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Impact of curing time on the compressive strength of self-compacting concrete with high fly ash content

Ảnh hưởng của thời gian bảo dưỡng đến cường độ nén của bê tông tự lèn có hàm lượng tro bay cao

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ABSTRACT

This paper presents the experimental findings on the influence of curing duration on the compressive strength of self-compacting concrete (SCC) with a high proportion of fly ash. The SCC mixtures examined had fly ash content ratios of 0%, 50%, and 60% by volume of powder. The concrete samples were subjected to water immersion curing for periods of 28 and 90 days. The experimental data revealed that prolonging the curing duration positively impacted the compressive strength of SCC with high fly ash content at later stages. Specifically, when the water immersion curing period was extended from 28 to 90 days, the compressive strength values at 90 days of the mixtures with 50% and 60% fly ash content increased 3.7% and 8.7%, respectively. Conversely, for the samples without fly ash, extending the curing period from 28 to 90 days resulted in a negligible increase in terms of compressive strength, approximately 0.99%.

Keywords: Self-compacting concrete; fly ash; curing time; workability; compressive strength of concrete.

TÓM TẮT

Bài báo trình bày kết quả nghiên cứu thực nghiệm về sự ảnh hưởng của thời gian bảo dưỡng đến cường độ nén của bê tông tự lèn (BTTL) có hàm lượng tro bay cao. Các cấp phối BTTL trong nghiên cứu có tỷ lệ tro bay lần lượt 0%, 50% và 60% thể tích bột. Các mẫu bê tông được tiến hành bảo dưỡng bằng ngâm nước với thời gian 28 ngày và 90 ngày. Kết quả thí nghiệm cho thấy kéo dài thời gian bảo dưỡng có tác dụng tăng cường độ nén ở độ tuổi muộn của BTTL có hàm lượng tro bay cao. Khi thời gian bảo dưỡng ngâm nước tăng từ 28 ngày lên 90 ngày, các cấp phối có hàm lượng tro bay 50% và 60% có giá trị cường độ nén ở tuổi 90 ngày tăng lần lượt 3.7% và 8.7%. Tuy nhiên, đối với mẫu BTTL không sử dụng tro bay, việc tăng thời gian bảo dưỡng từ 28 ngày lên 90 ngày, giá trị cường độ nén tăng không đáng kể, chỉ khoảng 0.99%.

Từ khóa: Bê tông tự lèn; tính công tác; cường độ nén bê tông.

1. INTRODUCTION

Concrete curing is a process implemented to preserve moisture and temperature levels, facilitating the complete hydration reaction of cement and the pozzolanic reaction of fine additives in concrete. As stated by Cather [1], curing aims to create an environment conducive for hydration reactions, thereby yielding concrete with minimal shrinkage. The curing duration is measured from the completion of surface finishing until the concrete acquires the desired properties. Appropriate concrete curing can enhance strength by up to 50% compared to uncured concrete, significantly diminish shrinkage and cracking, and potentially reduce capillary porosity by up to 80% [2]. Self-compacting concrete (SCC) with a high proportion of fly ash has demonstrated its ability to meet the requirements for workability, compressive strength, and durability in technical infrastructure construction in Vietnam. This type of concrete is characterized by a high fly ash content exceeding 50%, a low water-to-powder ratio (W/P), a large volume of mortar, and the use of superplasticizers. These characteristics result in different behaviors during the hardening process compared to traditional concrete, necessitating a specific curing duration to develop its unique properties.

Currently, there are no specific standards for the curing of SCC worldwide, including Vietnam. Existing concrete curing standards primarily focus on ensuring the hydration of cementitious materials without addressing the pozzolanic reactions of fine additives such as fly ash, silica fume, or blast furnace slag, posing challenges for the use of high fly ash content SCC in construction projects requiring long-term durability against aggressive environments. Several international standards and previous studies have shown the influence of curing time on concrete with the use of fine additives. Hilsdorf (1995) demonstrated that curing effectiveness depends on factors such as concrete material composition, environmental temperature, concrete temperature, and light exposure. The curing time required depends on the kinetics of the pozzolanic reaction between SiO2 in mineral additives and Ca(OH)2 [2]. Norwegian Standard NS 3420 specifies that concrete requiring strength must be cured for at least two weeks, with attention to minimizing early drying-induced cracking for concrete containing fly ash, silica fume [11]. Mekiso's research [1] on high-fines self-compacting concrete suggests that early curing to limit shrinkage and cracking is beneficial, and longer curing is required compared to conventional concrete. Nivelle's study [2] on high-performance concrete (HPC) indicated the need for extended curing time for concrete with low water-to-powder ratio due to self-desiccation, slow pozzolanic reactions of additives, especially in the early curing period. Gowripalan's research in the UK [2] investigated the impact of curing methods and time on concrete durability (assessing properties such as porosity, water permeability, and absorption). The study showed that concrete containing mineral additives (fly ash, silica fume) had reduced voids, requiring longer or higher temperature curing. Early curing was crucial to reducing concrete permeability. Sen Senetta and Scholer's study (1984) [2] evaluated curing effectiveness using absorption rate. They concluded that absorption rate accurately reflects hydration and void formation in concrete structures, and poor curing affects surface quality at a depth of 3cm.

Studies on the influence of curing time on the compressive strength of high fly ash content self-compacting concrete under the Vietnamese climate is limited. Moreover, the trend of using high fly ash content to produce self-compacting concrete to reduce costs and protect the environment is encouraged. Therefore, this research topic is practical and relevant to current applications.

2. EXPERIMENTAL METHOD, MATERIALS, AND MIX DESIGNS

2.1. *Experimental Procedure*

The workability test was conducted in accordance with TCVN 12209:2018 [3], and the concrete casting and curing followed TCVN 3105:2022 [4]. The concrete samples were of dimensions 10x10x10 cm. Samples were cast and cured under standard conditions on the first day, then immersed in water from the second day onwards. Compressive strength tests were carried out as per TCVN 3118:2022 [5] when the samples reached 90 days of age. Hydraulic compression testing was performed using a 200-ton DHR 200 hydraulic press. Figure 1 illustrates the curing of concrete samples by water immersion. To assess the impact of curing time on the properties of self-compacting concrete, samples were cast and cured by water immersion for varying durations: (i) continuous immersion for 28 days (BD28d); (ii) continuous immersion for 90 days (BD90d). Figure 2 shows the concrete compression testing.

Figure 1. Concrete sample curing by water immersion

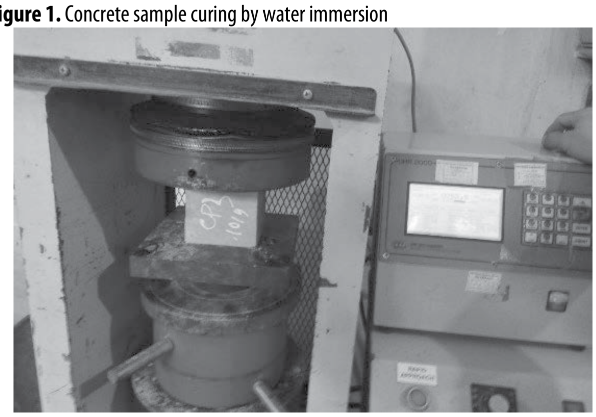

Figure 2. Concrete compression testing

2.2. *Materials Used*

The materials used in the experiment included: Vicem But Son PC40 cement; Yellow sand from the Red River, with a fineness modulus of 2.76; Crushed stone with Dmax=10mm, crushed stone, density 2.75g/m^3; Fly ash: Pha Lai thermal power fly ash, type F according to ASTM C618 standard; Superplasticizer (SP): BiFi-HV298 new-generation superplasticizer, improved polymer-based, density 1.05, compliant with ASTM C-494 type G standard; Viscosity-modifying admixture (VMA): Culminal MHPC400 type viscosity-modifying admixture.

2.3. *Experimental Concrete Mix Designs*

The concrete mix designs were conducted following the method proposed by Akamura and Ozawa [6]. In the experiment, a total of three different mix designs were used for evaluation. The mix designs were created by varying the Fly ash/Powder (FA/P) ratio, including 0%, 50%, and 60% FA/P, with a fixed water-to-powder ratio (W/P) of 0.35. The composition of the mix designs for 1m^3 of concrete is detailed in Table 1.

Table 1. Mix Designs of SCC

Mix Design	Cement PC40 (kg)	Fly Ash (kg)	Sand (kg)	Stone (kg)	SP (kg)	VMA (kg)	Water (kg)
CPF0	655.2	0	748.8	770	6.55	0.15	196.6
CPF50	303.4	303.4	748.8	770	6.07	0.21	182
CPF60	222.8	334.3	748.8	770	5.57	0.19	195

3. EXPERIMENTAL RESULTS

3.1. *Self-Compacting Concrete Workability Testn*

According to [7], the slump flow value (SF) should be within the range of 650-800mm, T500 flow time from 2-5 seconds, J-ring value from 0-10mm, V-funnel flow time from 6-12 seconds, and segregation degree Sr from 5-15%. The experimental results showed that the mix designs of self-compacting concrete met the EFNARC requirements for workability. Table 2 presents the measured workability parameters of the SCC mix designs.

Table 2. Results of SCC Workability Test

Mix Design	SF (mm)	T_{500} (second)	V_{funnel} (second)	L_{box}	J_{ring} (mm)	Sr (%)
CPF0	681	4.5	11.7	0.83	9.7	5.6
CPF50	730	3.37	11.1	0.91	9.1	7.1
CPF60	735	3.25	10.6	0.92	8.7	7.3

Table 3. Compressive Strength of SCC Mix Designs at Different Curing Times

Mix Design	Compressive Strength (MPa)		% Increase in Compressive Strength
	28-Day Curing	90-Day Curing	
CPF 0	60.4	61.0	0.99
CPF 50	54.0	56.0	3.7
CPF 60	46.0	50.0	8.7

3.2. *Compressive Strength Test Results of SCC*

The compressive strength test results indicated that the compressive strength of self-compacting concrete at 90 days of age with 0%, 50%, and 60% fly ash content was 60.4 MPa, 54 MPa, and 46 MPa, respectively, with 28 days of water curing, and 61 MPa, 56 MPa, and 50 MPa, respectively, with continuous 90 days of water curing. Thus, replacing fly ash at 50% and 60% ratios decreased the compressive strength of self-compacting concrete compared to the control samples by 10.6% and 23.84% with 28 days of water curing and by 8.2% and 18.03% with 90 days of continuous water curing (Figure 3 and Table 3).

Prolonged curing time positively impacted the compressive strength development of self-compacting concrete using fly ash as a mineral admixture. The compressive strength of self-compacting concrete at 90 days of age with fly ash replacement ratios of 50% and 60% with continuous 90 days of water curing increased compared to the samples cured continuously for 28 days by 3.7% and 8.7%, respectively. In contrast, mix designs without fly ash showed relatively little increase in compressive strength at 90 days of age with prolonged curing time; samples cured continuously for 90 days only increased by approximately 0.99% compared to samples cured continuously for 28 days. This is explained by the extended curing time creating favorable conditions for fly ash to react with the calcium hydroxide generated from the hydration process of cement. This increases the rate of formation of secondary hydration products of fly ash and fills the voids in self-compacting concrete, thereby increasing its strength [8]. However, due to the high content of fly ash, the amount of calcium hydroxide generated from the hydration reaction of cement is insufficient to carry out the reaction, so part of the fly ash acts as inert material, resulting in significantly lower compressive strength of mix designs with high fly ash content compared to control samples.

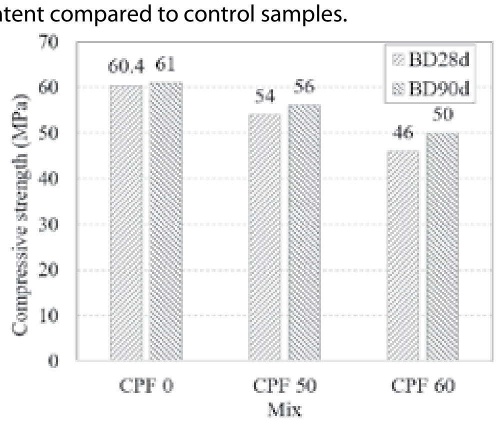

Figure 3. Compressive Strength of Mix Designs at 90 Days of Age with Different Curing Times

4. CONCLUSION

The compressive strength of self-compacting concrete (SCC) with fly ash replacement ratios of 50% and 60% at 90 days of age with 28 days of water curing achieved the values of 54 MPa and 46 MPa, respectively. Increasing the water curing time to 90 days, the compressive strength of SCC using Class F fly ash at 50% and 60% replacement levels increased by 3.7% and 8.7%, respectively, compared to samples cured for 28 days.

The compressive strength of SCC without fly ash at 90 days of age with 28 days of water curing reached a value of 60.4 MPa. The use of Class F fly ash at 50% and 60% ratios reduced the compressive strength of concrete compared to samples without fly ash by 10.6% and 23.84%, respectively, with 28 days of water curing, and by 8.2% and 18.3%, respectively, with 90 days of water curing. For SCC without fly ash, prolonging the water curing time from 28 days to 90 days resulted in a negligible increase in compressive strength, only about 0.99%.

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