Preparation of Shrinkage Compensating Concrete with HCSA Expansive Agent

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Abstract. Shrinkage compensating concrete (SCC) has become one of the best effective  
methods of preventing and reducing concrete cracking. SCC is prepared by HCSA high  
performance expansive agent for concrete which restrained expansion rate is optimized by  
0.057%. Slump, compressive strength, restrained expansion rate and cracking resistance test  
were carried out on SCC. The results show that the initial slump of fresh SCC was about  
220mm-230mm, while slump after 2 hours was 180mm-200mm. The restrained expansion rate  
of SCC increased with the mixing amount of expansive agent. After cured in water for 14 days,  
the restrained expansion rate of C35 and C40 SCC were 0.020%-0.032%. With the dosage of  
expansive agent increasing, restrained expansion rate of SCC increased, maximum  
compressive stress and cracking stress improved, cracking temperature fell, thus cracking  
resistance got effectively improvement.

1. Introduction  
Concrete will crack when internal tensile stress exceeds the tensile strength of concrete under  
restrained condition. Due to the emphasis on early strength, increase of concrete strength grade and  
cement fineness, the cracking caused by thermal shrinkage and drying shrinkage are the most common  
in actual projects. And these will inevitably result in a series of performance degradation and hence  
influence the durability and service life of concrete structure. The expansion generated by hydration of  
expansive agent establishes 0.2MPa-0.7MPa pre-stress in shrinkage compensating concrete (SCC).  
Thus, thermal shrinkage and drying shrinkage can be effectively compensated by the pre-stress. SCC  
has been widely used to prevent and reduce cracking of concrete in engineering.

HCSA is a double expansive sources high performance expansive agent for concrete. Calcium  
oxide is the major expansive sources, and gypsum and calcium sulphaolamate are the assistant  
expansive sources. HCSA has the advantage of high expansion (restrained expansion rate is 0.17% in  
water), fast expansion speed, anhydrous expansion, short expansion period, small drying shrinkage,  
and can activate the activity of mineral admixture [2]. HCSA can effectively compensate drying  
shrinkage and thermal shrinkage, thus improve crack resistance and anti-seepage of concrete. HCSA  
has been successfully used in concrete structural self-waterproofing, jointless constructing of the  
excessive-length construction, and cracks prevention of mass concrete [3].

It is well known that waterproofing is the premises to ensure the normal use of underground  
engineering. Once the concrete structure cracks, the leakage is unavoidable. So crack resistance is  
more important than anti-permeability of concrete in underground engineering. The object of this  
study is preparing SCC with 0.020%-0.032% restrained expansion rate by HCSA high performance  
expansive agent.
2. Experimental

2.1 Materials

Ordinary Portland cement (P.O 42.5), S95 ground granulated blast furnace slag (GGBS), Class F II grade fly ash (FA) and calcium sulfoaluminate-calcium oxide expansive agent (HCSA) were used in this study. The physical properties of cement and performance index of HCSA expansive agent are listed in Table 1 and Table 2, respectively. The restrained expansion rate of HCSA is shown in Figure 1. River sand with a fineness modulus of 2.60, crushed stone with a continuous gradation of 5mm-25mm were used as fine and coarse aggregate. Polycarboxylate superplasticizer with a water-reducing rate of 28% was also used. Tap water was used as mixing water.

### Table 1. Physical properties of cement.

| Density (g/cm³) | Specific surface area (m²/kg) | Setting time (min) | Flexural strength (MPa) | Compressive strength (MPa) |
|-----------------|-------------------------------|--------------------|-------------------------|---------------------------|
|                 |                               | Initial setting | Final setting | 3d  | 28d  | 3d  | 28d  |
| 3.15            | 345                           | 151              | 216              | 6.0 | 8.5  | 29.3| 49.6 |

### Table 2. Performance index of HCSA expansive agent.

| Items                                | Index | Measured value |
|--------------------------------------|-------|----------------|
| Fineness                             |       |                |
| Specific surface area (m³/kg)        | ≥ 200 | 325            |
| Residue on sieve (1.18 mm mesh,%)    | ≤ 0.5 | 0              |
| Setting time (min)                   |       |                |
| Initial setting                      | ≥ 45  | 195            |
| Final setting                        | ≤ 600 | 238            |
| Restrained expansion rate (%)        |       |                |
| Water curing 7 days                  | ≥ 0.06| 0.056          |
| Air curing 21 days                   | ≥ −0.010| 0.011       |
| Compressive strength (MPa)           |       |                |
| 7 days                               | ≥ 20.0| 26.7           |
| 28 days                              | ≥ 40.0| 48.2           |

![Figure 1. Restrained expansion rate of HCSA expansive agent](image)

### Table 3. Concrete mixture proportions (kg/m³).

| Sample | Cement | FA | GGBS | HCSA | Fine aggregate | Coarse aggregate | Water | Superplasticizer |
|--------|--------|----|------|------|----------------|------------------|-------|-----------------|
| C35B   | 230    | 117| 40   | 35   | 633            | 1175             | 175   | 8.34            |
| C35W   | 230    | 112| 40   | 40   | 633            | 1175             | 175   | 8.34            |
| C40E   | 255    | 91 | 50   | 45   | 595            | 1209             | 170   | 9.53            |
2.2 Mix Proportions

Based on the comprehensive consideration of strength, restrained expansion rate, workability and durability of concrete, the optimized mixture proportions of SCC are shown in Table 3. Samples were designated as C35B (SCC for bottom plate), C35W (SCC for external wall and top plate) and C40 (SCC for expansion reinforcing band), respectively.

Slump, slump loss and density of fresh concrete were tested conforming to the Chinese national standard GB 50080-2002. Compressive strength of 7days and 28days was tested with cube specimens of 100mm×100mm×100 mm conforming to the Chinese national standard GB/T 50081-2002.

Restrained expansion rate of SCC were tested by the field measuring device for restrained expansion rate of concrete which invented by China Building Materials Academy. This device can be used to detect the restrained expansion rate of concrete specimen, which was placed in the prism mould measuring 100mm×100mm×400 mm with vertical limiter, both in water and in air. The restrained expansion rate of SCC was calculated by from equation (1).

\[ \varepsilon = \frac{L_1 - L}{2L_0} \times 100 \]  

Where \( \varepsilon \) is the restrained expansion rate of SCC, %; \( L_1 \) is the specimen length measuring results at the measured age, mm; \( L \) is the initial specimen length measuring results, mm; \( L_0 \) is the reference length, 300 mm.

The schematic diagram of restrained expansion rate measuring device for SCC is shown in Figure 2.

![Figure 2. Restrained expansion rate measuring device for SCC](image)

Cracking resistance of SCC was tested by a temperature stress testing machine (TSTM) under fully restrained condition. The TSTM-specimen was shaped like a dog-bone with the dimension of 1000mm×150mm×150 mm in the center part and 150mm×280mm×150 mm at its ends. The imported temperature rise-cooling curve was obtained from the engineering field measurement. The maximum compressive stress, crack stress, and crack temperature of SCC were measured to evaluate the cracking resistance.

3. Results and Discussion

3.1 Property of Fresh Concrete

Slump and slump loss directly decide the both constructability and operability of fresh concrete. To ensure the strength, restrained expansion rate and durability of concrete, the slump of concrete should be as low as possible when the concrete can be vibrated well. Considering execution conditions and the quality of Chinese construction workers, (180±30) mm is appropriate for the control value of concrete slump. The performance test results of fresh concrete are listed in Table 4.
As shown in Table 4, the initial slump of fresh SCC was about 220mm - 230mm, while slump after 2 hours was 180mm to 200mm. The concrete construction from mixing, transportation to placing can be completed in 2 hours. Thus the slump of fresh SCC simultaneously satisfied the demands of construction, durability and cracking resistance of concrete. Besides, 2400-2410kg/m³ density were also in accordance with the specification requirements.

| Sample | Slump (mm) | Density (kg/m³) |
|--------|------------|-----------------|
|        | initial    | 2h              |                  |
| C35B   | 225        | 190             | 2410             |
| C35W   | 230        | 200             | 2400             |
| C40E   | 220        | 180             | 2405             |

3.2 Compressive Strength
Table 5 shows the compressive strength of SCC. According to the Chinese national standard JGJ 55-2011, the mixing strength of C35 and C40 strength grade SCC should be not lower than 41.6MPa and 46.6MPa, respectively.

| Sample | Compressive strength (MPa) | Compressive strength growth rate (%) |
|--------|----------------------------|-------------------------------------|
|        | 3d  | 7d  | 28d | 3d  | 7d  | 28d |
| C35B   | 23.8| 32.6| 45.5| 52.3| 71.6| 100 |
| C35W   | 23.6| 35.1| 47.1| 50.1| 74.5| 100 |
| C40E   | 28.9| 41.8| 54.5| 53.2| 76.8| 100 |

It could be seen that the strength of C35B and C35W SCC at 28 days were 45.5 MPa and 47.1MPa, while the strength of C40E at 28 days was 54.5MPa. Thus all the SCC had reached the design mixing strength requirements. Compressive strength growth ratio at 3 days was about 52%, and the ratio reached 75% at 7 days. The strength development was reasonable, long-term strength continued to increase. It is the best developing period for restrained expansion rate of SCC when the compressive strength increased from 5 MPa to 20MPa [1]. So the early strength of SCC not only met construction schedule, but also matched the expansion process. And this was beneficial to improve the cracking resistance.

3.3 Restrained Expansion Rate
Restrained expansion rate is an important design parameter for SCC, because it directly decides the compensating thermal shrinkage and drying shrinkage of SCC. Due to external wall and roof suffered more restraint degree, these parts are easier to crack. So, the restrained expansion rate of external wall and roof is higher than that of bottom plate [4]. Post-pouring joint can be replaced by expansion reinforcing band to release deformation and stress. The theory is that the higher pre-stress established in expansion reinforcing band can effectively strengthen the compensating ability of SCC in both sides. And therefore, both restrained expansion rate and strength of expansion reinforcing band are enhanced a rank. The restrained expansion rate of SCC was shown in Figure 3.

The restrained expansion rate of SCC increased with the mixing amount of expansive agent. After cured in water for 14 days, the restrained expansion rate of C35B, C35W and C40E were 0.021%, 0.027% and 0.032%, respectively. Meanwhile, the restrained expansion rate of SCC still remained at 0.006%-0.008% after 28 days’ air cured at 60±5% of RH. This illustrated that the SCC had been kept in press condition at all times. And there had established enough pre-stress for compensating early thermal shrinkage and later drying shrinkage. So the SCC had excellent crack resistance.
3.4 Cracking Resistance

TSTM can simulate different temperature gradient of concrete under fully-constrained condition. The test procedures cover actual temperature development of early concrete, the development process of mechanical property, thermal property and deformation performance of concrete as well. Therefore, the evaluation results of TSTM are more comprehensive and objective.

![Figure 3. Restrained expansion rate of SCC](image1)

![Figure 4. Stress curve of SCC](image2)

Based on the pre-stress generated by the hydrated expansive products of expansive agent, SCC can offset the tensile stress caused by shrinkage. And this is advantageous for improving the cracking resistance of concrete. The stress developing curve of SCC was shown in Figure 4, and the characteristic parameter of temperature-stress test were listed in Table 6.

| Items                      | C35B  | C35W  | C40E  |
|----------------------------|-------|-------|-------|
| Maximum compressive stress (MPa) | 1.00  | 1.43  | 1.60  |
| Maximum compressive stress time (h) | 15.42 | 17.41 | 20.38 |
| Second zero stress temperature (ºC) | 41.88 | 44.00 | 50.25 |
| Second zero stress time (h) | 41.50 | 38.55 | 30.38 |
| Cracking stress (MPa) | -2.32 | -3.00 | -3.47 |
| Cracking temperature (ºC) | -18.5 | -13.4 | -7.6  |

Maximum compressive stress, cracking stress and cracking temperature can comprehensive reveal the cracking resistance of SCC. The greater value of maximum compressive stress and cracking stress indicates a better cracking resistance of concrete. The lower value of cracking temperature, the better supporting temperature shock of concrete gets. With the dosage of HCSA expansive agent increasing from 35kg/m³ to 40 kg/m³ and 45kg/m³, the maximum compressive stress of SCC at temperature rise period increased from 1.00MPa to 1.43MPa and 1.60MPa. Meanwhile, the cracking stress at temperature-fall period also increased from 2.32MPa to 3.00MPa and 3.47MPa. These results further indicated that there was enough pre-stress to compensate shrinkage. In addition, cracking temperature decreased from -7.6 ºC to -13.4 ºC and -18.5 ºC. As a result, the thermal cracking tendency of concrete at early stage descended. The cracking resistance of SCC enhanced with the dosage increasing of HCSA expansive agent. The results accorded with restrained expansion rate growth law in chapter 3.3.

4. Conclusion

SCC prepared in this study had the characteristic of good workability, compressive strength increase steadily, coordinated growth of restrained expansion rate and compressive strength.

With the dosage of expansive agent increasing, restrained expansion rate of SCC increased, maximum compressive stress and cracking stress improved, cracking temperature fell, thus cracking resistance got effectively improvement.
5. Reference

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