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Experimental investigation on the behavior of normal strength and high strength self-curing self-compacting concrete

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ABSTRACT

Self-compacting concrete is used when compaction of concrete is difficult to execute. To use a type of concrete, which does not need conventional curing, self-curing concrete can be used. The combination of those two types together provides a suitable solution for the curing and compacting processes. This research aims to study the feasibility of obtaining normal and high self-curing self-compacting concrete using different curing agents. The effects of curing agents on the behavior of normal and high-strength self-curing self-compacting concrete were studied. This research consists of two stages. The first stage conducted to investigate the effect of curing agent on the main properties of normal-strength and high-strength self-compacted concrete to obtain self-curing self-compacting concrete. The main variables are; concrete grade, curing agent type, and dosage. The second stage was conducted to investigate the behavior of reinforced concrete beams cast using the suggested two concrete types. The results were driven in terms of initial cracking loads, ultimate loads, and crack patterns of testing beams. Results indicate that the both types used, normal-strength and high-strength self-curing self-compacting concrete are efficient in structural elements, which the curing and compacting processes are missing. Curing agents reduce the water evaporation from self-compacting concrete, and hence increase the water retention capacity of self-compacting concretes with sufficient hardened concrete properties.

1. Introduction

Self-Compacting Concrete (SCC) is a highly workable type of concrete which has high performance and suitable strength. It can also flow under its own weight through restricted sections without segregation or bleeding [1,2]. SCC has substantial commercial benefits because of ease of placement in complex forms with congested reinforcement [2,3]. Generally, there are several approaches for developing economical SCC such as using high volumes of economical pozzolanas to reduce the cement content and use of low-cost high range water reducers [4].

Efficient curing improves the strength and durability of concrete. Concrete curing is a major challenge in the construction industry, especially in areas, which suffer from the shortage of water. Normal curing methods seem to be the best methods for curing giving maximum strength and durability [5]. Sometimes the sufficient curing conditions cannot be produced so, self-curing concrete is suggested in such cases. Self-curing or internal curing is a new technique that can be used to provide extra moisture in concrete for more effective cement hydration and reduced self-desiccation without the need to use conventional curing regimes [6–8]. The self-curing main concept is to reduce the evaporation of water from concrete and therefore increase the water retention capacity of the self-cured concrete when compared to conventional concrete by using chemical curing agents [6–8]. In zones with a shortage of water, sustainability of water can be achieved by using a suitable chemical curing agents for curing of concretes [8–10]. Another concept for internal curing is to use porous aggregates to act as internal reservoirs to provide water to concrete during hydration. The internal curing for concrete can be performed using several materials such as; lightweight coarse aggregate (LWA) *(like Lightweight expanded clay aggregate (LECA), lightweight natural sand (LWS), wood powder)* and chemical curing admixtures *(like super-absorbent polymers (SAP) and shrinkage reducing admixture (SRA))* [10–13]. Shrinkage-reducing admixture (SRA) (like propylene glycol type and polyethylene glycol), based on the use of poly-glycol products in the concrete mixtures, has been recently advised to reduce the cracks in concrete structure caused by drying shrinkage. The mechanism of this admixture based on the reduction of the surface tension of the mixing water as a physical change rather than on a reduction of water evaporation [8,14–16]. Self-curing (SC) concrete with curing agents gives about 10% less compressive strength than normal water curing [17,18]. The

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main advantage of the SC is noticed when compared to those who are not cured. Also, SC resulted in better hydration processes with time under drying condition compared to conventional concrete. Water transport through SC is lower than air-cured conventional concrete. Sorptivity and permeability values for SC decreased with age due to lower permeable pores as a result of the continuation of the cement hydration [19].

The using of self-curing self-compacting concrete (SC-SCC) provides the benefits of both [20,21]. Curing agent type and dosage affects on SC-SCC behavior and performance [21,22]. Several researchers try to study the effect of curing agents on the performance of self-compacting concrete in order to obtain self-curing self-compacting concrete [17,23–26]. Durability is not affected much by using chemical compounds for curing [17,27]. Nearly, the performance of normal strength and high-strength conventional concrete and SCC are the same regardless the strength [28,29]. SCC and SC concrete with SAP have better flexural strengths, compared to self-compacting concretes and self-curing concretes with LWA [30]. The flexural behavior of reinforced concrete beams with chemical curing agents (such as PEG400) performed well compared to the conventional specimens [31].

This research aims to study the effects of using different types and dosages of curing agents with normal strength self-compacting concrete and high strength self-compacting concrete in order to have self-curing self-compacting concrete "SC-SCC". Also, it aims to study the behavior of reinforced SC-SCC beams cast using those curing agents.

2. Research significance

This research aims to study two main points. The first is studying the effects of using different types and dosages of chemical curing agents with normal strength and high strength self-compacting concrete in order to have self-curing self-compacting concrete. The second is to study the behavior of reinforced SC-SCC beams cast using this type of concrete. The main variables at the first stage of this investigation are; concrete grade *(N.S.-SCC and H.S.-SCC)*, types of self-curing agent *(PEG 400, PEG 600 and LECA)*, the dosage of curing agent *(PEG 400 and PEG 600 as 1%, 2%, 3%, 4%, and 5% of the cement weight while LECA dosages are; 1%, 2%, 3%, and 4% of the cement weight)*. The main variables at the second stage are; concrete grade and curing agent type. The outputs of this study are experimental results that the researchers can assimilate and disseminate to judge and use this type of concrete.

The innovation in this research is the comparative study of the properties and the behavior of the normal and high strength SC-SCC concrete mixes using different internal curing materials.

The importance of this research is to provide sufficient data for the researchers and engineers that concerns in using normal strength or high strength SCC in the desert sites or such places which the concrete curing processes are difficult.

3. Materials and test specimens

All tests in this research are carried out in the Construction Materials Laboratory in Civil Engineering Department, Faculty of Engineering, Menoufia University.

The materials used are; the design of test specimens and testing procedures were discussed in the following sections.

3.1. Materials

The cement used is the ordinary Portland cement CEM I 52.5 N from the *Misr Beni-Suef* factory. It satisfies the Egyptian Standard Specification (E.S.S. 4756-1/2009) [32]. The fine aggregate used is the natural siliceous sand that satisfies the (E.S.S 1109/2008) [33] and ASTM C-33 [34]. It is clean and nearly free from impurities with a specific gravity 2.58 t/m^3 and a fineness modulus of 2.72. Its mechanical properties are shown in Table 1 while its grading is shown in Table 2.

Table 1
Physical properties of the sand used.

Property	Value
Specific gravity	2.58
Volumetric weight (t/m^3)	1.72
Voids ratio (%)	32
% absorption (%)	0.7

The coarse aggregate used is recycled aggregate (crushed red brick and crushed concrete compared to crushed dolomite with a maximum nominal size of 20 mm), which satisfies the (E.S.S 1109/2008) [33] as shown in Tables 3 and 4. The shape of these particles is irregular and angular with a very low percentage of flat particles.

Drinkable clean water, fresh and free from impurities was used for mixing and curing the tested samples according to the Egyptian code of practice.

Two types of admixtures are used. The first is a chemical admixture, while the second is pozzolanic admixture. A high range water-reducing (HRWR) admixture as superplasticizer under the brand name of (Sika ViscoCrete® −5930 L) by Sika Company was used to help in increasing the workability of concrete without an additional amount of water. It meets the requirements of ASTM C-494 Types G and F and BS EN 934 [11]. Its main properties are shown in Table 5.

Silica fume imparts very good improvement to mechanical and chemical properties. It improves the durability of the concrete by reinforcing and improving the microstructure through filler effect and thus reduces segregation and bleeding. The silica fume used is a pozzolanic admixture, which contains a 95% of silica (SiO_2) in the powder form. Silica fume of specific gravity 2.34 was used in this study. Physical and mechanical properties of the silica fume used are shown clearly in Table 6 as provided by the manufacturer.

Two types of self-curing regimes were performed. The first was done by using chemical curing agents while the second is achieved by using LECA as internal reservoirs. The self-curing agent used in this study is Polyethylene glycol PEG400, PEG600 produced by Morgan Chemicals Pvt. Ltd in Egypt, as a chemical agent in a liquid form for internal curing of concrete. It is free of chlorides and produces an internal membrane, which protects and prevents fresh concrete against over-rapid water evaporation. Table 7 showed the characteristics of Polyethylene glycol PEG400 and PEG600 as produced by the manufacturer. Light Expand Clay Aggregate "LECA" was produced in a rotary kiln at about 1200 °C. LECA was imported from the National Cement Company, Egypt. The properties of LECA were shown in Table 8.

Two types of steel rebars were used in this investigation. The first is the mild steel of rounded plain bars, 8 mm diameter as stirrups and secondary steel. The second is the high tensile steel of 10 mm diameter as main reinforcement. Yield stress, ultimate stress, modulus-of-elasticity, and elongation were obtained by performing different tests. Test results are given in Table 9.

3.2. Concrete and test samples

The start point of choosing the proportions of self-compacted concrete was conducted firstly based on previous researchers [35–37]. Two mixes were used. The first is a normal strength self-compacted mix "NS-SCC" while the second is a high-strength self-compacted mix "HS-SCC". The conducted experimental program divided into two stages. The first was performed to have the effect of curing agent on NS-SCC and HS-SCC mixes. The second part was performed to get the behavior of reinforced self-curing self-compacting concrete beams. The experimental program is shown in Fig. 1.

To obtain the self-curing self-compacting concrete, the self-curing agents were added to the two self-compacted concrete mixes. The first