



Internal curing for mitigating high temperature concreting effects

Pericles Savva^{a,*}, Demetris Nicolaidis^b, Michael F. Petrou^a

^a Department of Civil and Environmental Engineering, University of Cyprus, 75 Kallipoleos Av. P.O. Box 20537, 1678 Nicosia, Cyprus

^b Department of Civil Engineering, Frederick University Cyprus, 1036 Nicosia, Cyprus

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ABSTRACT

It is widely accepted that high temperature during casting of concrete causes damage on the material microstructure. Several of the most prominent drawbacks of high temperature concreting include the increased water demand, slump loss, drying shrinkage, autogenous shrinkage, decreased mechanical and durability properties. The accelerated drain of capillary pores due to intense drying or rapid cement hydration (increased self-desiccation) may induce stresses within the material's structure.

The current research aims to mitigate high temperature concreting effects using internal curing (IC). Highly-absorptive normal weight aggregates (HANWA) were employed to deliver IC water. The investigated parameters included various cast temperatures, age, curing regimes and type of aggregates. A number of mechanical and durability properties were measured to assess the effectiveness of the proposed methodology of IC. It was shown that the employment of IC had a beneficial effect in all measured properties. This was more evident in the specimens exposed to adverse environmental conditions.

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1. Introduction

Concrete contains large quantities of cement, which is a pozzolanic material reacting chemically when it comes in contact with water. The reaction is exothermic, which means that the material's temperature is inherently increased during the reaction. Since cement is a fine granular material, each grain hydrates/reacts independently. The rate of hydration depends on the ambient temperature that acts catalytically and increases the pozzolanic activity of each cement grain separately. Cement grains are also affected by the ambient temperature, since a rapid reaction hinders the even distribution of the hydration products, causing flocculation of grains and subsequently increased porosity. During the chemical reaction, the cement paste shrinks due to autogenous shrinkage, chemical shrinkage and self-desiccation.

It is widely accepted that high temperature during casting of concrete causes damage on the material's microstructure. Some of the most prominent drawbacks of high temperature concreting include the increased water demand, slump loss, drying shrinkage, autogenous shrinkage, decreased mechanical (i.e. compressive, tensile and pullout strengths and modulus of elasticity) and durability (i.e. permeability) properties [1–5]. Restrained and free shrinkage experiments on concrete had shown that autogenous

shrinkage and early-age crack resistance are influenced by the increase of curing temperature [6]. The increased water demand and the slump loss occur due to rapid consumption of the available water. The degradation of mechanical and durability properties occurs due to rapid hydration of cement grains. Rapid hydration rate caused by increased temperature creates a dense outer shell [7] on the cement grains that restricts water from diffusing within the grains to trigger additional hydration [8]. The rapid nucleation of the cement grains leads to an intense flocculation of the hydration products in the vicinity of the cement grain, hampering the even distribution of products within the available space [9]. The poor dispersion of hydration products leads to additional porosity. During the curing period, an important parameter is the temperature fluctuation, which may lead in prominent shrinkage and swelling cycles, causing microcracking. The specific phenomenon increases the material's cracking susceptibility, especially in the early age, leading to poor durability and mechanical performance. The exposure of concrete to high temperatures along with inadequate curing leads to an intense drying starting from the material's surface, which causes differential deformations. The presence of differential shrinkage leads to the induction of stress values of several MPas, that despite their slight relief due to creep, are able to cause microcracking [9]. It is worth pointing out that the irreversibility of drying shrinkage effects on concrete varies between 30 and 60% [9]. The drying shrinkage is getting more prominent when the water to cement (w/c) ratio increases. The increased temperature also has a significant effect on the apparent activation

* Corresponding author.

E-mail addresses: savva.pericles@ucy.ac.cy (P. Savva), d.nicolaidis@frederick.ac.cy (D. Nicolaidis), petrou@ucy.ac.cy (M.F. Petrou).

energy of cement that consequently increases the material's auto-genous shrinkage rate and amplitude at early-ages [5]. Self-desiccation shrinkage, which increases as w/c ratio decrease, have been fairly compensated using the method of internal curing (IC) which arose at the early 2000s. The specific method incorporates various water-carrying agents, such as lightweight aggregates [10–12], superabsorbent polymers [13] and highly-absorptive normal weight aggregates (HANWA) [14–16], to provide water within the material's structure and maintain RH at high levels. Several researchers have attempted also to assess whether IC could have beneficial impact on drying shrinkage. Espinoza et al. [17] evaluated the effect of artificial expanded clay sand on high w/c mixtures. They observed a prominent (19%) increase in compressive strength and decrease in ion permeability (30%) that were attributed to an increased degree of hydration (15%).

The current work aims to reduce the detrimental effects of concrete exposed in adverse ambient environmental conditions using the method of IC. The main objective is to deliver IC water using HANWA. HANWA are one of the two sources of crushed aggregates available in Cyprus.

2. Experimental program

2.1. Mixture's variables

Sixteen different mixtures were prepared (Table 1) in order to evaluate the effect of mixing and curing temperature on concrete mechanical and durability properties. The mixture's variables were the moisture state of aggregates (SSD for HANWA and lab-dry for NWA), the curing regime and the mixing and curing temperatures. More specifically, mixtures were prepared using two different types of aggregates, cured at two different curing regimes and cast at four different temperatures, as presented in Table 1. The water cured specimens were immersed in water tanks right after their demolding. The water temperature was identical to the manufacturing temperature. The concrete specimens were cured at the corresponding temperature up to the age of testing or up to the age of 28 days, whichever came first. After the 28 days the water tank temperature was reduced to the standard temperature (20 ± 2 °C).

The specimens were encoded according to their production and curing variables. For instance 22EL corresponds to the mixture produced at 22 °C using NWA (L) and exposed to the environment (E).

The first mixture of the experimental program was cast at the beginning of July, and before the end of the specific month all the mixtures intended to be exposed to the environment were

completed. The specific batch of specimens tested were directly exposed to the environment, exposed to direct sun (~six hours per day and moderate RH (~55%)), as opposed to the control water cured specimens (mixtures designated with C) where the water curing temperature was constant and corresponded to the casting temperature. All specimens were kept in laboratory conditions until demolding (24 h). The ambient environmental temperature was continuously monitored with the use of thermocouples. The maximum and the minimum ambient temperatures recorded in the storing environment were 44.3 °C and 21.2 °C (Fig. 1), whereas the largest and smallest fluctuations (day to night difference) were 22 °C and 8.5 °C respectively. It has to be noted though, that over 80% of days monitored had a temperature fluctuation exceeding 15 °C. In Fig. 1, each vertical line intersects the value of the maximum and the minimum ambient environmental temperature on the day of each mixture's initial exposure.

2.2. Aggregates

2.2.1. Mineralogical composition

Both HANWA and NWA were crushed limestone aggregates. HANWAs source is located in the Troodos mountain range. It contains mainly micritic calcite which in restricted areas yields to microspar. The aggregates contain fossils whose composition is mainly recrystallized sparry calcite, in addition to minor quantities of micritic endoclasts non-carbonate grains such as quartz, chert, spinel and also traces of anhydrite [18]. Their high absorptivity is due to the significant intraparticle porosity obtained within fossils, whereas elongated pores are formed due to recrystallization of spar crystals. NWA source is located in the Kerynea Terrane and is one of the three main allochthonous geological formations, which forms the main carbonate masses of Pentadaktilos mountain range. The specific formation is composed of massive to thickly bedded dolomitic limestones [19].

2.2.2. Physical and mechanical properties

The aggregate physical properties were measured according to EN 1097-6 [20] and are presented in Table 2.

The compressive strength and modulus of elasticity of both types of aggregates utilized for this experimental program (HANWA and NWA) were tested according to EN 1926 [21] and EN 14580 [22], respectively. The average compressive strength of six cylindrical specimens was 33.5 MPa (standard deviation 4.4 MPa) for HANWA and 80.3 MPa (standard deviation 5.7 MPa) for

Table 1
Mixture's variables.

Aggregates	Curing Regime	Cast temperature	No. of mixtures
HANWA Highly absorptive (H) Saturated Surface Dry (SSD)	Exposed (E)	22 °C (22)	4
		30 °C (30)	
		35 °C (35)	
		40 °C (40)	
	Water cured (C)	22 °C (22)	4
		30 °C (30)	
		35 °C (35)	
		40 °C (40)	
NWA Low absorptive (L) Lab Dry	Exposed (E)	22 °C (22)	4
		30 °C (30)	
		35 °C (35)	
		40 °C (40)	
	Water cured (C)	22 °C (22)	4
		30 °C (30)	
		35 °C (35)	
		40 °C (40)	

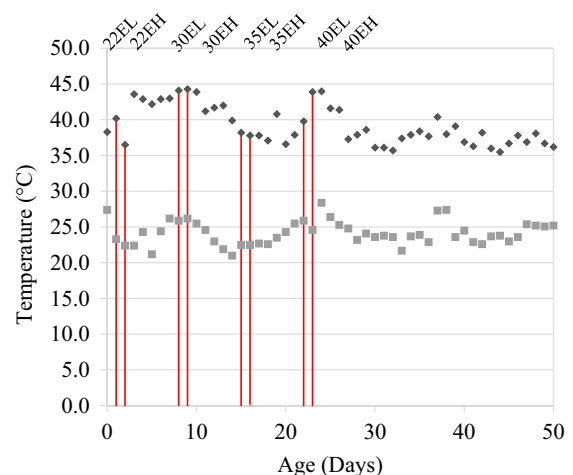


Fig. 1. Actual maximum and minimum temperature after each mixture's exposure to the environment.

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