

Research Article

Research on Fracture Toughness of C120 Ultra-High-Performance Concrete in Kingkey Financial Center Project

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Received 13 December 2011; Accepted 18 February 2012

Academic Editor: Jin Ping Lu

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By adding polypropylene fiber, fracture toughness of C120 ultra-high-performance concrete in Kingkey Financial Center project has been enhanced. The tests conducted by the Building Material Lab of the Civil and Water Conservancy Institute of Tsinghua University provided satisfactory results of mechanical property and fracture toughness of C120 ultra-high-performance concrete.

1. Preface

In order to understand the mechanical property of C120 ultra-high-performance concrete under static modulus of elasticity and anticracking properties, including fracture toughness, the research group of C120 ultra-high-performance concrete conducted a series of tests in the Building Material Lab of the Civil Water Conservancy Institute of Tsinghua University.

2. Experimental Details

2.1. Raw Materials. Following raw materials are used in this research: (1) cement (Nanjing Xiaoyetian PII52.5), (2) microballoon (Made in Kunming), (3) ganister sand (from Zhunyi, Guizhou), (4) Fine aggregate (sea sand, desalted, FM2.6~2.8), (5) coarse aggregate (macadam, 5–10, 10–20 mm in diameter), (6) Water reducer (BASF poly carboxylic acid, solid content: 40%, made in Guangdong), (7) water (Shenzhen tap water), and (8) polypropylene fiber (Grace 19 mm long fiber and short fiber provided by Shenzhen Lijian Concrete Company).

2.2. Mix Proportions. Please refer to Figure 1. This test aims to see what the difference is in concrete with long fibers and short fibers, so the compositions of every group of test pieces are the same, except fiber types and quantities.

2.3. Mixing Process. Get certain amount of raw materials ready. At first, put gelatinizer and sand into a mixer and run for 1 minute; then add water and additive, mix for 2 minutes; lastly, put in coarse aggregate, mix for 1 minute. For materials that are too sticky, mix 1 more minute after adding coarse aggregate. Find Mix Proportions in Table 1.

2.4. Specimens. Below specimens are used in the research:

100 mm × 100 mm × 400 mm prisms (3),

100 mm × 100 mm × 300 mm prisms (6),

100 mm × 100 mm × 100 mm cubes (3).

2.5. Curing. Upon being demoulded, specimens were transferred to the curing unit and soaked into calcarea hydrica solution (lime water) for 28 days. Finished specimens were immediately sent to the Building Material Lab of the Civil Water Conservancy Institute of Tsinghua University.

3. Main Mechanical Property Tests

Results of cube compression test, prismoid compression test, and static modulus of elasticity test have been listed in Figures 1 and 2. Equipment used in the tests included YE-200A hydraulic pressure test machine, YJR-5 static digital

TABLE 1: Mix proportions.

No.	W/B	C	SF + FA + BFS	S	G1	G2	Polycarboxylic acid additive	Fibers
1	0.17	550	150	750	285	665	2.5%	No fiber
2	0.17	550	150	750	285	665	2.5%	Long fiber, 1 kg/m ³
3	0.17	550	150	750	285	665	2.5%	Long fiber, 2 kg/m ³
4	0.17	550	150	750	285	665	2.5%	Short fiber, 2 kg/m ³



FIGURE 1: Damaged C120 concrete.

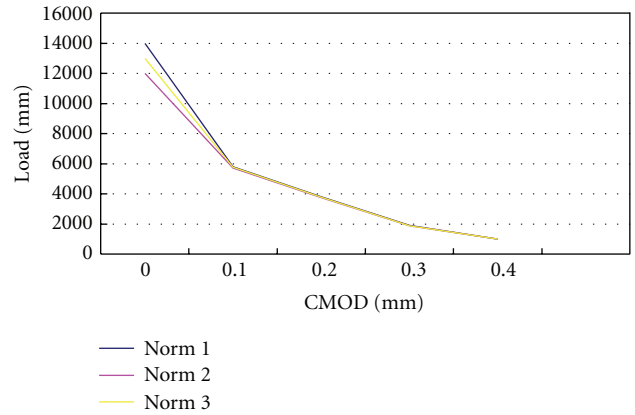


FIGURE 4: P-CMOD for basic concrete.



FIGURE 2: C120 high-performance concrete fracture parameter test.

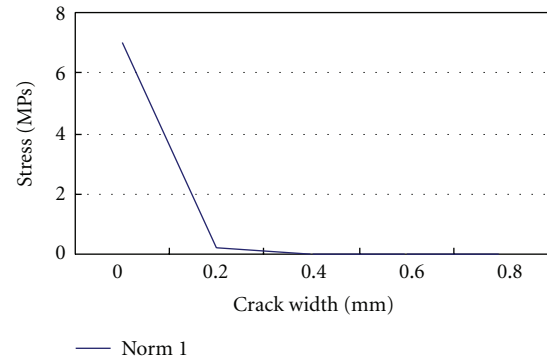


FIGURE 5: σ -w for basic concrete.



FIGURE 3: Crack opening displacement test.

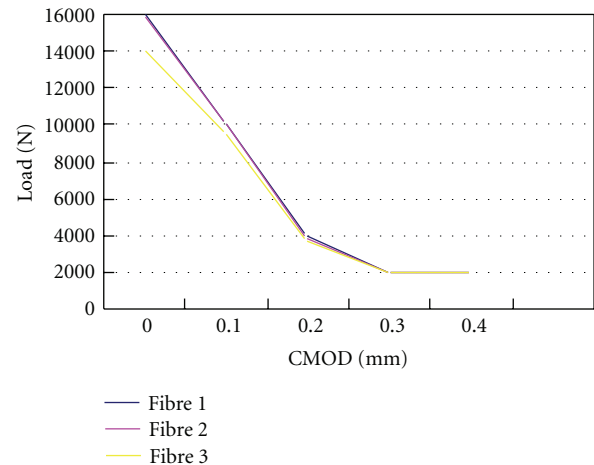


FIGURE 6: P-CMOD for concrete with 1 kg long fiber.

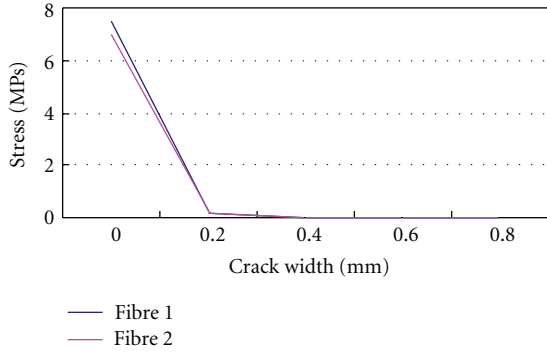


FIGURE 7: σ -w for concrete with 1 kg long fiber.

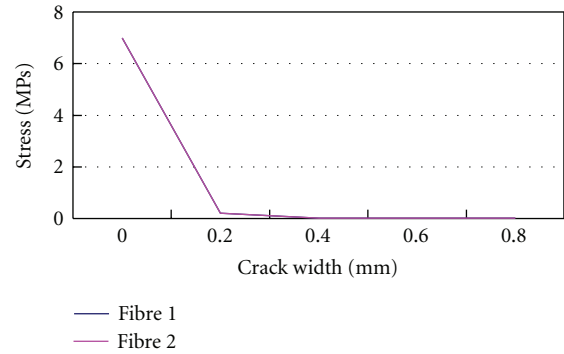


FIGURE 9: σ -w for concrete with 2 kg long fiber.

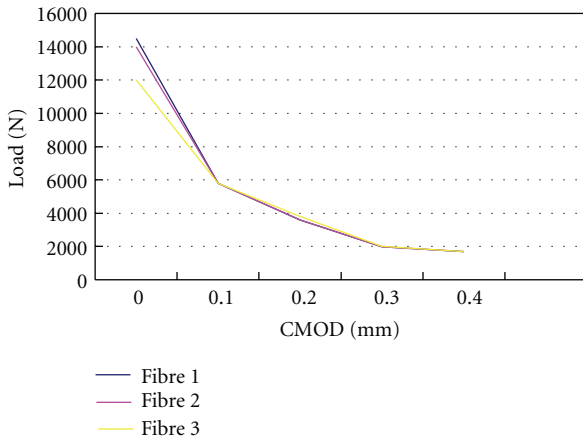


FIGURE 8: P-CMOD for concrete with 2 kg long fiber.

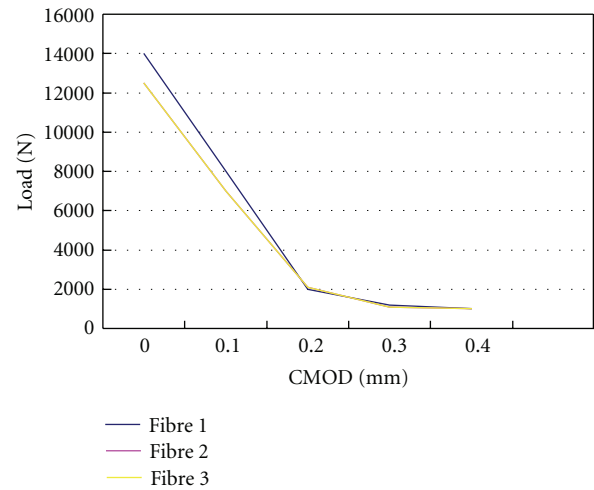


FIGURE 10: P-CMOD for concrete with 2 kg short fiber.

strain gauging unit, and YEW-200A dropping electrode compression-testing machine (Tables 2 and 3).

4. C120 Concrete Fracture Toughness Test

4.1. *Equipment.* Toni2071 Pressure Flexure Compression Testing Machine was made in Germany, Maximum Capacity 200 KN, for flexure and crack opening displacement tests under constant rate of loading or rate of displacement.

4.2. *C120 Concrete Fracture Parameter Test.* See Figures 2 and 3.

4.3. *P-CMOD and σ -w Curve Charts for 4 Types of Concrete.* Through tests, we got the P-CMOD (loading—crack opening displacement) curve charts for basic concrete, concrete with 1 kg long fiber, concrete with 2 kg long fiber, and concrete with 2 kg short fiber, on which we came up with the O-W (softening relation) curve charts (Table 4).

5. Analysis

(1) From Figures 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, and 15, we could tell that P-CMOD and O-W curves were similar for the same type of concrete, which meant test piece's dispersion was not large.

- (2) 4 types of concrete were almost the same, except fiber content, which only presented difference after cracking. Therefore, the cracking load for all 4 types of concrete was similar.
- (3) As fiber content increased, concrete's tensile strength almost remained the same.
- (4) As fiber content increased, concrete's cracking energy mounted too. When the fiber content remained the same, fiber type played a role in cracking difference. Test results suggested that cracking energy rose in order of basic concrete < concrete with 1 kg long fiber < concrete with 2 kg long fiber < concrete with 2 kg short fiber.
- (5) Characteristic length of brittleness " l_{ch} " notates the brittleness of concrete. The smaller the number is, the more brittle the concrete is. From the test results, we learnt that as fiber content increased, concrete's toughness enhanced too. Characteristic length of brittleness varies in order: basic concrete < concrete with 1 kg long fiber < concrete with 2 kg short fiber < concrete with 2 kg long fiber, and toughness varies in order: basic concrete < concrete with 1 kg long fiber

TABLE 2: Compressive strength test results of cube specimens.

No.	Age	Size	Individual value	Compression strength
1: Initial	28 days	100 × 100 × 100 mm	127.0 MPa	124.0 MPa
			121.0 MPa	
			124.0 MPa	
2: 1 kg long fiber	28 days	100 × 100 × 100 mm	129.0 MPa	124.7 MPa
			126.0 MPa	
			119.0 MPa	
3: 2 kg long fiber	28 days	100 × 100 × 100 mm	140.0 MPa	135.3 MPa
			123.0 MPa	
			141.0 MPa	
4: 2 kg short fiber	28 days	100 × 100 × 100 mm	120.0 MPa	118.0 MPa
			115.0 MPa	

TABLE 3: Results of compressive strength and static modulus of elasticity of prism specimens.

No.	Age	Size	Compression strength		Static modulus of elasticity	
			Individual	Average	Individual	Average
1: Initial	28天	100 × 100 × 300	115.2 MPa	138.0 MPa	5.20 × 10 ⁴ MPa	5.20 × 10 ⁴ MPa
			138.0 MPa			
			138.8 MPa			
2: 1 kg long fiber	28天	100 × 100 × 300	127.2 MPa	128.7 MPa	5.10 × 10 ⁴ MPa	5.23 × 10 ⁴ MPa
			126.8 MPa			
			132.0 MPa			
3: 2 kg long fiber	28天	100 × 100 × 300	137.2 MPa	136.6 MPa	5.22 × 10 ⁴ MPa	5.30 × 10 ⁴ MPa
			139.0 MPa			
			133.6 MPa			
4: 2 kg short fiber	28天	100 × 100 × 300	104.8 MPa	116.7 MPa	5.18 × 10 ⁴ MPa	5.25 × 10 ⁴ MPa
			116.4 MPa			
			128.8 MPa			

TABLE 4: Concrete fracture parameter test results.

Type	No.	E (GPa)	P_{fc} (N)	P_{max} (N)	σ_c (MPa)	σ_{fc} (MPa)	σ_t (MPa)	σ_f (MPa)	G_f (J/m ²)	l_{ch} (cm)
Basic	1	51.9	5000	14000	127.0	6.82	6.86	9.07	213.8	23.5
	2		4600	14500	121.0	6.27	—	9.39	—	—
	3		4700	13800	124.0	6.41	—	9.59	—	—
	Avg.		4767	14100	124.0	6.50	6.86	9.35	213.8	23.5
1 kg long fiber	1	52.2	4800	13800	129.0	6.55	6.67	8.94	291.8	33.8
	2		5000	15500	126.0	6.82	7.08	10.04	302.9	27.9
	3		5000	15300	119.2	6.82	—	9.91	—	—
	Avg.		4933	14867	124.7	6.73	6.88	9.63	297.35	30.9
2 kg long fiber	1	52.2	4800	12000	140.8	6.55	6.56	7.78	322.8	39.2
	2		5000	15000	123.6	6.82	—	9.73	—	—
	3		5200	14000	141.4	7.09	7.22	9.08	322.1	33.4
	Avg.		5000	13667	135.3	6.82	6.89	8.86	322.5	36.3
2 Kg short fiber	1	52.0	5100	14000	120.0	6.95	6.97	9.07	300.3	30.0
	2		5000	14000	115.0	6.82	6.84	9.07	321.8	30.7
	3		5200	14000	—	7.09	—	9.07	—	—
	Avg.		5100	14000	118.0	6.95	6.91	9.07	311.1	30.4

(P_{fc} = cracking load, P_{max} = maximum load, E = modulus of elasticity, σ_c = compression strength, σ_{fc} = cracking strength, σ_t = tensile strength, σ_f = flexural strength, G_f = fracture energy, l_{ch} = brittleness; the smaller the l_{ch} is, the more brittle the concrete is)

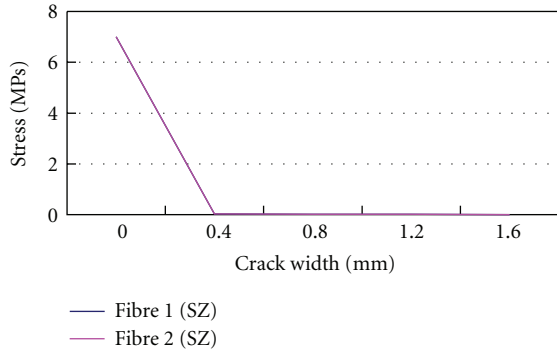


FIGURE 11: σ - w for concrete with 2 kg short fiber.

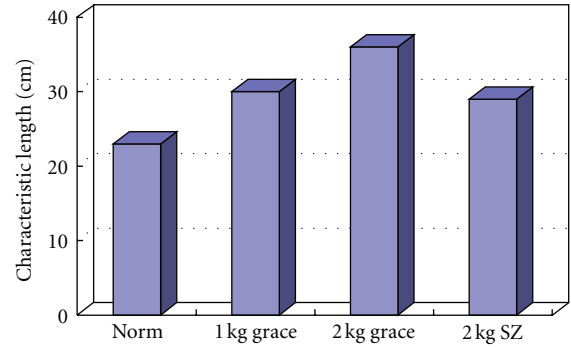


FIGURE 15: Characteristic length comparison.

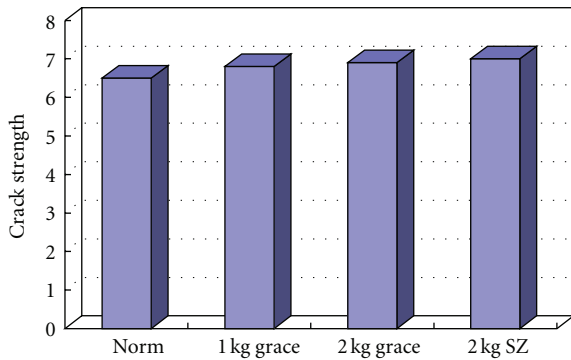


FIGURE 12: Cracking strength comparison.

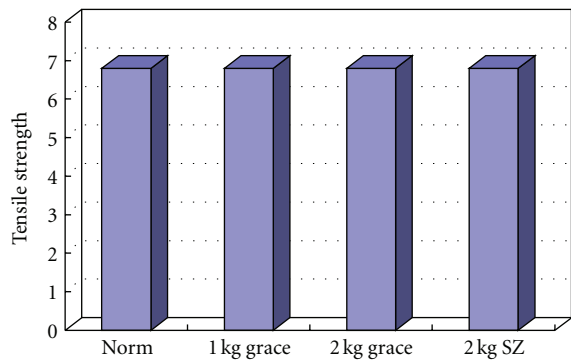


FIGURE 13: Tensile strength comparison.

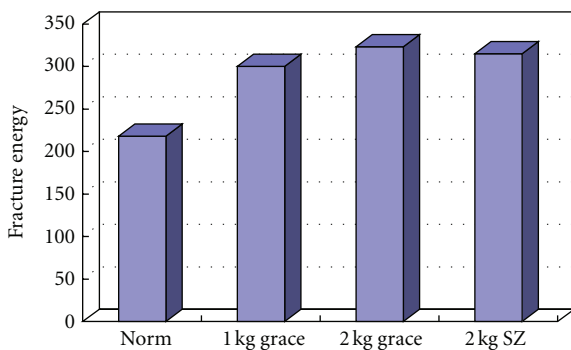


FIGURE 14: Cracking energy comparison.

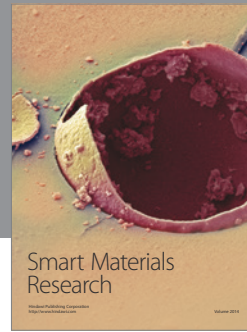
< concrete with 2 kg short fiber < concrete with 2 kg long fiber.

6. Conclusions

- (1) C120 ultra-high-performance concrete's fracture toughness can be enhanced by adding fiber, and as fiber content increases, cracking energy mounts too. When fiber content stays the same, fiber type makes difference too.
- (2) Characteristic length of brittleness notates the brittleness of concrete. The smaller the number is, the more brittle the concrete is. As fiber content increases, concrete's toughness enhances too.

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