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Research on the Strength of Cost-Effective UHPC Material based on Size Effect

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Abstract

Conventional concrete exhibits a size effect in compressive strength testing, whereas ultra-high-performance concrete (UHPC) shares a closer composition with ordinary mortar. This study investigates the compressive strength of cubic specimens with dimensions of 70.7 mm × 70.7 mm × 70.7 mm and 100 mm × 100 mm × 100 mm, analyzing their strength at different curing ages and deriving a 28-day strength ratio coefficient. The findings provide detailed performance data for UHPC, supporting both engineering applications and experimental research.

Keywords

Size Effect; Compressive Strength; UHPC; Strength Ratio Coefficient; Engineering Applications.

1. Introduction

Compared to conventional concrete, UHPC offers superior strength, elastic modulus, and toughness. However, its production requires high-quality raw materials and stringent curing conditions (e.g., high temperature and humidity), leading to elevated costs that limit widespread application. Recent studies have explored cost reduction strategies, such as substituting expensive materials with low-cost alternatives while maintaining mechanical performance, particularly compressive strength[1]. From the perspective of environmental protection, waste industrial materials (such as slag, steel slag powder, etc.) are fully utilized as alternative materials[2].

This study develops economically viable UHPC using locally sourced materials and evaluates its compressive performance at different curing ages. A comparative analysis of strength values for varying specimen sizes is also conducted.

2. UHPC Specimen Preparation

Following standards (JGT 472-2015)[3], CEM I 52.5[4]), high-strength cement was selected as the binder. Mineral admixtures (e.g., silica fume) were added to fill pores and enhance microstructural density, optimizing strength. Research indicates that a 35% silica fume content (by cementitious material weight) achieves optimal density and workability[5]. To mitigate weak interfacial transition zones and microcracks, coarse aggregates were excluded[6], while fine aggregates (≤0.8 mm) were used. Sand -binder ratio ≥1:1.2 and particle size ≤0.6 mm ensured workability and cost efficiency[7]. Water-binder ratio <0.25 necessitated superplasticizers for workability. Steel fibers (2–3% by volume, short smooth copper-coated type) were added to enhance mechanical properties[8]. Fiber is one of

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the important components of UHPC. It mainly plays the role of toughening and cracking resistance.The bending strength is approximately linear with the increase of the volume of steel fiber. The crude propylene fiber absorbs a lot of energy when it is pulled out or broken. The type of dimension, the amount and the way of incorporation have an effect on the mechanics of UHPC after high temperature. Based on the aforementioned selection criteria, and considering the supply situation of local building materials, propose a method for preparing UHPC using local materials.

Materials and Properties:

Cement: Ordinary Portland cement (52.5 MPa; properties in Table 1). Silica fume: Powdered, average particle size <0.2 μm (Table 2). Fine aggregate: River sand (≤0.6 mm, 0.1% silt content) replaced costly quartz sand.Superplasticizer: Polycarboxylate-based powder (Table 3). Steel fibers: 13 mm length, 0.2 mm diameter, tensile strength 2660 MPa.

During the mixing process, in order to make the distribution of steel fibers more uniform, half the volume of steel fibers and other materials are dried together for about 4 minutes when stirring, followed by wet-mixing with water and remaining fibers for 5 minutes. Flowability reached 25 cm after 25 vibrations in 15 s (ASTM C666/C666M-15[9]; Figure 1). Specimens were vibrated for 10 s to prevent fiber sedimentation, then cured at 20±0.5°C and RH >95% for 48 h before demolding.

Table 1. Mechanical properties of ordinary Portland cement

Fineness	Compressive Strength(MPa)		Flexural Strength(MPa)		Loss on Ignition
	3 d	28 d	3 d	28 d	
<10%	22	52.5	4.0	7.0	<5.0%

Table 2. Properties of silica fume

SiO_2	Cl^-	Fe_2O_3	Al_2O_3	CaO	MgO	K_2O	H_2O	Loss on Ignition	Particle Size
>92%	<0.02%	<1.0%	<1.0%	<1.0%	<1.2%	<1.2%	<3.0%	<6.0%	<6.0%

Table 3. Technical parameters of polycarboxylate superplasticizer

Bulk Density (g/L)	Active Content	Residual Moisture	pH	Mortar Water Reduction Rate
500-700	≥90%	≤3%	6.0-8.0	≥21%

Figure 1. The UHPC liquidity test

3. Compressive Strength Testing and Analysis

Specimens cured for 7, 14, and 28 days were tested under a 200-ton hydraulic press at a loading rate of 1.2 MPa/s.

3.1 Failure Modes

For 70.7×10.7×70.7mm^3 cubes, 7-day specimens exhibited spalling and vertical cracks but retained partial integrity (Figure 2(a)). Internal shear sliding planes indicated ductile shear failure. At 14 and 28 days, reduced cracking and improved integrity were observed due to enhanced fiber-matrix bonding (Figure 2(b),(c)).

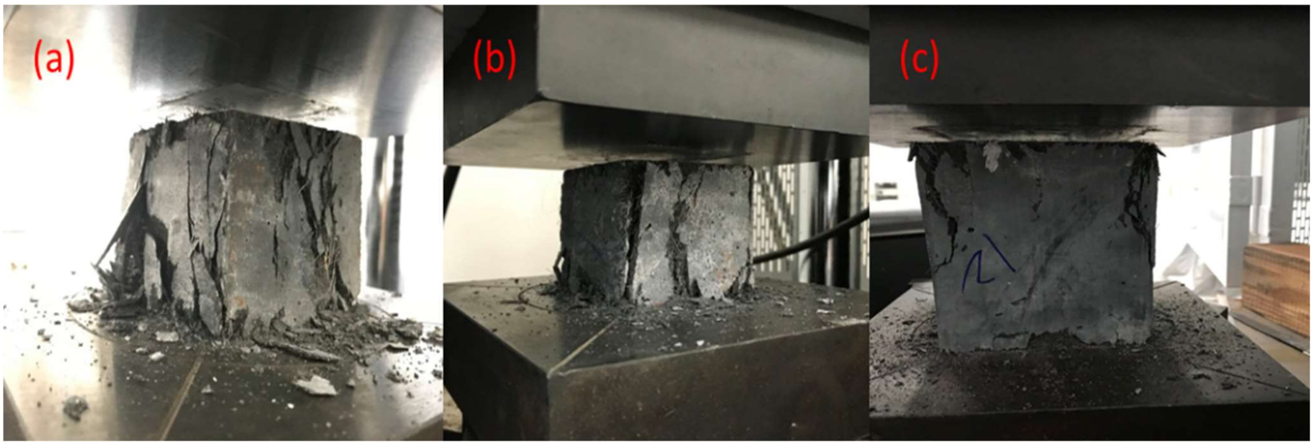

Figure 2. Compression failure of UHPC samples at different curing ages

3.2 Curing Age Effect

Compressive strength increased with curing age (Table 4). At the 7th day, the compresive strength reached 73.2% of the 28-day value (129.3 MPa), and at the 14th day, the compresive strength reached

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83.7% of the 28-day value. This meets the development law of concrete strength in concrete curing, and when it is at 28th day, the strength of the test block also meets the domestic standard requirements, that is, the China's UHPC strength standard (120 MPa)[10].

Table 4. Compressive strength of UHPC at different curing ages (MPa)

fcu	7d			14d			28d		
	93.3	94.6	96.3	108.9	105.8	110.3	128.4	130.7	128.7
Means	94.7			108.3			129.3		

3.3 Size Effect Comparison

100×100×100 mm^3 cubes cured for 28 days showed an average strength of 121.2 MPa, this also meets the strength requirements in the specification. Its failure patterns is similar to the 70.7×10.7×70.7mm^3 cubes specimens. The strength ratio between 70.7×10.7×70.7mm^3 and 100×100×100 mm^3 specimens was 0.937 and 1.067.

4. Conclusion

In this paper, local building materials are used to prepare economical UHPC, and the compressive strength test of the cube was maintained to different ages under the same curing conditions as ordinary concrete. The compression failure form of this type of UHPC is shear failure, and its compressive strength increases with the growth of curing age. Based on the experimental value of compressive strength of different sizes, the proportion coefficient is proposed, so that the strength of two sizes of test block can be reasonably calculated, which facilitates the calculation of material strength test value and also has guiding significance for engineering practice.

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