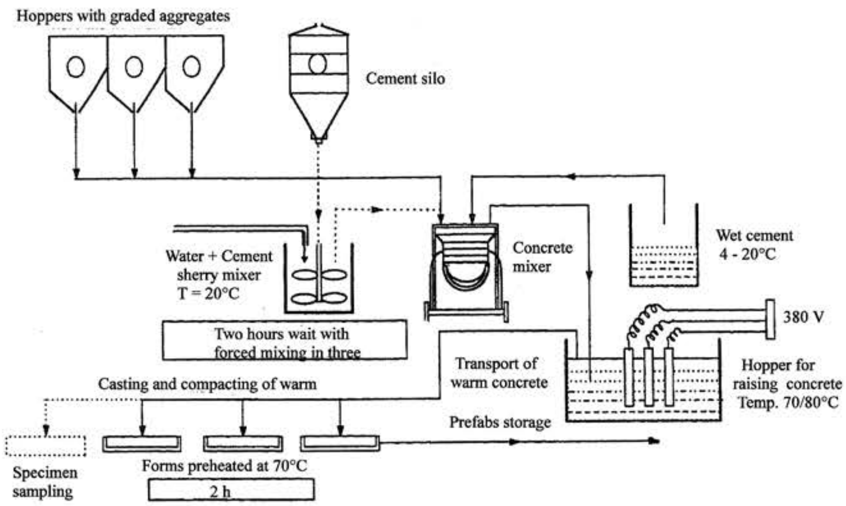

Fig. 4: Technologic scheme of concrete preparing and thermal treating

The remaining cement is wetted with the left mixing water and is stored into a vessel next to the mixer. This undergoes a pre-hydration that is so much slower and penetrating as the temperature is lower. Keeping this mixture at temperatures around + 4°C for 2…3 h has favorable effects on the subsequent hardening at high temperatures.

After having completed the two above-mentioned operations, which occur before the manufacturing cycle, the cement slurry and the wet cement are introduced into the concrete mixer over the weighted aggregated and are mixed.

The resulting concrete is heated very fast in a separate hopper, it is transported and cast into preheated moulds, at 70°C, after which it is compacted, while being warm.

The technological scheme of preparing and thermal treatment by this method is shown in Fig. 4. This procedure, due to such variables as transport, handling and placing of the concrete with such an active cement showed be used in prefabricating plants, where the above mentioned operations occur in a minimal time, with no negative consequences on the concrete compactness and structure.

It is recommended that, when using quick setting cements, the three operations should be performed while the concrete is kept at low temperatures.

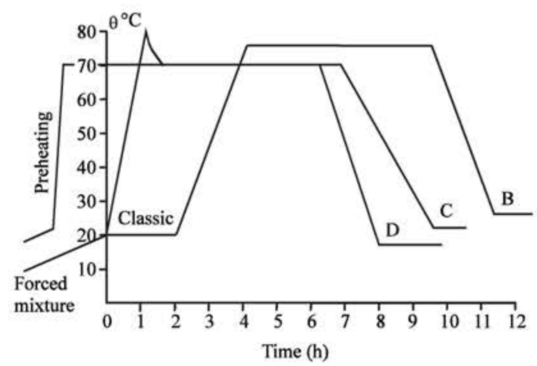

Fig. 5: Variants of experimental thermal cycles (idealized diagrams)

The technology becomes somewhat simpler as heating in the hopper and the two transport operations disappear-in this case the heating will take place can be as high as the thermal plant can allow for.

Further on, the thermal cycle, compared to the common one, develops according to the data presented in Fig. 5.

RESULTS

The concrete composition corresponded to that or C40/50, identical in all investigated technologies, without increasing the cement amounts in the concretes to be

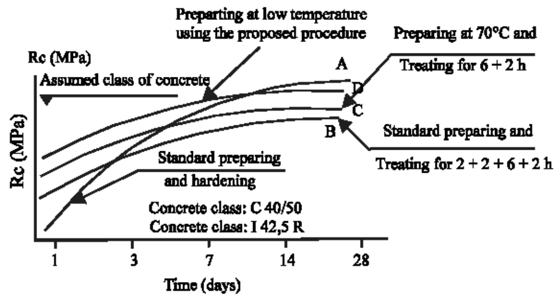

Fig. 6: Evolution of high quality concrete compressive strength depending on preparation and thermal treatment technology

thermally treated. A high quality Romanian I 42,5 R cement was used. The efficiency of the procedure was checked both in laboratory and on the production line.
The results obtained with the following series of specimens and members are:

- Concrete prepared and hardened under standard conditions;
- Concrete prepared under standard conditions and treated thermally at 70°C, after a cycle of 2 + 2 + 6 + 2 h;
- Concrete prepared with preheated components at 70°C and subjected to isothermal treatment for 6 h with 2 h cooling;
- Concrete prepared at low temperature using the proposed method and thermally treated after a cycle of 0.5 + 4 + 2 h.

The evolution of compressive strength was watched up to the age of 90 days; as the graphs presented in Fig. 6, significant results are shown up to 28 days, after which the evolution of the treated concrete is extremely low.

In industrial units the prehydration by forcibly mixing the cement slurry at 70°C can be applied in the cements with a slower hardening than it was the case with I 42,5 R.

The proposed procedure revealed the possibility of the cement dosage reduction which characterise the high-strength concretes and, also, the possibility of the isothermal treatment's temperature reduction and/or its duration reduction, including all the favourable effects which resides from this aspect. The obtained results are significant from the economically and structural points of view. The proposed technology could be extended also in case of the medium-class concretes, which represent the main percent in the structural elements production made from the reinforced concrete precast elements or even monoliths.

CONCLUSIONS

High strength concretes, so necessary for the manufacturing of initially stressed members and structures and of high rise buildings can be obtained by using large amounts of high quality cements and special placing and subsequent treatment technologies.

Especially with the prefabricated members, the acceleration of concrete hardening by thermal treatment is compulsory if the reduction of production cycle and the profitability of the manufacturing plants are aimed at.

Besides the clear advantage of reducing the hardening time and for obtaining, in short time, of the strengths necessary for formwork removal, transport, transfer of prestressing force, etc., thermal treatments produce major destructive modifications in the concrete structure.

From among these, the most important ones are due to the differential dilating of concrete components and member layers, to the screening effect of cement grains and the premature loss of a sufficiently large amount of free water.

In order to compensate for the strength losses thus produced, the present day technologies recommend an increase of cement consumption and a waiting period for the concrete in moulds at normal temperature. Both measures have a negative economic effect and the technical gains are nor spectacular.

The reduction of structural faults and hydrating intensifying can be achieved by preparing the concrete with components preheated at the temperature with the material is to be isothermally treated. A considerable reduction of the thermal cycle as well as a relative improvement of the concrete quality have been obtained.

Preheating does not meet the requirements of optimally using the potential chemical energy of cement, therefore the amount of binder introduced in the mixture remains, to a large extent, unused.

The previous preparation of cement slurry by waiting and forced mixing in high revolution mixers, especially so with the finely ground cements leads to their use, almost integrally

Combining both proposed methods can bring about important increases of initial and final strengths, with minimal losses at 28 days, as compared to the strength coefficient obtained after hardening under normal conditions. An increase in the cement batching is not necessary. As far as the thermal cycle is concerned, this is sensibly reduced, as both operations over apart form the thermal cycle.

This complex method should be used with relatively low amounts of concrete or, in the case of cements with moderate hardening rate, the preparation, transport and placing should be done in minimal time, as the premature stiffening of concrete can affect the quality of concrete members.

With high quality, finely ground cements, the forced mixing of cement slurry showed take place at normal temperature and after its placing, the temperature can quickly rise, to be followed by an isotherm treatment and cooling.

The technical and economic advantages of the proposed technology are self-evident:

- Drastic reduction of structural defects
- High initial and final strengths
- Savings in cement consumptions
- Reduction of manufacturing cycles

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