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Preparation and Application of C60 High Performance Concrete

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Abstract: C60 High Performance Concrete (HPC) was prepared by limiting cement content and adopting composite superplasticizer, low-alkalinity expansive agent and high-quality fine mixture. The results showed that the performance of the prepared C60 HPC was excellent. By adopting some advanced construction techniques such as using secondary vibration and secondary face compaction, controlling temperature difference and paying special attention to early curing in the construction process, the prepared C60 HPC had been successfully applied in the monolithic structure of huge building.

Key words: concrete performance; construction techniques; application of C60 high performance concrete

The future of concrete materials is to develop high performance such as high strength, lightweight, high fluidization and durability, but most of concrete used in China is low-grade concrete, such as C20 or C30. Although some structure members have been constructed with C50 or C60 concrete, it was rare to construct any monolithic structure of huge building with C60 High Performance Concrete (HPC) in China before [1~3].

The extension of Beijing Capital International Airport includes following subdivisions: New Port Building, Garage Building, 17 Viaducts, Parking Apron, East and West Runways. The New Port Building is a four-story building of 747.5 m in length and 342.9 m in width with an all cast-in-situ frame structure. The architectural area is 335 000 m^2, and the building costs nearly 3 billion RMB. Except baseslabs are to be constructed with 45,000 m^3 C40 and S8 concrete, all the New Port Building should be constructed with C60 or C65 HPC. This is the first time to construct so huge a monolithic structure with C60 HPC in China.

1 Experimental

1.1 Raw materials

(1) Cement.

The cement used is 525# normal Portland cement and its properties are shown in **table 1**.

(2) Aggregates.

The coarse aggregates are the well-graded crushed pebbles with nominal diameter 5~20 mm. The apparent density of the coarse aggregates is about 2 700 kg/m^3 and clay content is less than 1%. The fine aggregates are the well-graded medium sand with fineness modulus 2.7 and clay content less than 2%.

(3) Water-reducing agent.

YGU-F3T composite superplasticizer is adopted and it has following properties: water reducing ratio is 30%, compressive strength ratios are 200% (3 days), 140% (7 days), 122% (28 days).

(4) Active fine mixture.

The 1st grade fly ash is used as the active fine mixture.

(5) Expansive agent.

The expansive agent used is UEA low-alkalinity expansive agent.

1.2 Preparation

Based on the experience of the pre-developed C60

Table 1 Properties of the cement

Compressive strength/MPa		Bending strength/MPa		Residue of 0.08 mm sieve / %	Standard consistency / %	Setting time / min	
3 days	28 days	3 days	28 days			initial	final
31.5	56.2	6.1	8.6	8	26.7	133	315

HPC, the typical mixture ratio of the C60 HPC was determined and shown in **table 2**. In the preparation process of C60 HPC, the following techniques were adopted:

Table 2 The typical mixture ratio of the C60 HPC

Materials	cement	fine aggregate	coarse aggregate	fly ash	UEA	YGU-F3T	water
Content/kg·m^{-3}	450	680	1020	83	60	30	180

(1) Limiting the cement content less than 450 kg/m^3, which can effectively reduce the hydration heat and prevent shrinkage without lowering the concrete strength.

(2) Adding extra 20%~25% 1st grade fly ash, which can prolong setting time, lower the hydration heat, enhance the long-term strength and durability, and improve workability.

(3) Adding UEA low-alkalinity expansive agent 8%~12%, which can compensate shrinkage and prevent the concrete from cracking.

(4) Adopting composite superplasticizer.

2 Results and Discussion

2.1 Volumic mass

The volumic mass of both experimental C60 HPC samples and actual C60 HPC samples is from 2 400 to 2 500 kg/m^3, and the average value was 2 456 kg/m^3 by measurement.

2.2 Hydration temperature

Figure 1 shows the hydration temperature difference between C60 common high-strength concrete and C60 HPC in 7 days. The results indicated that the hydration heat peak decreased from 73 (common C60) to 55℃ (C60 HPC) and the highest hydration temperature occurred 10 h latter than that of the common C60 concrete, which is favorable for avoiding cracks caused by temperature stress.

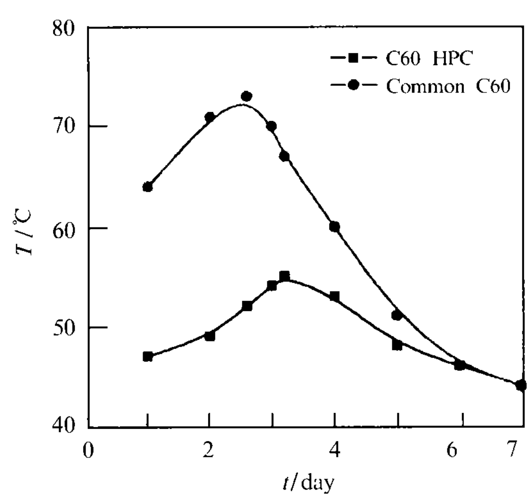

Figure 1 Hydration temperature

2.3 Setting time and slump loss

Since the adoption of the composite superplasticizer, the setting time of the mixture was postponed to be 10~14 h so that the working face could be covered conveniently in the construction process. The slump loss within 2 h was less than 10%, which was satisfactory for pump concrete [4]. Furthermore, it can postpone the occurring time of the cement hydration heat peak. Some results are shown in **figures 2 and 3**.

2.4 Gas content of the fresh concrete

The gas contents (mass fraction) are shown in **table 3**. The gas contents of fresh concrete were 1.7%~2.5% and become 0.7%~1.0% after vibration. So the con-

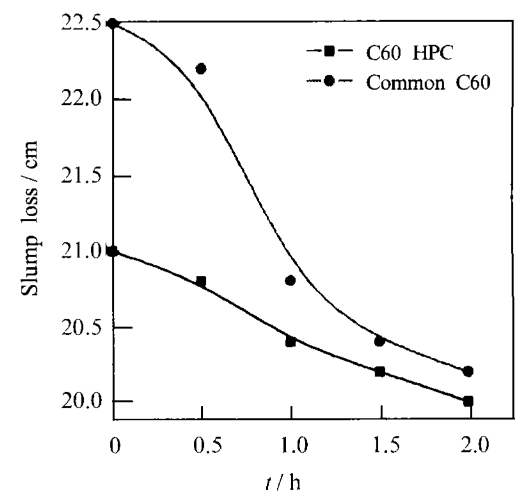

Figure 2 Slump loss of the mixture

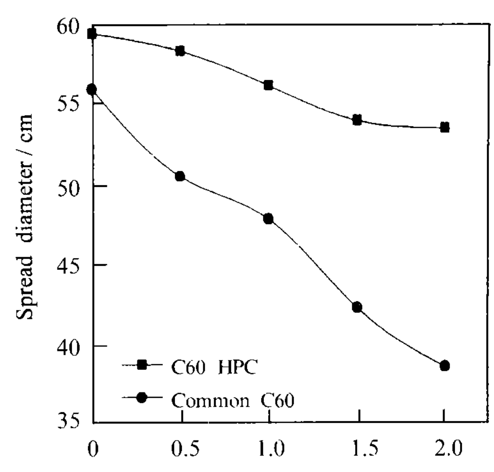

Figure 3 Spread diameter of the mixture

Table 3 Gas contents of the fresh concrete

Specimen	Superplasticizer / %	Fly ash / %	Slump / cm	Gas content, w_{gas}/ %	
				before vibration	after vibration
1	1.0	0	16.0	1.2	0.5
2	1.4	20	19.0	1.7	0.7
3	1.8	20	22.5	2.5	1.0

crete should be fully vibrated in the casting process to minimize the gas content.

When the naphthalene-system composite superplasticizer was substituted for common water-reducing agent, the gas content was much less, the micro-bubbles caused by the gas was closed and well distributed, so the concrete strength did not reduce, while the workability, water-retentivity and pumpability of the C60 HPC were improved.

2.5 Impermeability

The mixture ratio for the blocks used for impermeability experiments was the same as that of the actual C60 HPC. After 28 days standard curing, the blocks were pressured 8 h with 3.5 MPa water pressure. The results showed that there was no water penetration on the top surface, but in the bottom of the blocks, the depth of the water penetration was 5~10 mm.

2.6 Shrinkage

The test cubes were 100 mm× 100 mm× 515 mm. After 24 h standard curing, the test cubes were cured at 20~25℃ with RH (relative humidity) ≥ 90%. The length variation had been measured since the third day.

The results showed in **figure 4** indicated that the shrinkage rate of the C60 HPC was less than that of the common C60 concrete. After 60 days, the shrinkage rate was about 250×10^{-6}~ 400×10^{-6}.

2.7 Modulus of elasticity

Series of measurements suggested that the final modulus of elasticity (E_c) of C60 HPC was in the range from 4.16×10^4 to 4.28×10^4 MPa, the average value was 4.2×10^4 MPa. Since the increase of the modulus ofelasticity, the ultimate deformability of the C60 HPC was strengthened.

2.8 Freezing thawing test

The results of the freezing thawing tests are shown in **table 4**. The excellent freezing thawing resistance of the C60 HPC was resulted from its low water cement ratio, high strength and dense structure [5]. The strength loss of the C60 HPC after 150 circles was only 2.5%~3.1%, far less than that of the common concrete. So, the durability of the C60 HPC was better.

2.9 Other mechanical properties

Other mechanical properties of the C60 HPC are shown in **table 5**.

In general, the C60 HPC should meet the following technical indexes [5]: (1) Design strength, $R_{Design} \geq R + 1.645\delta$. (2) Setting time, the initial setting time should be 10~12 h and 12~14 h for the final setting time. (3) Slump loss, slump loss should be less than 10% after 1 h and spread diameter within 2 h should be more than 450 mm. (4) Hydration heat, the occurring time

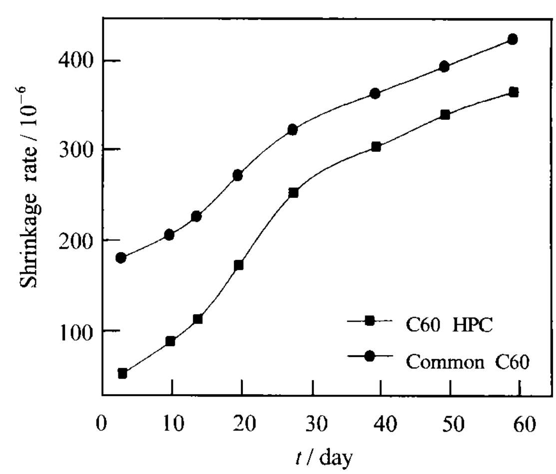

Figure 4 Shrinkage rate of the concrete

Table 4 Results of the freezing thawing test

Type	Compressive strength / MPa	50 cycles			100 cycles			150 cycles		
		A / MPa	B / MPa	loss / %	A / MPa	B / MPa	loss / %	A / MPa	B / MPa	loss/ %
experimental	71.9	70.1	71.0	1.3	71.7	73.2	2.0	68.1	69.8	2.5
actual	71.2	69.4	70.2	1.1	70.5	72.1	2.2	69.2	71.4	3.1

Note: "A" and "B" express the strength after and before freezing thrawing test, respectively.

Table 5 Mechanical properties of the C60 HPC

Age / day	fcc / MPa	fcp / MPa	f_f / MPa	fts / MPa	Strength ratio		
					fcp / fcc	fcc / fts	fcc / f_f
28	71.9	54.8	8.6	5.4	0.76	8.34	13.2

Note: fcc is the cube crushing strength, fcp the axial compressive strength, f_f the bending strength and fts the cleavage strength.

of the hydration heat peak should be postponed and the peak should be lowered by 15%~20% than that of common concrete, the maximum temperature should be less than 55℃. (5) Shrinkage, shrinkage in each age should be less than that of C30 common concrete.

The above performance showed that the prepared C60 HPC had possessed of excellent performance such as high strength, low hydration heat, low shrinkage, super durability and favorable workability. It was good enough to meet the technical indexes of C60 HPC.

3 Application of the C60 HPC in the New Port Building

The application of C60 HPC is a comprehensive technique, which includes two aspects: preparation process and construction process. In order to assure the quality of construction projects, besides the above techniques being taken in the preparation process, some other construction techniques must also be adopted cooperatively in the construction process. For example:

(1) High-frequency vibrator should be used, and undervibration or overvibration should be avoided.

(2) Secondary vibration and secondary face compaction should be adopted to minimize cracks before and after hardening.

(3) Special attention should be paid to early curing. The concrete should be covered immediately after casting to avoid early water-loss. When the concrete achieve the strength of 5~10 MPa (after 16~20 h), baseslabs should be water-retaining cured, and walls should be stripped and covered with gunny bag immediately. Then, the concrete should be cured by pouring water for 14 days. In this way, the internal water-loss was avoided and the temperature difference between the surface and interior of bulk concrete was minimized.

By optimizing the mixture ratio of the C60 HPC and adopting the above mentioned techniques in both preparation process and construction process, not only the strength of the C60 HPC was ensured, but also the cracks resulted from temperature stress and dry shrinkage were avoided. By the April 1997, the C60 HPC had been successfully applied in the monolithic structure of the New Port Building in Beijing Capital International Airport. The total consumption of C60 HPC was about 160 000 m^3. The maximum pump distances were 260 m in horizontal and 30 m in vertical. A few statistical strength data of the concrete are shown in **table 6**.

Table 6 A few statistical strength data of the C60 HPC

Group number	Average / MPa	Maximum / MPa	Minimum / MPa	Standard deviation
1000	69.2	87.7	61.8	3.6

4 Conclusions

(1)By limiting cement content and adopting composite superplasticizer, low-alkalinity expansive agent and high-quality fine mixture, the C60 HPC with excellent performance can be prepared.

(2) The successful application of the prepared C60 HPC in the monolithic structure of the New Port Building in Beijing Capital International Airport indicates that by adopting some advanced construction techniques such as using secondary vibration and secondary face compaction, controlling temperature difference and paying special attention to early curing in the construction process, the prepared C60 HPC can be applied in the monolithic structure of huge building.

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