Research on Shrinkage Inhibition Technology of C50 Steel Shell Immersed Tube Self-Compacting Concrete

Xudong Wu¹, Yingjun Peng ², Tao He¹ and Putao Song ³*  
¹Poly ChangDa Engineering Co., Ltd. Guangzhou 510620, China;  
²Shenzhen-Zhongshan Link Management Center, Zhongshan 528400, China;  
³China Academy of Building Research, Beijing 100013, China  
*Corresponding author email: song-pu-tao@163.com

Abstract: The effects of shrinkage reducing agent and expansion agent on workability, strength and shrinkage of C50 self-compacting concrete with steel-shell immersed tube were studied. It is found that the expansive agent can increase the 28d compressive strength of concrete and restrain the shrinkage of concrete, but it can reduce the mixture property of concrete, and the shrinkage reducing agent can reduce the 28d compressive strength of concrete, but it can obviously restrain the shrinkage of concrete and improve the performance of concrete mixture. On the basis that the performance of concrete mixture meets the technical index, when the dosage of shrinkage reducing agent is 1.5%, the performance of concrete mixture is the best, and the drying shrinkage rate of 28d is the smallest. At this time, the properties of C50 steel-shell sunk pipe self-compacting concrete are as follows: slump flow 720mm, T50 2s, pour-down time 2s, v-shaped funnel passing time 6s, 28d compressive strength 59.6 MPa, 28d drying shrinkage 135×10⁻⁶.

1. Introduction
Self-compacting concrete has the characteristics of large flow state, non-segregation, uniformity and stability, and compact filling without additional vibration. It is a new type of building material that has emerged in recent decades [1-2]. In order to ensure the good "self-compacting performance" of self-compacting concrete, in the preparation process of self-compacting concrete, high amount of cementitious material and large ratio of slurry to bone are often selected, which leads to relatively large drying shrinkage of self-compacting concrete and is not conducive to the control of concrete volume stability [3-5].

Shenzhen-Zhongshan Passage is one of the key construction projects in China in recent years, with high construction difficulties and high quality requirements. Shen-Zhong passage immersed tube tunnel adopts steel shell concrete composite structure. This structure is the first application in China and the first large-scale application in the world. In order to ensure the good construction quality of steel shell immersed tube concrete and improve the compactness of steel shell immersed tube concrete, The Shenzhen-Zhongshan Passage Management Center and other engineering construction units organized experts to repeatedly study and demonstrate. It is proposed to use C50 self-compacting concrete in Shen-Zhong channel steel shell immersed tube. At the same time, considering the large drying shrinkage of self-compacting concrete, the engineering construction unit proposed the actual demand for research on shrinkage suppression technology for C50 steel shell immersed pipe self-compacting concrete. It is necessary to reduce the drying shrinkage rate and shrinkage cracking of concrete on the basis of ensuring good self-compacting performance of concrete.

According to the technical requirements, the 28d compressive strength of C50 steel shell immersed
tube self-compacting concrete $\geq 59$ MPa, the slump extension of concrete $\geq 650$ mm, the V-shaped funnel test 15s, T500 $\leq 5$s, and the emptying time of inverted slump cylinder (inverted cylinder time) $\leq 5$s.

In this paper, the effects of shrinkage reducing agent and expansion agent on the self-compacting property and shrinkage property of C50 steel shell self-compacting concrete used in Shenzhong tunnel are studied. The admixture which has little effect on self-compacting concrete and most significant inhibition on drying shrinkage in 28d is put forward, which solves the technical problem of drying shrinkage of self-compacting concrete and provides reference for the application of Shenzhong channel and similar projects in China.

2. Materials

(1) Cement: P· II 42.5 Portland cement produced by China Resources Cement Co, LTD. the surface area should be controlled at 350m$^2$/kg, alkali content should be 0.30%, chloride ion content should not be more than 0.01%, 3-day strength 29MPa, 28-day strength 46.8MPa. (2) Fly ash: Grade I fly ash produced by a power plant of National Energy Group, loss of burning 3.2%, 45μm sieve residue 5%, water requirement 93%. (3) Ore powder: S95 granulated blast furnace slag powder produced by Tangshan Caofeidian New Building Materials Co, LTD. The 7-day active index 79%, the 28-day active index of 96%, and the fluidity ratio 98%. (4) Water reducing agent (PCE): polycarboxylic acid high-performance water reducing agent, solid content 30%, water reduction rate 33%. (5) Shrinkage reducing agent (SRA): standard type, light yellow liquid, shrinkage reduction rate of 35% in 28d. (6) Expansion agent: type I calcium sulfoaluminate (EA1) expansion agent and type I calcium oxide (EA2) expansion agent produced by a Jiangsu admixture factory; (7) Sand: medium sand in zone II, with mud content of 0.5% and fineness modulus of 2.7; (8) Gravel: 5-10mm and 10-20mm graded impact crushed stone produced by the ShenZhong, the crushing value is 9%, and the strength of the parent rock is 112MPa.

3. Test Method and Mix proportion of Concrete

3.1 Mix Proportion of Concrete

Benchmark mix ratio of C50 steel shell immersed tube self-compacted concrete is shown in Table 1. Among them, the total amount of cementitious material is 550kg/m$^3$, the water-binder ratio is 0.31, the sand rate is 0.5, the proportion of fly ash in the total mass of cementitious material is 36%, the proportion of mineral powder in the total mass of cementitious material is 15%, and the dosage of water-reducing agent is 1%.

| NO | Cement | Fly ash | Mineral powder | River sand | Gravel | Water | Water reducing agent |
|----|--------|---------|----------------|------------|--------|-------|-----------------------|
|    |        |         |                |            | 5mm-10mm | 10mm-20mm       |                       |
| 0  | 270    | 196     | 84             | 815        | 270    | 544   | 171                   | 5.5                   |

| Based on the benchmark mix ratio, the test mix ratio of C50 steel shell immersed tube self-compacting concrete mixed with different amounts of shrinkage reducing agent and expansion agent is shown in Table 2. The content of shrinkage reducing agent SRA corresponding to mixture ratio S1, S2 and S3 was 0.5%, 1% and 1.5%, the content of expansion agent EA1 corresponding to mixture ratio S4, S5 and S6 was 8%, 9% and 10%, and the content of expansion agent EA2 corresponding to mixture ratio S7, S7 and S9 was 3%, 4% and 5%, respectively. Considering that the amount of expansion agent is generally high, a large increase of powder material will have a great impact on the performance and strength of concrete mixture, So expansion agent is used to replace the |
cementitious material in equal quantity. Considering that the proportion of cement in the benchmark mix is already very low (50%), in this study, expansion agent is used to replace fly ash in equal quantities by adding it into concrete.

**Table 2.** C50 steel shell immersed tube self-compacting concrete test mix ratio

| NO | Cement | Fly ash | Mineral powder | River sand | Gravel 5mm–10mm | 10mm–20mm | water | PCE | SRA | EA1 | EA2 |
|----|--------|---------|----------------|------------|-----------------|-----------|-------|-----|-----|-----|-----|
| S1 | 270    | 196     | 84             | 815        | 270             | 544       | 171   | 5.5 | 2.75| 0   | 0   |
| S2 | 270    | 196     | 84             | 815        | 270             | 544       | 171   | 5.5 | 5.5 | 0   | 0   |
| S3 | 270    | 196     | 84             | 815        | 270             | 544       | 171   | 5.5 | 8.25| 0   | 0   |
| S4 | 270    | 152     | 84             | 815        | 270             | 544       | 171   | 5.5 | 0   | 44  | 0   |
| S5 | 270    | 146.5   | 84             | 815        | 270             | 544       | 171   | 5.5 | 0   | 49.5| 0   |
| S6 | 270    | 141     | 84             | 815        | 270             | 544       | 171   | 5.5 | 0   | 55  | 0   |
| S7 | 270    | 179.5   | 84             | 815        | 270             | 544       | 171   | 5.5 | 0   | 0   | 16.5|
| S8 | 270    | 174     | 84             | 815        | 270             | 544       | 171   | 5.5 | 0   | 0   | 22  |
| S9 | 270    | 168.5   | 84             | 815        | 270             | 544       | 171   | 5.5 | 0   | 0   | 27.5|

3.2 Experimental Method

(1) Concrete slump extension and 1h slump extension, T50, pouring time, V-funnel through the time test method according to the *Ordinary concrete mixture performance test Method Standard* (GB/T50080)

(2) 28d compressive strength test method refers to *Standard for Mechanical Properties test of Ordinary Concrete* (GB/T50081)

(3) The test method of 28d drying shrinkage rate refers to the *Standard for Long-term performance and Mechanical Properties test method of Ordinary Concrete* (GB/T50082)

4. Results and Discussion

Table 3 shows the test results of C50 steel shell immersed tube self-compacting concrete with reference fit ratio, test mix ratio, mixture performance, 28d compressive strength and 28d drying shrinkage ratio.
Table 3. Test results of C50 steel shell immersed tube self-compacting concrete

| NO. | Slump extension (mm) | TS0(s) | Pouring time (s) | V-shaped funnel time(s) | 28d compressive strength (MPa) | 28d Drying shrinkage rate ($\times 10^{-6}$) |
|-----|----------------------|--------|------------------|------------------------|--------------------------------|---------------------------------------------|
|     | Initial | 1h     |                  |                        |                               |                                             |
| S0  | 690     | 680    | 3                | 4                      | 10                             | 61.9                                        | 223                                         |
| S1  | 700     | 690    | 3                | 3                      | 9                              | 61.5                                        | 186                                         |
| S2  | 710     | 710    | 2                | 2                      | 8                              | 60.9                                        | 160                                         |
| S3  | 720     | 720    | 2                | 2                      | 6                              | 59.6                                        | 135                                         |
| S4  | 680     | 660    | 4                | 5                      | 11                             | 63.3                                        | 172                                         |
| S5  | 670     | 640    | 5                | 6                      | 13                             | 64.2                                        | 145                                         |
| S6  | 660     | 620    | 8                | 9                      | 15                             | 65.3                                        | 112                                         |
| S7  | 680     | 650    | 4                | 5                      | 11                             | 62.2                                        | 179                                         |
| S8  | 660     | 630    | 6                | 5                      | 14                             | 62.5                                        | 151                                         |
| S9  | 640     | 590    | 9                | 10                     | 16                             | 62.9                                        | 122                                         |

4.1 The Slump Extension

Table 3 and Figure 1 show the initial and 1h slump extension test results of C50 steel shell immersed tube self-compactable concrete.

![Figure 1. Initial and 1h slump extension of C50 steel shell immersed tube self-compacting concrete](image)

According to the test results, the initial slump of mix ratio S9 group is 640mm, which does not meet the technical requirements, and other mix ratios all meet the technical requirements. The addition of external shrinkage reducer is beneficial to the increase of slump extension of concrete. The higher the dosage of shrinkage reducing agent SRA is, the greater the initial slump expansion of concrete is. When SRA content is 0.5%, 1% and 1.5%, the initial slump expansion of concrete increases by 1.4%, 2.9% and 4.3%, respectively, compared with the basic mix ratio. The expansion agent has a restraining effect on the increase of concrete slump extension. The higher the expansion agent content, the lower the initial slump extension of concrete. Compared with the basic mixture, the initial slump extension of concrete decreases by 1.4%, 2.9% and 4.3% when the EA1 content is 8%, 9% and 10%, respectively; the initial slump extension of concrete decreases by 1.4%, 4.3% and 7.2% when the EA2
content is 3%, 4% and 5%, respectively. After EA2 was added, the initial slump extension of concrete decreased more obviously.

The addition of shrinkage reducing agent can reduce the time loss of concrete slump extension. The higher the content of shrinkage reducing agent SRA, the greater the 1h slump extension of concrete. Compared with the basic mix ratio, when the content of SRA is 0.5%, 1% and 1.5%, the 1h slump extension of concrete increases 1.5%, 4.4% and 5.9%, respectively. The addition of expansion agent will increase the time loss of concrete slump extension. The higher the content of expansion agent is, the smaller the slump extension of concrete will be. When EA1 content is 8%, 9% and 10%, the 1h slump extension of concrete decreases by 2.9%, 5.9% and 8.8%, respectively, compared with the basic mix ratio. When the content of EA2 is 3%, 4% and 5%, the 1h slump extension of concrete decreases by 4.4%, 7.3% and 13.2%, respectively. Comparatively speaking, the loss of slump extension of concrete is more obvious after the addition of EA2.

As is shown in the studies [6-7], shrinkage reducing agent is a kind of surfactant, and after the addition of shrinkage reducing agent, the gas content of concrete is appropriately increased. The workability of concrete and the slump of concrete are improved. After the expansion agent replaces fly ash, the effect of "micro-aggregate" and "ball bearing" of fly ash are weakened [8-9], and the fluidity and slump extension of concrete are reduced. Expansion agent needs to chemically react with water before it can take effect. With the effect of expansion agent, the free water that plays a positive role in the flow of concrete decreases, and the slump extension of concrete decreases.

### 4.2 T500 and Pouring Time

The test results of C50 steel shell immersed tube self-compacting concrete T500 and pouring time are shown in Table 3 and Figure 2.

![Figure 2. C50 steel shell immersed pipe self-compacting concrete T50 and pouring time](image)

It can be seen from the test results that the T50 of the mix ratios S5, S6, S8 and S9 are all greater than 5s, which does not meet the technical requirements, and other mix ratios meet the technical requirements. The addition of shrinkage reducing agent is beneficial to the reduction of concrete T500, which firstly decreases and then remains unchanged with the increase of the content of shrinkage reducing agent SRA. Compared with the benchmark mixture ratio, when the content of SRA is 0.5%, 1% and 1.5%, the concrete T500 decreases by 0%, 33.3% and 33.3%, respectively. The addition of expansion agent will increase the T500 of concrete, and the higher the content of expansion agent is, the higher the T500 of concrete will be. Compared with the benchmark mixture ratio, when the content of EA1 is 8%, 9% and 10%, the concrete T500 will increase by 33.3%, 66.7% and 166.7%, respectively; when the content of EA2 is 3%, 4% and 5%, the T500 of concrete increased by 33.3%, 100% and 200%, respectively. Comparatively speaking, the T500 of concrete increased more.
obviously after EA2 incorporation.

Mixing ratio S6, S8 and S9 group pouring time is greater than 5s, which does not meet the technical requirements, and other mixing ratios meet the technical requirements. The addition of shrinkage reducing agent is conducive to the reduction of the concrete pouring time. With the increase of shrinkage reducing agent SRA, the concrete pouring time decreases firstly and then remains unchanged. Compared with the benchmark mix ratio, the SRA content is 0.5% and 1%. At 1.5% and 1.5%, the concrete pouring time is reduced by 25%, 50% and 50%, respectively. The addition of expansive agent will increase the pouring time of concrete. The higher the content of expansive agent is, the longer the pouring time of concrete is. Compared with the benchmark mix ratio, when the content of EA1 is 8%, 9% and 10%, the concrete pouring time increased by 25%, 50%, and 125%, respectively. When the EA2 content was 3%, 4%, and 5%, the concrete pouring time increased by 25%, 25%, and 150%. Relatively speaking, the concrete pouring time increases more obviously after the addition of EA2.

Studies have shown that the air content of the concrete increases after the shrinkage reducing agent is added, the viscosity of the concrete decreases, and the concrete T50 and the pouring time decreases. As mentioned above, after the expansion agent replaces fly ash, it weakens the "micro-aggregate" and "ball" effects of fly ash. At the same time, the expansion agent absorbs free water, which causes the flow viscosity of concrete, T50 and pouring time to increase.

4.3 V Shaped Funnel Passing Time
V-shaped funnel passing time test results of C50 steel shell immersed tube self-compacting concrete are shown in Table 3 and Figure 3.

![Figure 3](image-url)

**Figure 3.** V-shaped funnel passing time of C50 steel shell immersed tube self-compacting concrete

According to the test results, the passing time of V shaped funnel in S9 group is more than 15s, which does not meet technical requirements. However, other mix proportions all meet technical requirements. The addition of shrinkage reducing agent is beneficial to the decrease of the passing time of concrete V-shaped funnel, and the passing time of concrete V-shaped funnel decreases gradually with the increase of the dosage of shrinkage reducing agent SRA. When SRA content is 0.5%, 1% and 1.5%, the passing time of concrete V-shaped funnel decreases by 10%, 20% and 40%, respectively, compared with the basic mixture ratio. The addition of expansion agent will increase the passing time of concrete V-shaped funnel. The higher the content of expansion agent is, the longer the passing time of concrete V-shaped funnel will be. Compared with the benchmark mixture ratio, when the content of EA1 is 8%, 9% and 10%, the passing time of concrete V-shaped funnel will increase by 10%, 30% and 50%, and when the content of EA2 is 3%, 4% and 5%, respectively. The passage time...
of concrete V-shaped funnel increases by 10%, 40% and 60%, respectively. Comparatively speaking, the passage time of concrete V-shaped funnel increases more obviously after EA2 is added. The V-shaped funnel passing time is proportional to the concrete viscosity. After the reduction agent is mixed, the concrete viscosity and the V-shaped funnel passing time decrease. The concrete viscosity and the V-shaped funnel passing time increase after the expansion agent is mixed.

4.4 28d Compressive Strength

The 28d compressive strength test results of C50 steel shell immersed tube self-compacting concrete are shown in Table 3 and Figure 4.

According to the test results, the 28d compressive strength of each group meets the technical requirements. The 28d compressive strength of concrete decreased after the addition of shrinkage reducer, and the 28d compressive strength of concrete decreased gradually with the increase of the dosage of shrinkage reducer SRA. Compared with the benchmark mixture ratio, when the dosage of SRA was 0.5%, 1% and 1.5%, the 28d compressive strength of concrete decreased by 0.6%, 1.6% and 3.7%, respectively. The addition of expansion agent can increase the 28d compressive strength of concrete. And the higher the content of expansion agent is, the greater the 28d compressive strength of concrete is. Compared with the benchmark mixture ratio, when the content of EA1 is 8%, 9% and 10%, the 28d compressive strength of concrete increases by 2.3%, 3.7% and 5.5%, and when the content of EA2 is 3%, 4% and 5%, respectively. The 28d compressive strength of concrete increased by 0.5%, 1.0% and 1.6%, respectively. Comparatively speaking, the 28d compressive strength of concrete increased more obviously after EA1 incorporation.

The reduction of 28d compressive strength of concrete by shrinkage reducing agent may be related to its delaying effect on the cement hydration process in concrete and its "air entraining" effect. After shrinkage reducing agent is added, cement hydration in concrete is delayed and the strength increases slowly. The "air-entraining" effect increases the number of air bubbles in the concrete and reduces the compressive strength of the concrete[10-11].

4.5 28d Drying Shrinkage Rate

Table 3 and Figure 5 show the drying shrinkage test results of C50 steel shell immersed self compacting concrete for 28d.
According to the test results, the addition of shrinkage reducing agent is beneficial to the reduction of 28d drying shrinkage rate of concrete, which gradually decreases with the increase of the dosage of shrinkage reducing agent SRA. Compared with the benchmark mix ratio, when the dosage of SRA is 0.5%, 1% and 1.5%, the drying shrinkage of concrete decreased by 16.6%, 28.3% and 39.5% after 28 days. The addition of expansion agent can reduce the 28d drying shrinkage rate of concrete, and the higher the content of expansion agent is, the lower the 28d drying shrinkage rate of concrete is. Compared with the benchmark mix ratio, when the content of EA1 is 8%, 9% and 10%, the 28d drying shrinkage rate of concrete decreases 22.9%, 35.0% and 49.8%, respectively. When the content of EA2 is 3%, 4% and 5%, the dry shrinkage rate of concrete decreases 19.7%, 32.3% and 45.3%, respectively. Comparatively speaking, the dry shrinkage rate of concrete increases more obviously after EA1 is added.

Comprehensively considering the test results of the effects of shrinkage reducing agent and expansion agent on the performance, compressive strength and 28d drying shrinkage rate of concrete mixture, it can be seen that on the basis that the performance of concrete mixture meets the technical index requirements, when the content of shrinkage reducing agent SRA is 1.5%, the performance of concrete mixture is the best, the 28d compressive strength meets the technical index requirements, and the 28d drying shrinkage rate is the lowest.

5. Conclusions

(1) On the basis that the performance of the mixture meets the technical index requirements, when the content of shrinkage reducing agent SRA is 1.5%, the performance of the concrete mixture is the best, the 28d compressive strength meets the technical index requirements, and the 28d drying shrinkage rate is the lowest. At this time, the slump expansion of concrete is 720mm, T500 is 2S, the pouring time is 2S, the passing time of V-shaped funnel is 6S, the 28d compressive strength is 59.6MPa, and the 28d drying shrinkage is $135 \times 10^{-6}$.

(2) The addition of shrinkage reducing agent SRA can improve the initial and 1h slump expansion of concrete, and reduce the T500, pouring time and v-funnel passing time of concrete, which can reduce the 28d compressive strength and the 28d dry shrinkage rate of concrete. The higher the SRA content is, the more significant the impact on various properties of concrete is. When the SRA content is 1.5%, the impact on various properties of concrete is the most obvious.

(3) The addition of expansion agent EA1 and EA2 can reduce the initial and 1h slump expansion of concrete, and increase the T500, pouring time and v-funnel passing time of concrete, which can improve the 28d compressive strength of concrete and reduce the 28d dry shrinkage of concrete. The

\[ y = 1.5x^2 - 23.5x + 230 \]
higher the content of expansion agent is, the more significant the impact on each performance of concrete is. When the content of EA1 and EA2 is 10% and 5% respectively, it has the most obvious effect on the properties of concrete.

(4) By comparing the effects of expansive agent on various properties of concrete, it can be seen that the slump expansion of concrete at the initial stage and 1h decreases more obviously after EA2 is added, and T500, pouring time and V-funnel passing time increase more obviously, the 28d compressive strength of concrete increases more obviously after EA2 is added, and the 28d dry shrinkage of concrete decreases more obviously.

6. Acknowledgments
Guangdong Province key field research and development plan project (2019B111105002)

7. References
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