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Highly absorptive normal weight aggregates for internal curing of concrete

Pericles Savva *, Michael F. Petrou

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

HIGHLIGHTS

- Highly absorptive normal weight aggregates were utilized for internal curing.
- Internal curing concrete mixtures were compared with reference mixture.
- Mechanical properties and durability were measured.
- Internally cured concrete mixtures demonstrated a satisfactory performance.

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ABSTRACT

The objective of this research was to develop an internal curing (IC) approach aiming to reduce early-age shrinkage and maintain the materials properties intact. Attention was given on delivering curing water within the material's structure using existing constituents of the mixture. Highly absorptive normal weight aggregates (HANWA) were employed to deliver water for IC within the material's structure. Concrete mixtures including dry and saturated HANWA were compared with ordinary (low-absorptive) normal weight aggregates (NWA) in order to evaluate the IC effectiveness. Furthermore, superabsorbent polymers (SAP) were employed also for IC and evaluated in mixtures with NWA. The mixtures were compared in terms of autogenous shrinkage, compressive strength, chloride diffusivity, open porosity and restrained shrinkage. It has been shown that HANWA material can be used effectively as an IC agent in order to reduce early-age shrinkage and at the same time maintain the mechanical properties and durability of concrete.

1. Introduction

Autogenous shrinkage could be described as the bulk shrinkage of a sealed, isothermal cementitious material without being subjected to external forces [1]. Chemical shrinkage, after the rigid skeleton formation, is considered as the internal shrinkage [2]. This occurs because the hydrated products occupy less space than the sum of cementitious reacted materials and non-evaporable water. For a typical cement, chemical shrinkage is estimated at approximately 6–7 ml per 100 g of cement reacted and at around 20 ml for 100 g silica fume reacted [3]. Similarly, Henkensiefken et al. estimated chemical shrinkage as 8–10% by volume of mature paste [4]. Prior to setting, the formation of internal voids is not possible due to poor strength that causes the material to collapse over the voids. During this period of time, autogenous and chemical shrinkage are equal. However, when the material develops adequate strength, voids due to chemical shrinkage are formed causing a divergence between autogenous and chemical shrinkage.

In normal strength concrete, autogenous shrinkage is relatively small and its effect on material's performance is negligible. Advances in concrete technology the last decades helped to develop high performance concrete (HPC) mixtures, characterized by their high compressive strength and low permeability. Their performance is attributed to the improved packing of the constituent materials due to coarse aggregates elimination and water content reduction, resulting a dense matrix. The low w/b ratio, however, causes a shortage in water which increases autogenous shrinkage, due to physical mechanisms known as self-desiccation [2].

Self-desiccation is mainly governed by two physical mechanisms, namely, the reduction of disjoining pressure and the meniscus formation. The disjoining pressure occurs when the attractive forces between the calcium silicate hydrate (C-S-H) gels are outweighed by the multi-layer water molecules adsorbed on their

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* Corresponding author.
E-mail addresses: savva.pericles@ucy.ac.cy (P. Savva), petrou@ucy.ac.cy (M.F. Petrou).

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surface [5]. It is developed as a result of the presence of adequate amount of water. A drop in RH – which is known to occur earlier in low w/b ratio mixtures – causes the reduction of disjoining pressure, resulting in additional shrinkage [3]. Moreover, the second physical mechanism that describes self-desiccation is the water-air meniscus which appears in unsaturated pores due to pressure decrease (Kelvin's Law) [3]. It results in tensile stress development within the pore fluid and subsequent compressive stress development from the surrounding material that causes further contraction [2,3]. It is, therefore, understandable that in order to prevent self-desiccation, additional water should be provided. Since the w/b ratio increase is not possible in HPC, other methods must be employed. Several proposed methods include the addition of internal reservoirs in order to replenish the consumed water and maintain the RH at high levels, namely, internal curing (IC), shrinkage reducing agents to reduce pore fluid's surface tension [6], and expansive minerals to counteract shrinkage. The dispersion of water reservoirs is a well-established method that reduces early-age shrinkage and self-desiccation. The IC water reservoirs are employed to replenish the consumed water and restore the pressure within the pore.

Great interest on the technique of IC was expressed at the beginning of the last decade after Jensen's and Hansen's comprehensive work [7] and many advancements were achieved since then. It is an on-going research topic and it attracts great attention since the advantages of establishing an IC technique are both short and long term. Improved performance during the structure's service life as well as extended life-cycle are two of the main benefits that contribute to a less expensive construction and lower maintenance cost, ensuring environmental sustainability. The ideal IC method should be able to reduce the autogenous shrinkage of HPC without compromising any other properties.

2. Background

As mentioned before, in order to prevent self-desiccation in a concrete mixture, it is necessary to maintain RH at high levels. The matrix structure of HPC, which yields to depercolated capillary pores, hinders the diffusion of the external moisture throughout the material's structure [6]. Therefore, in order to reach the inner core of such material's body, dispersed water reservoirs must be employed. It is implied that a better dispersion will result in uniform water utilization throughout the material's matrix increasing IC effectiveness. Two well established methods of IC are the use of superabsorbent polymers (SAP) and the use of lightweight aggregates (LWA). Both methods have drawbacks. Namely, the addition of SAP weakens the material due to additional porosity and the addition of LWAs compromises the mechanical and transport properties of the material due to the introduction of porous and mechanically weak materials [8]. Zhutovsky et al. reported that internally cured LWA mixtures' compressive strength decreases in comparison with the corresponding reference mixtures' compressive strength [9]. A round-robin test conducted by 13 different laboratories across the world used the same mix design but local aggregates and examined the effect of including SAP in concrete [10]. The added water for IC was adjusted according to the SAPs absorption where several laboratories made additional adjustments in order to reach the targeted slump. The majority of the researchers reported a decrease in compressive strength for concretes including SAP [10]. Some researchers, however, support that compressive strength reduction is not a consequence of SAP inclusion in concrete [11]. The consistent reduction in HPCs compressive strength can be surpassed by a proper design, regarding the amount of SAP and the curing of each mixture [12]. It suggests that the objective must be focused on achieving IC without affecting other properties of the material. Furthermore, other properties of the material are affected by the introduction of IC. Young's modulus and flexural strength seem to decrease due to lower stiffness and increased porosity [8,10,13]. Additionally, in NWA mixtures, the permeability is governed by the cement paste permeability. In concrete mixtures including LWA, the permeability is influenced by the properties of LWA [1]. A reduction in permeability and diffusivity can be expected in IC mixtures due to extended hydration that leads in capillary pores depercolation. However, in both SAP and LWA IC methods, additional porosity is expected to be introduced in concrete [14]. Finally, it is reported that an IC design may yield to a compromise where certain material's properties are inevitably reduced in order to reduce shrinkage [15]. It is, therefore, understandable that both methods have some drawbacks and in several occasions trial mixtures may be required prior to any application.

The objective of this research was to evaluate the effectiveness of using HANWA as an IC agent without compromising the mechanical or durability properties of HPC. It has to be mentioned that the aggregates employed for the control (CTRL) mixtures (NWA) were transferred from a source that is not available to the local construction companies. The HANWA aggregates is one of the main local sources of aggregates. Therefore, the effort emphasizes on improving the specific poor-quality material, by reversing a negative characteristic, very high absorption, into a beneficial action, IC. The principles of the specific work can be modified and be applicable in other applications (i.e. recycled aggregates) and countries.

3. Experimental program

3.1. Mixtures

The cement utilized for this research was CEM I 52.5R (Table 1). Due to the type of cement, it was expected that the mixtures would develop their properties earlier. Therefore, out of the four tests scheduled for each mixture (3, 7, 28 and 90 days), the two tests were conducted during the first week after casting. The mixtures effect on workability was measured with respect to the required amount of polycarboxylate polymer superplasticizer (SP) added to the mixture. The objective was to maintain the slump within the range of 100 ± 30 mm. The fraction of the coarse aggregates utilized was 4–10 mm. A similar fraction (4–8 mm LWA) was also used by Weber who established their IC effectiveness [16]. The aggregate water absorption at 24 h (WA_{24}) was measured according to EN-1097-6 [17] (Table 2) and the aggregates sieve analysis is provided in Fig. 1 and Fig. 2 (EN933-1 and EN12620). Both HANWA

Table 1
Typical cement properties for portland-composite cement EN197-1 CEM I 52.5R.

Chemical Analysis	
Loss on Ignition %	4.46
SiO2 %	18.91
Al2O3 %	4.23
Fe2O3 %	2.99
CaO %	61.99
SO3 %	3.51
MgO %	1.79
Na2O %	0.34
K2O %	0.58
Chlorides %	0.02
Mechanical and Physical properties	
Specific surface, Blaine (m^2/kg)	400
Normal consistency % H2O	28
Initial setting time (Vicat) min	220
Soundness expansion (Le Chatelieur) min	0–1