Degani I
Cardiff University
School of Engineering

Maddalena R
Cardiff University
School of Engineering

Kulasegaram S
Cardiff University
School of Engineering

CIVIL INFRASTRUCTURE

Shrinkage Potential and Water Transport Properties of Self-compacting Concrete at Different Temperatures

In recent years, self-compacting concrete (SCC) has gained popularity due to its numerous advantages. While the fresh properties of SCC have been extensively discussed, there is a need for further research on its durability properties, particularly with respect to SCC cured at different temperatures. The present study aims to investigate the shrinkage, water absorption rate, and chloride permeability of high-strength SCC cured under water at four different temperatures i.e., 10 °C, 20 °C, 35 °C, and 50 °C.

The results showed that the samples which were cured at temperature 50 °C gained the largest shrinkage, while the samples cured at 10 °C temperature resulted in low shrinkage value, low sorptivity and electrical resistivity after 90 days of curing.

Keywords:
Self-compacting concrete, shrinkage, sorptivity, curing temperature, electrical resistivity.

Corresponding author:
DeganiIM@cardiff.ac.uk

I. Degani, R. Maddalena, and S. Kulasegaram, ‘Shrinkage Potential and Water Transport Properties of Self-compacting Concrete at Different Temperatures’, *Proceedings of the Cardiff University Engineering Research Conference 2023*, Cardiff, UK, pp. 66-69.

doi.org/10.18573/conf1.q

INTRODUCTION

Self-compacting concrete (SCC) is a new type of high-performance concrete, where the concrete has a high flow rate and can spread into place by itself, achieving good consolidation without vibration and minimising segregation and bleeding. The SCC mix is designed to ensure that the mix has both fluidity and resistance to water dilution and segregation [1]. The SCC has excellent deformability and passing ability, as well as high segregation resistance that allows it to be used in heavily reinforced applications and compacted under its own weight. In addition to improving construction productivity and decreasing the total cost of the structure, SCC enhances the work environment, by achieving sustainable characteristics, increasing the practically allowable reinforcement rate, and increasing the construction rate and total quality of the casting structures [2][3]

The fresh properties of self-compacting concrete have been widely researched in the last decades. However, the durability properties of SCC need more investigations. Durable concrete is concrete that has mechanical characteristics, protective properties, and visual appearance which are not adversely influenced by harsh environmental conditions after prolonged exposure [4]the studies that have addressed the use of the recycled aggregate in concrete subjected to freeze-thaw cycles are divergent. Thus, the present work suggests the use of recycled coarse aggregate (RCA. There are many factors that influence the durability of concrete and these factors can lead to concrete structure damage or deterioration including shrinkage, water absorption, and chloride permeability.

According to [5-[6] and [7], there is a direct correlation between autogenous shrinkage and temperature; autogenous shrinkage increases with increased temperature where high temperatures at early ages lead to cement hydration which accelerate and result in a non-uniform distribution of calcium silicate hydrate. This results in increased porosity and a higher risk of shrinkage and cracks formation.

The temperature, microstructure and porosity of concrete are some of the main factors contributing moisture transport in concrete. Concrete may experience a reduction in pH value due to the inevitable ingress of moisture with harmful ions [8]. In addition, the temperature plays a critical role in the rate of moisture transfer in concrete due to the fact that it can alter the pore pressure at a critical level to leading concrete spalling. It is reported in [9]-10] that concrete cured at 50 °C had a greater penetration, higher absorption, and higher moisture diffusivity than concrete cured at 20 °C.

The objective of this study is to investigate the effects of curing under water at different temperatures (i.e., 10 °C, 20 °C, 35 °C and 50 °C) on high strength self-compacting concrete and study its shrinkage potential and water transport properties.

MATERIALS AND METHODS

Materials

Portland cement CEM I 52.5 N was used as binder in accordance with [11]. A superplasticiser of Poly-Aryl-Ether based type [12] ,with a specific gravity of 1.07 was used. In this study, crushed limestone coarse aggregate with a specific gravity of 2.65 and a maximum size of 10 mm was used. River sand, sieved to a diameter of 2.0 mm and specific gravity of 2.55 was used as the fine aggregate. The fine aggregate was substituted by a percentage of (30%) limestone dust with a specific gravity of 2.6 and size between 0.125 mm and 2 mm.

Test methods

The fresh properties were investigated according to [11]. Three SCC samples were prepared for each test, the samples were wrapped with plastic sheet and cured in water directly after casting. Cubes with size of mm3 were prepared for the compressive strength test. Prismatic moulds sized (width 280 mm and cross-section 75×75 mm2) were used to measure the shrinkage potential by using a length comparator device, as outline in the methodology BS EN 12390-16:2019 [20]. Measurements of rate of water absorption were conducted according to ASTM C1585[21].

In this investigation the samples were cured at 10 °C, 20 °C, 35 °C and 50 °C. Total of 12 beams were prepared for the shrinkage potential test, 3 beams for each curing temperature, and the samples were cured for 90 days. For the water absorption rate, 24-cylinder samples with 100 mm diameter and 50 mm height were prepared in which 6 samples were used for each curing temperature and the tests were done at 3 days and 90 days. For electrical resistivity test 12 cylinders with 100 mm diameter and 200 mm height were used,and these samples were cured for 90 days.

RESULTS AND DISCUSSIONS

Fresh and hardened properties

Table 1 shows the results of fresh properties test and compressive strength at 28 days. The slump flow, J-ring, and compressive strength tests have been conducted as quality control to ensure this mix achieved the predicted strength.

Slump flow diameter	Slump flow diameter – slump flow in J-ring	Compressive strength at 28 days
670 mm	18 mm	71.2 MPa

Table 1. Fresh and compressive strength results.

Length change

Fig. 1 shows the results of shrinkage potential measurements for all samples cured at different temperatures. All samples showed autogenous shrinkage due to the hydration process in the concrete. The largest shrinkage value at all ages was recorded for the samples cured at 50 °C in which case the shrinkage was measured in the range between -623.1 µm/m to -653 µm/m. The second largest shrinkage value obtained was for the sample that cured at 35 °C for which shrinkage value for all ages was in the range of -250.7 µm/m to -452 µm/m. When the temperature increases the shrinkage increases as noted in [6]. The lowest shrinkage value for all ages was for the sample that cured at 10 °C where the measurement was within the range of (-160.8 µm/m to -291.5 µm/m. Curing the samples at low temperatures led to slowing of hydration reaction in the concrete which reduced the risk of shrinkage [15].

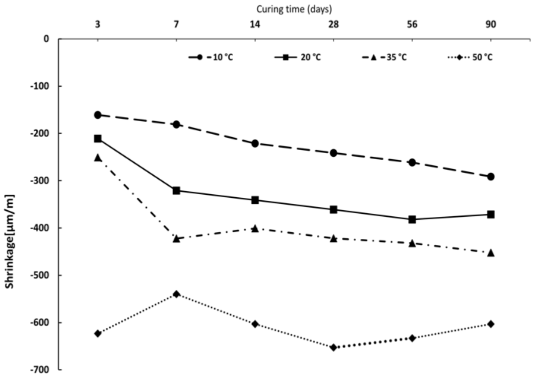

Fig. 1. Result of shrinkage for samples cured at 10°C, 20°C,35°C and 50°C.

Sorptivity
The calculated sorptivity values for the samples cured at different temperatures are shown in Fig. 2. It can be observed that the sorptivity values after 3 days were within the range of 0.113 to 0.147 , while the values after 90 days test were between 0.053 and 0.135 . The lowest sorptivity value after 3 days was 0.113 for the curing temperature 50 °C, while after 90 days the highest sorptivity value was recorded for 50 °C with the 19% increase in the rate . This may be attributed to the fact that high curing temperatures accelerate the hydration reaction at the early ages, leading to a denser microstructure and lower absorption properties initially; while, at later ages, the accelerated hydration can result in a more porous microstructure, allowing for higher water absorption and higher sorptivity values [16]. The highest value of sorptivity at 3 days was noted for samples cured at 10 °C, which was 0.147 , whereas the lowest value of sorptivity was recorded at 90 days, which was 0.053 , where the sorptivity value decreased about 63% from the early age. This may be due to the fact that lower curing temperatures result in slower hydration, leading to less hydration, increased porosity, and higher sorptivity values at early ages. However, over time, continued hydration fills voids, reduces porosity, and creates a denser microstructure, resulting in lower water absorption rates [17].

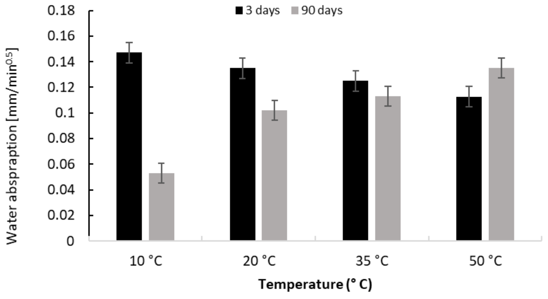

Fig. 2. Result of Sorptivity test for 3 days and 90 days.

Surface Electrical Resistivity
Fig. 3 shows the results of the surface electrical resistivity test. This test is generally performed to determine chloride permeability within the concrete samples. It can be noted from Fig. 3 that the best electrical resistivity after day 1 was for the samples cured at 35 °C and 50 °C (2.3 kΩ.cm), which was approximately 17% higher compared to the samples cured at 20 °C. This is due to the hydration process at an early age which was much faster at higher temperatures and made the hydration products fill the microstructure [18].

Nevertheless, at 90 days, the samples cured at 35 °C and 50 °C exhibited the lowest resistance values of 4.03 kΩ.cm and 3.13 kΩ.cm, respectively. These values were approximately 52.8% and 96.8% lower than the resistance value observed for the samples cured at 20 °C, where the high curing temperature led to change in pore structure, which allowed water and aggressive materials to penetrate the concrete [9]-[19].

At the early age, the samples cured at 10 °C and 20 °C exhibited the lowest electrical resistivity values of 1.33 kΩ.cm and 1.96 kΩ.cm, respectively. However, after 90 days, higher electrical resistivity values of 6.06 kΩ.cm and 6.16 kΩ.cm were observed for the samples cured at 10 °C and 20 °C, respectively. This represents a growth rate of approximately 78% for the 10 °C sample and 68% for the 20 °C sample. At the early age, the hydration reaction proceeds slowly at lower temperatures of 10 °C and 20 °C. As a result, only a limited number of hydration products are formed, leading to increased penetration and higher porosity. However, as the curing period reaches 90 days, the ongoing hydration process results in the filling of more voids and a significant reduction in porosity [18].

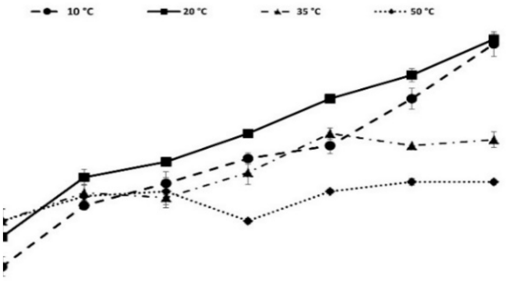

Fig. 3. Result of electrical resistivity.

CONCLUSION

In this study shrinkage, sorptivity and chloride permeability of self-compacting concrete cured at temperatures 10 °C, 20 °C, 35 °C and 50 °C have been evaluated:

Curing at 35 °C and 50 °C temperature led to increase shrinkage values, while, curing at 10 °C temperature resulted in the lowest shrinkage value.

At early age of sorptivity test samples cured at low temperatures revealed the highest sorptivity values. However, at 90 days most of the samples showed lower sorptivity.

Curing at temperatures 10 °C and 20 °C resulted in high electrical resistivity at later ages. However, curing at higher temperatures produced lower electrical resistivity.

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Research Conference

E. Spezi and M. Bray (eds.) 2024. *Proceedings of the Cardiff University Engineering Research Conference 2023.* Cardiff: Cardiff University Press.
doi.org/10.18573/conf1

Cardiff University Engineering Research Conference 2023 was organised by the School of Engineering and held from 12 to 14 July 2023 at Cardiff University.

The work presented in these proceedings has been peer reviewed and approved by the conference organisers and associated scientific committee to ensure high academic standards have been met.

Cardiff University Press | Gwasg Prifysgol Caerdydd

First published 2024

Cardiff University Press
Cardiff University, PO Box 430
1st Floor, 30-36 Newport Road
Cardiff CF24 0DE

cardiffuniversitypress.org

Editorial design and layout by
Academic Visual Communication

ISBN: 978-1-9116-5349-3 (PDF)