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Determination of temperature course in concrete during hydration

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Summary

Durability of the concrete responds very close with the microstructure - cement stone microstructure. Each crack in a concrete microstructure very strongly decreases mechanical properties and durability of final concrete structure. Determination of temperature course in concrete structure during hydration and estimation of possibility for cracks inception is possible through modeling.

Hydration heat liberation is dependent on type and amount of cement, additives, and chemical admixtures. For most of modern concretes, is used relatively high amount of chemical (plasticizing) admixtures for improvement of their properties and decreasing of binder amount. These admixtures significantly influence hydration heat course and from the point of view of determining temperature course in concrete during hydration, it is necessary to know co-reaction of binder and chemical admixtures.

On basis of prediction of concrete massive temperature, it is possible to change the material amount of a concrete mixture by carrying out the choice of optimum chemical admixture and amount of binder. By means of such a process, it is possible to reduce risks of crack creation for concrete structures efficiently and so that to increase final properties and their durability.

KEYWORDS: hydration, heat, concrete, cement, temperature, additives, admixtures, chemicals.

1. INTRODUCTION

If we want to predict temperature course in concrete solids during hydration, it is necessary to know thermal technical properties of hydrating concrete at first. One of basic thermal technical properties is dependency of intensity of hydration heat liberation in time and further value of heat transfer coefficient of concrete and heat capacity of hydrating concrete. The entire calculation procedure has been demonstrated below on the model example of real structure.

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2. DETERMINATION OF HYDRATION HEAT LIBERATION

This relation can be usually assessed on binder itself by means of direct calorimetric methods. One of the possible methods is determination of hydration heat liberation of used binder with help of izoperibolic calorimeter. Measurement is to be carried out under required boundary conditions responding to those ones under which concreting of building structure will be carried out.

The measurement has been carried out on modified cement paste at temperature +20°C in the first stage. The composition of cement paste has been as follows:

- CEM I 42,5 R (factory – Radotin) – 390g,
- batch water – 165 g,
- superplasticizing admixture – 2,30g

The calculation of intensity of hydration heat liberation has been carried out on basis of temperature course of hydrating cement paste, thermal technical properties of calorimeter, and boundary conditions. The following graph shows the curve of intensity course of hydration heat $\dot{Q}_{hydr}$ v $W.kg^{-1}$ for modified cement paste (for composition see above) which hydrated in calorimeter at environment temperature + 20°C.

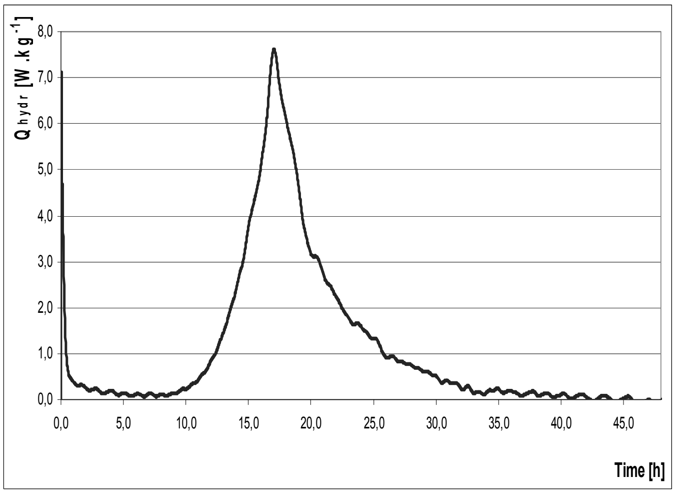

Figure 1. Course of intensity of hydration heat liberation for examined modified cement paste

As it is obvious from the Figure 1, maximum value of intensity of hydration heat liberation of given mixture has been equal to 7,5 $W.kg^{-1}$ and has been reached in time of 17.2 hours.

3. DETERMINATION OF HEAT TRANSFER COEFFICIENT

Determination of heat transfer coefficient has been carried out with samples of hydrated concrete by stationary method of plate by means of device Holometrix Lambda 2300. Value of heat transfer coefficient changes during hydration of concrete but with respect of the fact that this change of heat transfer coefficient is very difficult to be express, approximation relation is being used for calculations.

$$\lambda = \frac{(\lambda_b - \lambda_a)\,\tau}{0{,}3989\sqrt{2\pi\frac{\tau_{\max}}{3}}}\, e^{-\left(\frac{\tau-\tau_{\max}}{\frac{2\tau_{\max}^{2}}{9}}\right)} . + \lambda_a \tag{1}$$

$$\lambda = \frac{(\lambda_b - \lambda_c)\,\tau}{0{,}3989\sqrt{2\pi\frac{\tau_{\max}}{2}}}\, e^{-\left(\frac{\tau-\tau_{\max}}{\frac{2\tau_{\max}^{2}}{2}}\right)} . + \lambda_c \tag{2}$$

where:

- λ_a thermal conductivity in time 0 [$W.m^{-1}.K^{-1}$],
- λ_b th. conductivity in time of max. hydration heat liberation [$W.m^{-1}.K^{-1}$],
- λ_c thermal conductivity of hydrated concrete [$W.m^{-1}.K^{-1}$],
- τ time [s],
- τ_{max} time of maximal hydration heat liberation [s].

max

As follows from above mentioned relation, value of heat transfer coefficient of fresh concrete varies within range 1.8 – 2.3 $W.m^{-1}.K^{-1}$ (regarding thermal technical properties of aggregates and concrete composition).

Tab.1: Overview of measured values of heat transfer coefficient, volume mass, and compression strength in three selected concrete specimens

Specimen	Volume mass $kg.m^{-3}$	Heat transfer coefficient $W.m^{-1}.K^{-1}$
1	2442,0	1,750
2	2551,4	1,750
3	2295,4	1,768
Average	2429,6	1,710

Note: Values for hardened concrete after 28 days.

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Further, value of heat transfer coefficient increases and reaches its maximum value approximately in the same time when intensity of hydration heat liberation reaches its maximum. After that, value of heat transfer coefficient of concrete gradually decreases to value of hydrated hardened concrete.

Results of measurement are listed in Table 1.

4. CALCULATION OF TEMPERATURE COURSE IN CONCRETE STRUCTURE DURING HYDRATION

Calculation has been carried out on model of tunnel lining with wall thickness of 0.5 m. Concrete fragment with dimensions 0.4x1x1 m has been selected as a specific element and concrete properties has been selected consistent with measured values and table values as follows:

$\lambda_a = 2,0\ W.m^{-1}.K^{-1}$, :
$\lambda_b = 3,0\ W.m^{-1}.K^{-1}$,
$\lambda_c = 1,71\ W.m^{-1}.K^{-1}$,
$c_0 = 1124\ J.kg\text{-}^{1}.K^{-1}$,
$\rho = 2378\ kg.m^{-3}$.

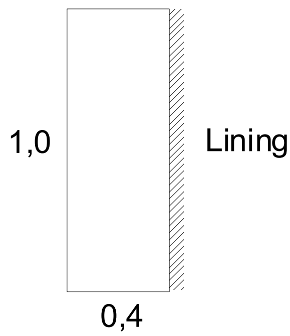

Figure 2. Scheme of calculated model fragment

The following has been considered for the calculation:

Temperature of laid mixture equal to + 22.0 °C,
Temperature of environment equal to + 20.0°C,
Temperature of sub-lining equal to + 16,0 °C.

Note: Heat transfer coefficient of hydrating concrete reaches value approx. 50% higher than hardened concrete (see above).

The calculation has been carried out by means of finite element method with isometric meshing. The results of calculation are graphically displayed Figure 3.

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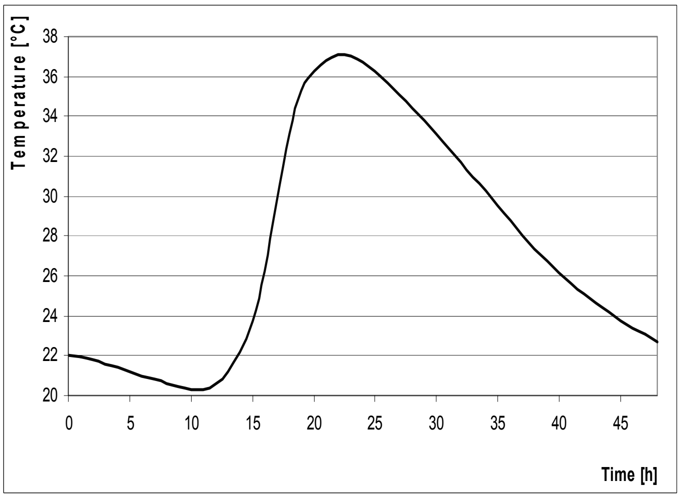

Figure 3. Temperature courses in centre of examined profile dependent on time.

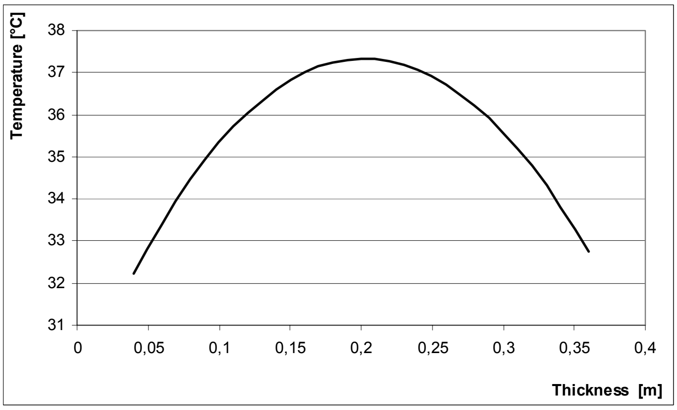

Figure 4. Thermal field distribution in lining profile after 22 hours of hydration

As it is obvious from the graph, maximum temperature in the centre of profile is approximately + 37,3°C and it is reached after 22 hours.

The Figure 4 shows distribution of thermal field in lining profile in time of reaching the maximum temperature.

As it is obvious from the graph, temperature difference between centre and surface of lining is approximately 6 K.

5. CONCLUSIONS

As it has been demonstrated, it is possible to predict temperature course in concrete structure during hydration. As it has been elicit from calculation on the model of real structure, temperature inside the concrete profile should not exceed temperature 38.0°C during hydration process.

Temperature of laid concrete during concreting equal to +22.0°C and temperature of environment equal to +20°C have been considered in the calculation. In case that temperature of concrete laid during concreting is higher, it is necessary to deal with acceleration of hydration process and with higher temperature increase in profile. We may assume that temperatures in profile even at higher temperatures or at higher temperature of laid concrete will not be critical due to relatively low thickness of structure.

In this manner, it is possible to estimate temperature course inside massive concrete structures during hydration of binder with sufficient accuracy and provide relevant arrangements in sufficient timing advance to prevent structural disruption due to unfavorable affects of stress from thermal gradients and volume changes during hydration.

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