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# Technology of Concrete with Low Generation of Hydration Heat

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**Abstract**

Modern technology of concrete includes a comprehensive elaboration of proposal related to concrete composition depending on the required parameters of fresh and hardened concrete. One of the fields related to the technologies of concrete is the issue of the generation of hydration heat. Heat generation in the process of hydration is observed mainly in concretes. Here, we emphasize the need of avoiding potential cracking due to thermal expansion, which is mainly the case of putting concrete in massive units and also other cases in which critical stress and damaging to the concrete may occur due to the influence of high temperature gradients.

Hydration of concrete is a very difficult and complex process that depends on a number of direct and indirect factors. Speed indicators of hydration reactions are represented by the intensity of the hydration heat generation. The paper deals with the general methodology for the proposal of prescriptions for concrete mass intended for structures with high demands on low level of hydration heat generation. There are various intermediate steps presented, those leading to a successful proposal of concrete composition, including verification of the proposed measures and creation of a 3D model of calculation.


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*Keywords:* Concrete; hydration of concrete; hydration heat;

## 1. Introduction

During the maturing of the concrete and the hardening of the binder, important changes occur in the structure which in the first phases are indicated concrete or cement hydration. These are exothermic reactions from the binder

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with water which is accompanied by the development of heat. Calorimetric measurements are successfully used to monitor the development of hydration heat during hydration [1-6] and to complete the description of the running reactions, then further advanced methods [7] can be used. The speed index of the course of hydration reactions is the intensity of the development of hydration heat. In practice, the hydrating reactions are influenced by a series of internal and external factors that principally influence the kinetics of the hydration reactions. The most important of these are:

- type, quantity, chemical-mineralogical composition and fineness of the cement milling,
- water coefficient
- adding chemical ingredients and additives
- type and specific surface of the aggregate used,
- temperature, pressure,
- method of pouring the concrete into the construction; method of testing the concrete [8,9].

The speed of running hydration reactions depending on the temperature is described by the Arrhenius law:

$$k = A\, e^{-\frac{Ea}{R\,T}} \tag{1}$$

where Ea is the activation energy, R is the universal gas constant, T is the temperature and A – proportional constant.

The hydration of the concrete is the exothermic reaction of the binder with water. Due to speeding up the hydration reactions, there is an acceleration of the release of the hydrating heat and the increase of the temperature of the hydrating concrete. The increase of the speed of hydration is negatively reflected on the creation of the crystallized structure of the hydration products which causes a decrease in the strength of the hardened concrete. Due to the influence of the temperature of the concrete, stress occurs in the structure of the concrete (thermal dilatation), and water steam is released which leads to the origination of hydrating cracks that decrease the mechanical properties, the durability and other important utility values in the hardened concrete [10, 11].

## 2. Methodology

This paper describes the methodology used to design the concrete with low development of the hydrating heat which was gradually developed at VUT in Brno and successfully applied in practice several times. This concerns the methodology for the proposal for the recipe of the concrete for constructions with high demands for low development of hydrating heat. The methodology uses three levels of laboratory tests and measurement of the consequent numeric simulation and verification of the measured and calculated values directly within the implementation of the concrete element or part of. Individual steps for the complete process of the proposal are shown in Fig. 1.

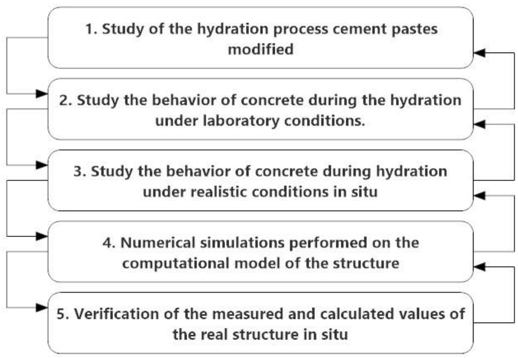


Fig. 1. Partial steps in the design of concrete with low hydration heat

### *2.1. Definition of primary requirements and boundary conditions*

In the first phase, there is the definition of the requirements for fresh and hardened concrete properties:

- definition of the requested processibility in fresh status
- definition of the requested strength class in hardened status
- definition of the requested level of environmental aggression
- In addition, it is necessary to define the geometry of the concrete construction and boundary conditions.
- definition of the geometry of the construction, including attached construction and surrounding environment,
- definition of material properties,
- definition of climatic conditions during concreting and hydration of the binder,
- definition of the treatment method,
- definition of concreting.

The final step is to propose the basic recipe for the concrete and to select suitable chemical ingredients and additives (fine parts).

According to the mentioned procedure for individual steps (Fig. 1.) simpler systems are studied by which cement pastes are modified, on which it is possible to observe changes in the cement matrix influenced by the composition, i.e. cement, ingredients, additive and the volume of mixing water. The measured results are evaluated and the intensity of the development of hydration heat is calculated. The proposed composition from the viewpoint of minimising the development of hydrating heat is focused on the binding element and the regulation of the course of the intensity of the development of hydrating heat by the cement used (low C3S and C3A content), use of latent hydraulic, Pozzolana or internal ingredients. To regulate the development of hydrating heat, then chemical ingredients into the concrete can be successfully used.

Based on results achieved from measuring modified cement pastes, the selection of suitable recipes can start (or the proposal for new recipes if the requested properties of recipes already proposed are not achieved).

This is followed by the further phase, i.e. testing the properties of fresh and hardened concrete. For selected concrete recipes, it is necessary to verify the further requested properties which, as a rule, is the determination of the rheological properties of selected concrete recipes under laboratory conditions in a fresh status, laboratory determination of mechanical (or other requested) properties of the selected concrete recipes in a hardened status. Based on monitoring the temperature changes and the intensity of the hydrating reactions of the cement pastes, there was the proposal for the composition of concrete recipes and after selection of possible suitable combinations, laboratory tests were conducted on the concrete when the concrete is placed in the thermo-insulating box under a constant ambient temperature and the course of hydrating temperatures is monitored and analyzed. This is similar as in the case of modified cement pastes which are monitored using the system of isoperibolic calorimeters, as the primate tests during selection of suitable raw materials. With utilization of the measurements taken, the secondary selection of recipes is conducted which fulfils the requested conditions for properties of the concrete in fresh and hardened statuses (per the proposal for new recipes if the requested properties for the proposed recipes are not achieved). In these phases there is optimising of the composition of the concrete with the emphasis on minimising the development of the hydration heat.

During the proposal and selection of raw materials with respect to minimising the development of hydrating heat, it is suitable to increase the heat (and thermal) conductance of fresh concrete and to increase the heat capacity of the hydrating concrete. This result is to increase the water coefficient, use components with a higher thermal conductance, increase the level of reinforcement, increase the density of fresh concrete (e.g. use of aggregate with higher density, such as basalt, etc.). The diagram (Fig. 2) demonstrates influence of water cement ratio on hydration of cement pastes (CEM I 42,5R).

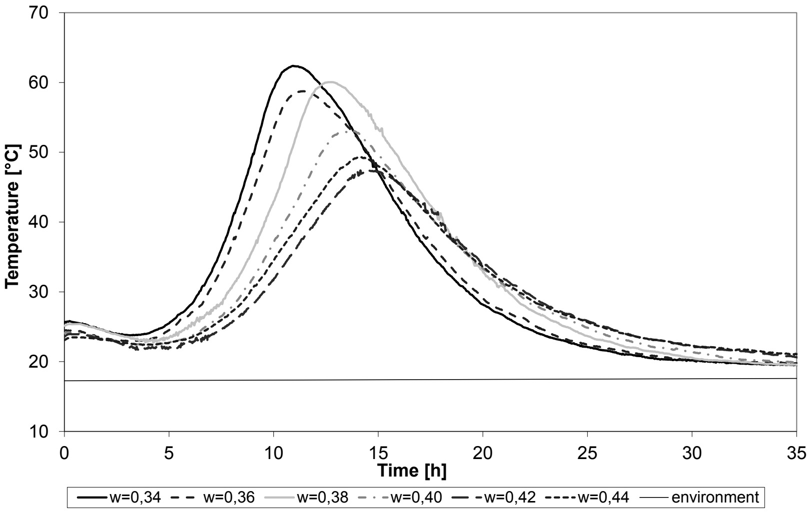


Fig. 2. Influence of water cement ratio on hydration of cement pastes from cement CEM I 42,5 R

### *2.2. Computing model*

The successful processing of the suitable composition of the concrete is followed by the proposal for the procedure of concreting and treating the concrete and the production of a real construction design model in simulation programmes (e.g. Ansys), including the proposal for loading the model with boundary conditions. With utilization of the defined boundary conditions, the course of temperatures in conditions during hydrating is calculated including the production of graphs showing the dependence of temperatures on the time in critical points in the construction. These design courses are evaluated and the recipe for the composition of the concrete is corrected. In addition, there is the evaluation of new laboratory tests and the application of results on the design model, recalculation of temperature courses in the construction and any modification of the proposal for the concreting and concrete treatment procedure. Finally, there is the evaluation of results (in the case of unsatisfactory results, the mentioned points are repeated).

In the case of carrying out actual concrete construction on the basis of the design of the concrete with low hydrating heat, then thermal sensors for monitoring and recording actual temperatures during the concreting and hydrating of the binder can be inserted into the critical nodes of the construction. Due to the actual records, it is possible to compare the measured values on an actual construction and the calculated temperatures on the simulating model and draw general conclusions.

### *2.3. Practical example*

A practical example was the evaluation of the design of the concrete with low development of hydrating heat for concreting a foundation slab with dimensions 15 x 15 m and a thickness of 1.9 m. Two concrete recipes were stated which differed by the plasticizer ingredient and partially by the ingredients used. The cement was requested to be constant. As it concerned a very thick foundation slab and a large volume of concrete, it was not necessary to consider the movement in time when pouring the concrete; two geometries of the construction were selected:

- concreting in layers with the thickness 1.17 m (model No. 1),
- concreting in layers with the thickness 0.88 m (model No. 2).

Depending on these two considered procedures, the design calculation selected distances of individual control nodes for modelling the behaviour of the construction in terms of the development of hydrating heat and the allocation of a thermal field in the construction during the hydrating of the binder when taking the boundary conditions into consideration:

- temperature of the placement of the concrete +26 °C to 32 °C,
- temperature of the air +28 °C to +32 °C,
- temperature of the foundation concrete: +21 °C to +26 °C.

The courses of the temperatures at critical points were achieved from modelling on the basis of the mentioned conditions (height profile in the centre of the construction) for the two analyzed concrete recipes. In the diagram, (Fig. 4) for illustration, outputs from the modelled course of hydrating temperatures in time in critical points for the first evaluated variation of the concrete with different heights of the concreting are displayed. The maximum values of the mentioned temperatures were monitored in the centre of the massive element.

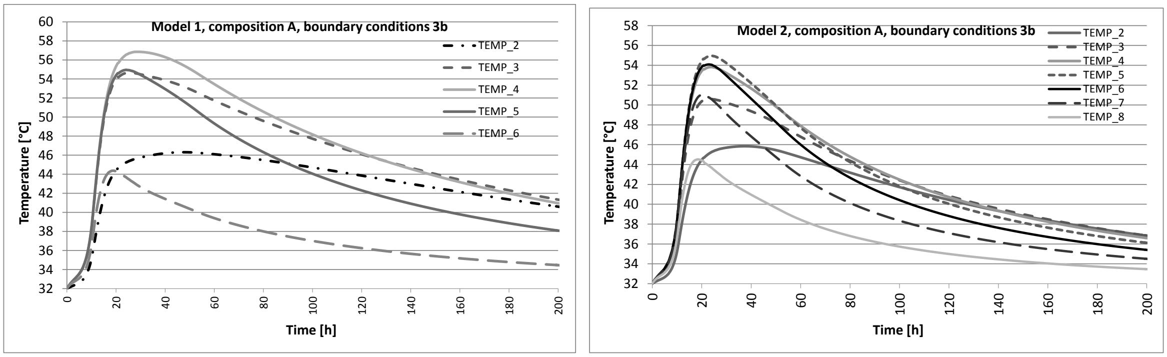


Fig. 3. Example of the output of the design model processed by the ANSYS program, the first variation of the composition of the concrete – recipe A, boundary conditions 3b (extreme temperatures)

Control measurements stated on the construction and verified in the model were taken in accordance with the requirements for maximum temperatures during hydrating and on the concreted element there were no imperfections or origination of cracks due to different thermal gradients and thermal stressing of the concrete. Conclusions stated for the 3D model are as follows:

- model 1, recipe A, boundary conditions 3b (extreme temperatures):
  - maximum temperature: +57.2 °C,
  - time of achieving maximum temperature 29.1 hours from starting the concreting,
- model 2, recipe A, boundary conditions 3b (extreme temperatures):
  - maximum temperature: +55.1 °C,
  - time of achieving maximum temperature 24.0 hours from starting the concreting,
- model 1, recipe B, boundary conditions 3b (extreme temperatures):
  - maximum temperature: +56.7 °C,
  - time of achieving maximum temperature 29.4 hours from starting the concreting,
- model 2, recipe B, boundary conditions 3b (extreme temperatures):
  - maximum temperature: +54.6 °C,
  - time of achieving maximum temperature 24.0 hours from starting the concreting.

## 3. Conclusion

Based on the above-mentioned methodological procedure, starting with tests on simpler systems, which are cement pastes through concrete up to the development of a 3D model using the finite element method, it is possible to create a complex concrete design with low development of hydration heat.

In addition to the proposal for the composition, then using the mentioned procedure, it is possible to optimise the proposal for concreting and concrete treatment procedure with respect to the anticipated boundary conditions (which can be selected during the calculations in a variable manner).

With utilization of the calculations, it is possible to calculate internal stresses in the structure of the concreted unit, to evaluate any risk of the origination of cracks in the concrete structure and where necessary, to optimise the reinforcement of the construction.

The output of the 3D model is also a graphic display of the allocation of the temperatures of the analyzed element, and the animation of the procedure and the change of temperature when filling with concrete in time, where it is visible how the thermal field is changed during hydrating.

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