TERMOVIZIJSKI MONITORING TOPLOTE HIDRATACIJE BETONA

THERMOVISION MONITORING OF CONCRETE HEAT OF HYDRATION

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Usled hemijske reakcije Portland cementa, koja se uvek javlja u betonu prilikom očvršćavanja, izvesna količina toplote se razvija. Ova toplota mora biti kvantifikovana, obzirom da ona može oštetiti beton ili pomoći mu, zavisno od komponenata betona, elementa konstrukcije, uslova sredine i gradilišta. Postoji veći broj postavki za monitoring toplote hidratacije, od kojih su dve primenjene u slučaju prikazanom u ovom radu. Četiri vrste betona su praćene pomoću pomenute dve tehnike u trajanju od 24 sata. Prva upotrebljena postavka koja je upotrebljena je termovizijska kamera, pomoću koje je praćena površina, a druga je termosenzor – upotrebljena za monitoring unutrašnjosti sveže betonske mase koja je očvršćavala. Potencijal primenjene postavke leži u jednostavnosti montiranja, niskoj ceni i mogućnostima za masovnu upotrebu, što može značajno doprineti monitoringu i predupredititi podbačaj betona.

Ključne reči: *beton; toplota hidratacije; monitoring; termovizija; termopar.*

Due to the Portland cement chemical reaction, which always takes place in a hardening concrete, a certain amount of heat is released. This heat should be quantified, as it can harm or aid the concrete itself, depending on the concrete components, structure element, ambient and building site conditions. There are number of possible setups for the monitoring of heat of hydration, two of which have been applied in the case presented in this paper. Four concretes were monitored with the use of the two stated techniques for 24 hours. First technique used is thermo-vision camera which monitored the surface, and the second is thermosensor - used for monitoring of interior of fresh concrete hardening mass. The potential of the applied setup lays in the ease of installation, low price, and possibilities of mass application, which could substantially aid the monitoring and prevent concrete failure.

Key words: *concrete; heat of hydration; monitoring; thermography; thermosensor*

1 Introduction

Concrete presents the most prominent structural material in the building industry worldwide. Low price, the availability of components, ease of production and placement can be regarded as aspects which make it almost impossible to provide an alternative for concrete in near future. The collection of knowledges, rules and skills resulting in the production of strong and durable structural concrete are contained and explained in the technical field of concrete technology [1].

Based on the chronology and the behavior of concrete, there are two stages of concrete treated in the concrete technology, fresh and hardened concrete. The flow (kinetics) of the chemical reaction between Portland cement and water presents the basis for the chronology, dividing the first several hours of the placed concrete behavior into setting and hardening. During setting, which normally

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takes up to 10 hours, a structure is formed in concrete causing it to transform from soft and almost liquid state into hardened state. After this short period, a structure is changed, providing higher strengths and other favorable properties of concrete through hardening, which takes months, and sometimes years, to finish completely.

During the setting of concrete, the exotherm chemical reaction of Portland cement with water (cement hydration) results in heat generation, referred to as heat of hydration. The chemical reaction can be divided in several phases (Table 1) [2]. In terms of the heat of hydration, the first three phases presented in this table are crucial. The generated heat increases the temperature of concrete during this sensitive phase, often resulting in occurrence of cracks in the setting and hardening concrete. Higher classes of Portland cement, larger quantities of concrete in mass elements, and unfavorable environmental condition (high ambient temperature) present the most important risk factors [3]. Therefore, timely and reliable information on the heat of hydration results in providing a proper curing regime for concrete, thus preventing strength and durability losses through crack generation.

Table 1 – Phases of the Portland cement hydration

Reaction Stage	Kinetics of Reaction	Chemical Processes
1 Initial hydrolysis	Chemical control; rapid	Dissolution of ions
2 Induction period	Nucleation control; slow	Continued dissolution of ions
3 Acceleration	Chemical control; rapid	Initial formation of hydration products
4 Deceleration	Chemical and diffusion control; slow	Continued formation of hydration products
5 Steady state	Diffusion control; slow	Slow formation of hydration products

Four mixtures of concrete were made for the experimental study, with different content. Compositions of these mixtures were different due to the differences in contents of components: water, cement, mineral addition of fly ash and chemical admixtures (accelerator and superplasticizer).

The monitoring of the heat of hydration was conducted with the aid of IR camera, and thermo-sensor beads. This experimental setup was applied on sampes of all of the concrete mixtures with different expected developments of heat of hydration.

2 Experimentals

The composition of four concrete mixtures made for this study is presented in Table 2. The quantities of aggregate for the concrete production were the same for all mixtures. The content of sand (grains finer than 4 mm) was 840 kg/m^3 for all the mixtures, with 543 kg/m^3 and 656 kg/m^3 of the II (4/8mm) and III (8/16mm) fractions of coarse aggregate. All of the mixtures were made using laboratory pan mixer Controls with the capacity of 50 dm^3. After the mixing, concrete was placed in the molds and compacted on the vibrating table. The experimental procedure in the main phase of the experiment involved the placement of the monitoring equipment on five samples (four representative 15 cm cubes, each made of different concrete mixtures) and data acquisition during the period of 24 hours. The experimental setup is shown in Figure 1.

Table 2 – Composition of concrete mixtures

	Water (kg/m^3)	Cement (kg/m^3)	Fly ash (kg/m^3)	Superplasticizer (kg/m^3)	Accelerator (kg/m^3)
Mixture 1	160	400	-	-	-
Mixture 2	160	400	-	2	4
Mixture 3	160	320	80	8	4
Mixture 4	200	240	160	8	4

The experimental setup involved a number of equipment units. Thermovision camera FLIR AX8 was used to record temperature on the surface of all of the cube specimens. At the same time, each of the sample was equipped with two IC LM35 thermo sensors, one at the surface and the other placed in the middle of each fresh concrete cube sample, which were still in plastic molds. Program VLC was used to record the thermography video file, and eight canal system for measurement, display and recording of real time temperature was used for eight thermo couples. Temperature of the ambient in the laboratory was recorded with the aid of FLIR DM 93, during the total recording period of 24h. Two lap top computers were also used, one for the recording of thermography video and the other with the LabVIEW application for real time measurement of temperature in 8 spots [4].

Figure 1 – Experimental setup for the monitoring of heat of hydration of cement

The measured values of ambient temperature in the laboratory conditions were ranging between 24.3°C and 22.2°C. Heat generation from the hydration process in concrete resulted in the increase of temperature in the samples. Different quantities of heat in different samples confirmed direct relationship with the quantity of cement used for production of different concretes. The highest recorded temperature peak of 26°C corresponded with the highest quantities of cement in the first two mixtures. The third mixture exhibited similar behavior, but the generation of heat was lower, with lower recorded temperature peak of 25.5°C. For the last mixture, made with the lowest quantity of cement, temperature peak reached only 23.5°C, testifying of the lowest heat generation in this concrete mixture. This confirmed also one of the concrete technology points that, for structures with massive concrete elements, concrete mixtures with lower quantity of cement and higher quantity of pozzolanic materials (such as fly ash) present more suitable solution. The use of accelerating chemical admixture was also noticed through the recording process, providing following effect: faster temperature development was recorded both on the surface and in the middle of the samples, but the temperature of the specimen remained in the same limits, testifying of the same amount (but faster achieved) of the generated heat of hydration. The graphical interpretation of the measured temperatures with all of the 8 thermo couples is shown in Figure 2.

3 Conclusions

The experimental study presented in this paper was conducted with the aim to accentuate monitoring effects of heat of hydration generation in concrete structures, due to the fact that this heat can induce substantial cracks in concrete, resulting in strength and durability failures. The technique for prevention of such effects was offered in a form of presented experimental setup including thermography camera and thermo sensors.

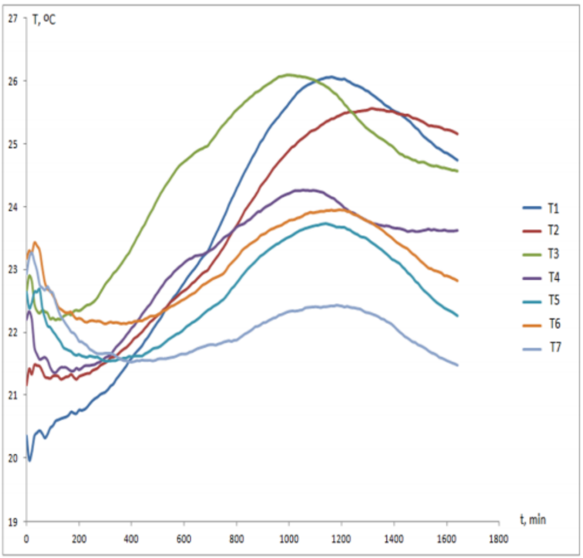

Figure 2 – The real time measured temperatures by two thermo sensors for each sample

Despite the fact that the concrete surface can emit different heat than the interior, thermography camera gave comparable and usable results for the produced concrete mixtures. Thermo sensors showed up to be part of good and simple tracking system to understand the effects of cement hydration in any concrete.

The valorization of the suggested novel experimental setup showed that this inexpensive and conditionally simple method can be applied on site, especially under harsh environmental conditions such as low and high ambient temperatures. In order to comprehend directions of development and the limitations of this method, an increase in the scope of research is expected.

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