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Research Article

Effects of cementitious ingredients on long term properties of self compacting concrete

Yuvaraj L. BHIRUD[1,*], Om V. VAIDYA[1], Swapnil A. PATARE[1]

[1]*Department of Civil Engineering, SNJB's LSKBJ College of Engineering, Chandwad, Nashik, 423101, India*

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ABSTRACT

The paper "Properties of Self-Compacting Concrete with High Volume of Cementitious Material" investigates the impact of higher binder content on the properties of self-compacting concrete (SCC). The study was conducted using three SCC mixes with binding materials of 550 kg/m^3, 600 kg/m^3, and 650 kg/m^3 with a constant water-to-binder ratio and 40% of the binder being fly ash. The properties of the concrete were evaluated in the fresh stage using tests like the slump flow test and V-funnel test and in the hardened stage using tests like the compressive strength test and shrinkage test. The results showed that while there was a correlation between higher binder content and higher compressive strength, there were also differences in shrinkage and creep values that were estimated using ACI 209 R-92 and BS EN 1992-1-1-2004. The study highlights the need to investigate the effects of high binder content on SCC properties.

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INTRODUCTION

Self-compacting concrete (SCC) is a type of concrete that can be placed without the need for external efforts such as vibration, floating, or poking. Its flowing nature requires it to be stable against segregation, which can be achieved by using chemicals such as Viscosity Modifying Agents (VMA type SCC) or a high amount of binder materials like GGBS, fly ash, or limestone powder (Powder type SCC). This change in ingredient proportions results in a change in various properties of SCC compared to normal vibrated concrete (NVC) [1-6]. Among these properties, shrinkage, creep, and elastic shortening can cause losses in prestress force.

In India, fly ash is abundant [8] and its disposal contributes to environmental pollution. Utilizing this available fly ash through high volume fly ash SCC is a way to reduce this pollution. Studies have shown both similarities and differences between the properties of SCC and NVC. While some research has shown that the creep, shrinkage, and elastic modulus properties of SCC are comparable to NVC when the strength of both is kept constant [1, 10, 27-29] other studies have shown that NVC has less shrinkage and creep than SSC [5, 7, 30-32].

***Corresponding author.**
*E-mail address: yuvarajbhirud@gmail.com

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Several codes have been used to predict the shrinkage, creep, and elastic modulus of SCC, with varying degrees of accuracy. ACI 209 R [13] has been shown to accurately predict SCC shrinkage by Jin-Kenn Kim et al [5] and Stefanus A Kristiawan et al [12], while B. Barr et al [17] found that it is accurate for low strength concrete but differs when the concrete strength exceeds 45 N/mm^2. Euro Code 2 [15] has been shown to accurately forecast the elastic modulus of concrete by Lino Maia et al [18], and to accurately forecast SCC creep if the stress level is below 30% of strength.

While studies have been carried out for SCC with cement and filler material quantities of up to 550 kg/m^3, there is limited literature on the behavior of SCC with cementitious substance of 600 kg/m^3 or more. Thus, there is a need to investigate the effect of higher binder content on properties such as shrinkage, creep, and elastic shortening. To address this gap, an experimental investigation was conducted to study the properties of SCC with a high volume of cementitious material. Three mixes with binding materials of 550 kg/m^3, 600 kg/m^3, and 650 kg/m^3 were prepared with the same water-to-binder ratio. The workability, segregation resistance at the fresh stage, and compressive strength, elastic modulus, shrinkage, creep, and elastic shortening at the hardened stage were determined. The shrinkage and creep values were estimated using ACI 209 R-92 and BS EN 1992-1-1-2004, and compared with experimental values obtained in the study.

EXPERIMENTAL PROGRAM

The self-compacting concrete properties of workability, resistance to segregation, and flowability were evaluated in the fresh stage using the Slump Flow Test, V-Funnel Test, and L-Box Test. The mixture proportions were determined based on the EFNARC (European federation dedicated to specialist construction chemicals and concrete systems) guidelines [11] and previous research findings [19-22]. The permissible limits for acceptance of SCC at fresh stage by EFNARC guidelines are mentioned in last column of table 3. The specific surface area of aggregate were determine based on IS 4030(Part-II)-1988. Three SCC mixes with binding materials of 550 kg/m^3, 600 kg/m^3, and 650 kg/m^3 were prepared, with 40% substitute binder being fly ash (SCC550, SCC600, and SCC650, respectively). Class F fly ash and OPC 53 grade cement were used as binders, and crushed basalt stone aggregates with a maximum size of 20mm and fine natural river sand were employed as the coarse and fine aggregates, respectively. The water-to-binder ratio was kept constant for all mixtures, and a polycarboxylate ether superplasticizer was used to enhance workability. Table 1 shows properties of ingredients used while the mixture proportions are presented in Table 2.

In order to study the mechanical properties of concrete, the elasticity, shrinkage, creep, and elastic shortening moduli were evaluated using concrete specimens in their hardened state. To assess the compressive strength, 150mm cubes were produced and evaluated at seven, twenty-eight,

Table 1. Binding substance and aggregate properties

Types	Cement	Fly Ash	Fine aggregates	Coarse aggregates	
				10 mm	20mm
Specific Surface area	325 m^2/kg	374 m^2/kg	-	-	-
Specific gravity	3.15	2.3	2.79	2. 9	2.9
Fineness Modulus	-	-	2.93	6.09	8.11

Table 2. Mix proportion used for concrete

		Mix		
		SCC550	SCC600	SCC650
Cement (kg)		330	360	390
Fly ash (40%) (kg)		220	240	260
Natural sand (kg)		1130	1090	1060
Coarse aggregates (kg)	10 mm (70%)	321	308	359
	20 mm (30%)	137	136	154
Water/Binder ratio		0.33	0.33	0.33
Super-plasticizer		1.30%	0.95%	0.85%

Figure 1. Shrinkage test setup

surfaces of the specimen at the prestressing reinforcement location with epoxy adhesive (Figure 2).

The prestressing cable was gradually released after 7 days of casting at a rate of 0.8 kN/s and the strain gauge readings were taken just before and after cable release. The difference between these two readings is defined as the elastic shortening (ε_e).

After the release of the tendon, the total strain (ε_t) that occurred in the specimens was recorded periodically. This total strain includes shrinkage strain, elastic shortening and creep. From this total strain, shrinkage strain, which was measured separately, and elastic shortening is subtracted to get creep strain and given in equation 1.

$$\varepsilon_c = \varepsilon_t - \varepsilon_s - \varepsilon_e \tag{1}$$

Readings were taken once a week for the first 4 weeks and then every four weeks thereafter. The shrinkage and creep measurements were taken up to 112 days of age to obtain a comprehensive understanding of the concrete's behaviour over time.

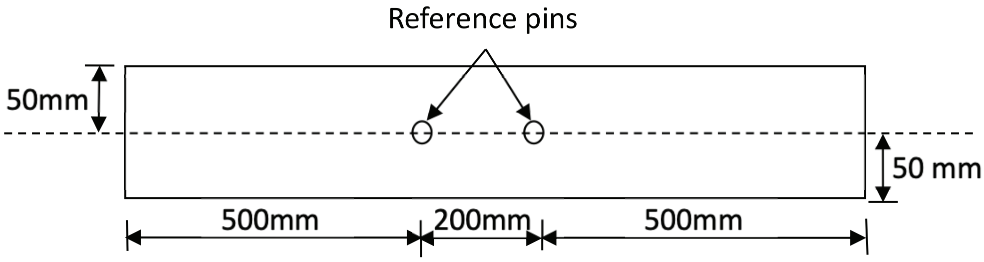

Figure 2. Positioning of the reference pins and the prestressing wire on sample.

and fifty-six days of age. The elasticity modulus was determined using 150mm diameter cylinders.

Prismatic specimens with a cross section of 100x100mm were used to determine shrinkage. The shrinkage behaviour of the self-compacting concrete samples was evaluated using a dial gauge with an accuracy of 0.001mm. The samples were vertically stacked and kept in a controlled environment with a temperature of 20±1°C and relative humidity of 50%. In this research endeavour, the objective was to determine the total shrinkage of the concrete samples (Figure 1).

100x100x1200mm prismatic specimens were specifically designed for the pretension prestressing system. In the study, a 12.5mm diameter high tensile strand wire with a tensile strength of 1750 N/mm^2 was utilized throughout the experiment. The cable was positioned at the centre of the sample cross section (100x100x1200mm) to eliminate eccentricity and ensure that the concrete section remains under compressive stress when the prestressing cable is released. Strain gauge points were attached to the lateral

RESULTS AND DISCUSSION

Fresh Characteristics of Self-Compacting Concrete

In this study, the fresh characteristics of self-compacting concrete were evaluated. Initially, trials were conducted on the SCC550 mix, and upon achieving satisfactory results, the percentage of superplasticizer was adjusted for the specific performance of the other mixes. The workability results are presented in Table 3. It was observed that as the binder concentration increased, the required amount of superplasticizer decreased. The SCC550 required 1.3% superplasticizer, the SCC600 required 0.95%, and the SCC650 required 0.85%. The higher binder concentration resulted in an increase in the available paste, which provided better lubrication and reduced the need for superplasticizer to achieve the desired workability. The visual examination of the concrete flow provided insight into segregation, as significant segregation results in a concentration of coarse particles in the centre of the concrete flow, while only the cement paste reaches the edges. The Slump flow test revealed that the coarse aggregates

Table 3. Results for workability of concrete

Test	Mix			Permissible Limits
	SCC550	SCC600	SCC650	
Slump flow diameter (mm)	680	710	690	600 - 750
V-funnel Time T_0 (Sec)	8.2	7.2	7.42	6 - 12
V-funnel at $T_{5minute}$ (Sec)	10.9	9.9	10.25	£T_0 + 3
L-box T_{20cm} (Sec)	0.89	0.9	0.92	1 ± 0.5
L-box T_{40cm} (Sec)	2.34	2.2	2.09	2 ± 0.5
L-box blocking ratio (H_2/H_1)	0.86	0.9	0.85	0.8 – 1.0

were evenly distributed within the concrete flow, and the presence of coarse aggregates and mortar paste at the edge of the flow indicated the stability of the mix. These findings are illustrated in Figure 3.

Hardened Characteristics of Self-Compacting Concrete

(a) Compressive Strength of Self-Compacting Concrete

The compressive strength of each of the SCC mixes, SCC550, SCC600, and SCC650, was evaluated and the results are presented in Figure 4. The results showed that the compressive strength of the concrete increased with an increase in the concentration of binding material. The compressive strength of SCC550 was found to be the lowest among the three mixes, while that of SCC650 was the highest at all ages. This can be attributed to the fact that SCC600 and SCC650 mixes contain a higher concentration of binding material, thus resulting in greater compressive strength.

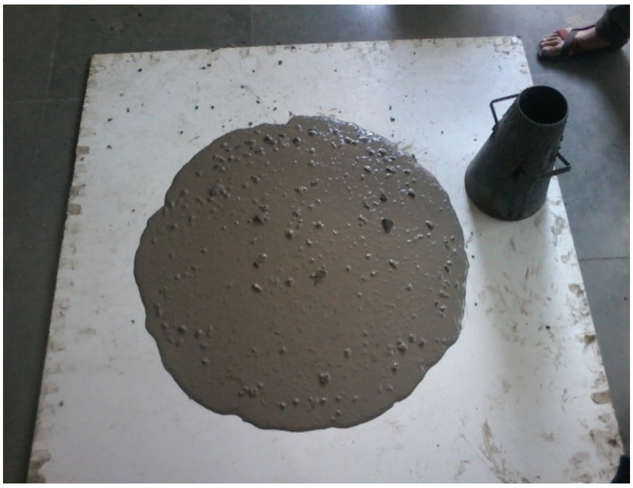

Figure 3. Slump flow of concrete.

(b) Elastic modulus

The elastic modulus of the concrete samples at 28 days of age is depicted in Figure 5. The results indicate a slight increase in the elastic modulus for SCC600 and SCC650 mixes compared to SCC550. The elastic modulus of concrete is commonly estimated by multiplying a constant by the square root of its characteristic strength ($\sqrt{f_{ck}}$). The ACI 318-89 [16] recommends the relation 4700 $\sqrt{f_{ck}}$ for predicting concrete's elastic modulus. Table 4 presents the results of the experimentally obtained constants for the calculation of the elastic modulus by multiplying with $\sqrt{f_{ck}}$ It can be seen that the constant decreases as the powder content in the SCC mix increases. Higher powder content results in a larger volume of paste and a smaller quantity of coarse aggregates, causing the aggregates to be stiffer than the paste [9], [23]. This leads to a higher strain in the concrete at the same stress level, causing the constant to decrease.

The experimental values and the predicted values of the modulus of elasticity using the ACI 318-89, ACI 363R-84, and BS EN 1992-1-1-2004 methods are shown in Figure 4.

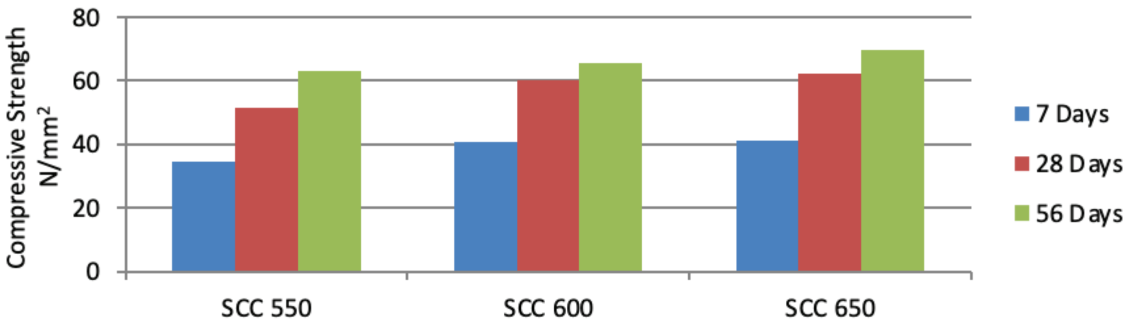

Figure 4. Compressive strength of concrete at various ages.

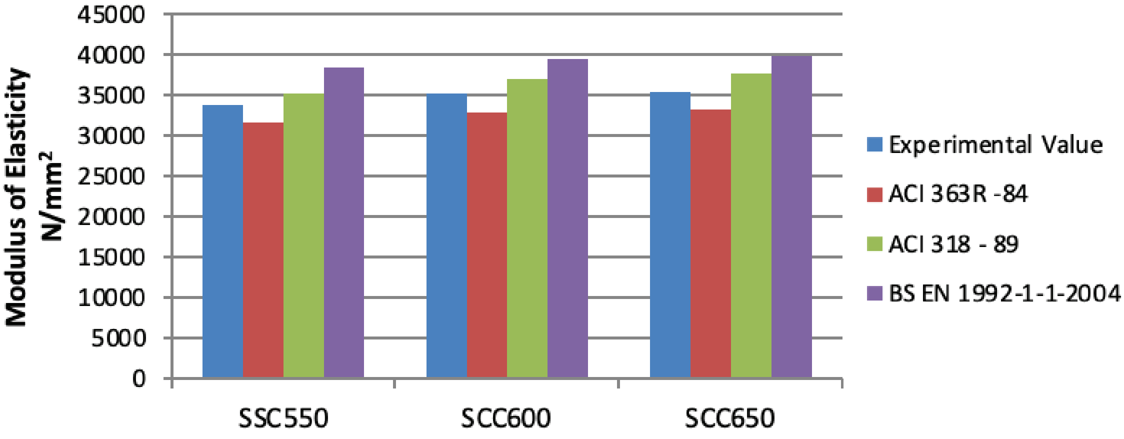

Figure 5. Modulus of elasticity comparison between experimental and projected values

Table 4. Multiplying constant for $\sqrt{f_{ck}}$

Mix	Value of multiplying constant for √fck
SSC550	4503
SCC600	4464
SCC650	4410

The results indicate that the estimated elastic modulus values using the ACI 363R-89 approach are found to be lower, while the values obtained using the ACI 318-89 and BS EN 1992-1-1-2004 methods are higher than the experimental values. The experimental analysis reveals a high degree of agreement between the predicted and measured modulus of elasticity using the ACI 363R-89 approach.

(b) Shrinkage, Elastic Shortening and Creep

The results of the shrinkage, as measured by the change in length, are shown in Figure 6. It was observed that the shrinkage increased with an increase in the binder content of the concrete. In comparison to SCC550 at 112 days, the shrinkage for SCC600 was 13.04% higher and for SCC650 it was 34.78% higher. The predicted values of shrinkage based on ACI 209 R-92 and BS EN 1992-1-1-2004 were found to be lower than the experimental values. The difference between the predicted and experimental values of shrinkage was found to be 17% for SCC550 concrete based on ACI 209 R-92 and 54% based on BS EN 1992-1-1-2004. The gap between the predicted and experimental values of shrinkage was found to be highest for SCC650 concrete, where the difference was 34%.

The results obtained for elastic shortening are presented in Figure 7. The results indicate that concrete with higher binder content has a higher elastic shortening, with SCC600 and SCC650 having 6.52% and 13.25% more elastic shortening, respectively, compared to SCC550.

After the release of the tendon, the total strain (ε_t) that occurred in the specimens was recorded periodically. Readings were taken once a week for the first month and then every four weeks thereafter till for total 112 days. The creep strain (ε_c) was calculated using Equation 1.

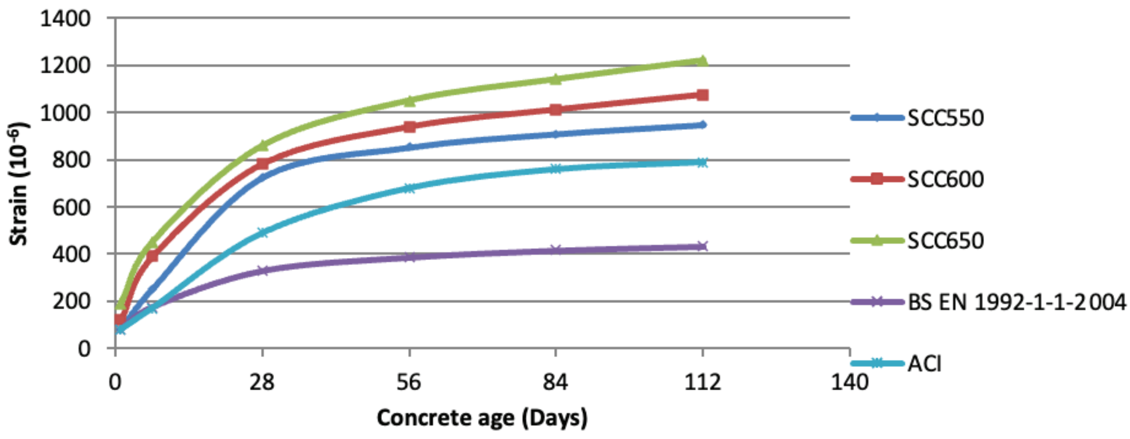

Figure 6. Comparison of shrinkage of various mixes.

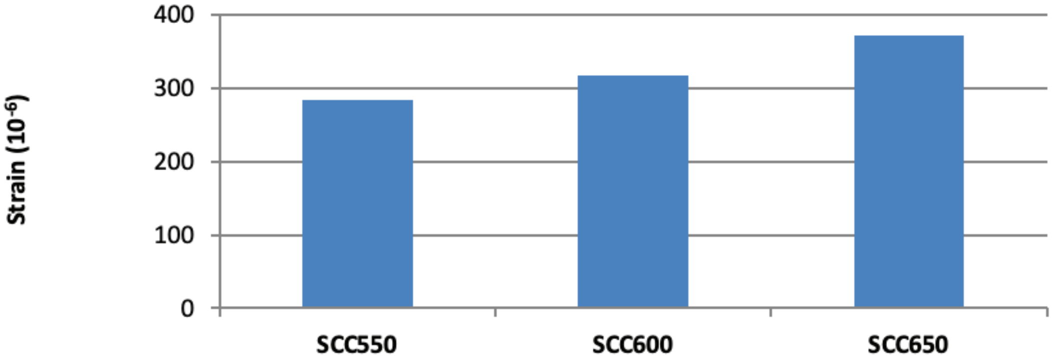

Figure 7. Elastic shortening of mixes.

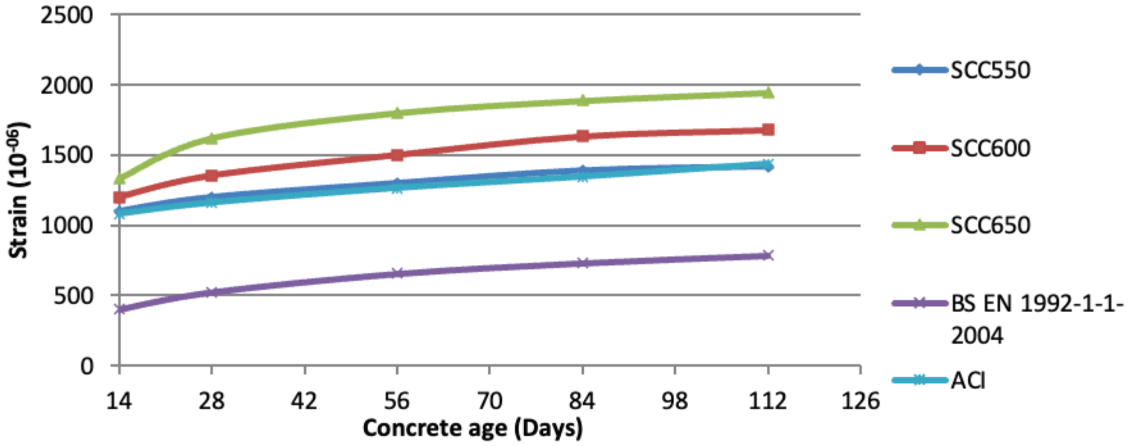

Figure 8. Comparison of creep of mixes.

Table 5. Binding material and coarse aggregate ratio in concrete

Mix	Binding material ratio to concrete	Coarse aggregates ratio to Concrete
SCC550	0.233	0.234
SCC600	0.254	0.223
SCC650	0.275	0.217

Figure 8 shows the results of creep in concrete and indicates that concrete with a higher binding material has more creep. The results also show that the rate of creep in the first week is rapid for all mixes and decreases in subsequent weeks. In comparison with SCC550, creep for SCC600 is 18.3% more and for SCC650 it is 36.6% more at 112 days of concrete age. The predicted values for creep by BS EN 1992-1-1-2004 for SCC550 are lower than the experimental values, but the predicted values by ACI 209 R-92 are nearly identical to the experimental values. However, for SCC600 and SCC650, the experimental values are more than the prediction by ACI 209 R-92 by 14% and 24% respectively.

Table 5 presents the data on the relationship between the amounts of binding material and coarse aggregates in concrete. The results indicate that as the amount of binding material increases, the proportion of coarse aggregate decreases. This shift in the composition of concrete has significant implications on its properties.

Firstly, an increase in the volume of paste in concrete results in finer pore structures and smaller capillaries. This process is known as self-desiccation, which leads to a higher surface tension and greater attraction forces between the pores. This results in higher shrinkage of concrete, as the increased surface tension causes the pores to pull together [24, 26].

Secondly, the decrease in coarse aggregate volume and increase in paste volume also contributes to increased creep and elastic shortening. These properties can cause concrete to deform over time, affecting its strength and durability.

In conclusion, the results from Table 5 highlight the importance of the balance between binding material and coarse aggregates in concrete. An increase in the volume of binding material results in a reduction of coarse aggregate, which can lead to increased shrinkage, creep, and elastic shortening. These factors must be considered when designing concrete mixtures to ensure their durability and performance over time.

CONCLUSION

In summary, this study investigated the impact of varying binder content on the properties of Self-Compacting Concrete (SCC) mixes. Three SCC mixes were cast with binder contents of 550 kg/m^3, 600 kg/m^3, and 650 kg/m^3, respectively, and all mixes were stored under identical conditions. The results showed that all mixes met the workability requirements of SCC, and that the amount of superplasticizer required decreased with an increase in binder content. Additionally, all mixes demonstrated stability against segregation.

The modulus of elasticity was found to decrease with an increase in binder content, and the predicted values by the ACI 363R-89 method were in close agreement with experimental values. Meanwhile, the predicted values by the ACI 318-89 and BS EN 1992-1-1-2004 methods were higher compared to the experimental values.

The shrinkage was found to increase with an increase in binder content, and the estimated values by the ACI 209 R-92 and BS EN 1992-1-1-2004 codes were lower than the experimentally measured values. The difference between the predicted and measured values increased with the powder content, reaching 34% for the SCC650 mix.

The study also found that creep increased with an increase in binder content. The creep predicted by the ACI 209 R-92 method was in close agreement for the SCC550 mix, but was lower for the higher binder content mixes (SCC600 and SCC650). Similarly, the estimated values by the BS EN 1992-1-1-2004 method were lower than the measured values for all mixes.

AUTHORSHIP CONTRIBUTIONS

Authors equally contributed to this work.

DATA AVAILABILITY STATEMENT

The authors confirm that the data that supports the findings of this study are available within the article. Raw data that support the finding of this study are available from the corresponding author, upon reasonable request.

CONFLICT OF INTEREST

The author declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

ETHICS

There are no ethical issues with the publication of this manuscript.

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