Study on the Influence of Polycarboxylate Superplasticizer Compound on the pump PHC

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Abstract. This article disclosed the effects of polycarboxylate superplasticizer (PCE), air entraining agent, defoamer, accelerator on the properties of prestressed high-strength concrete (PHC). The introduction of DAC and AMPS into the molecular structure of PCE is helpful to improve compressive strength of PHC. The air entraining agent can be used to improve the PHC workability. The Defoamers and accelerators are beneficial for increasing PHC compressive strength. The admixture compounding technology by using PCEs, air entraining agents, defoamers and accelerators can help to get excellent properties of PHC.

1. Introduction

The prestressed high-strength concrete (PHC) pipe piles have the characteristics of convenience construction speed, high bearing capacity, high density and cost saving. It is widely used in the foundation engineering of various buildings and structures, such as skyscraper, highway, railway and sea port[1,2].

The processes of steam curing and autoclaved curing are used in the fabrication of PHC in order to improve production efficiency, quality control and attaining a sufficient concrete compressive strength[3,4]. Because cement hydration is a complicated reaction, which is influenced a lot factors, such as temperature, pressure and water binder ratio etc. The required compressive strength of PHC is above 40 MPa after steam curing process and generally over 80 MPa after autoclaved curing process. At present, the developing trend of PHC is using high fluidity to realize the automatic distribution. So how to solve the relationship between fluidity and strength growth is a difficult problem and hotspot research during these years.

2. Experiments

2.1. Materials

Isopentenylpolyoxyethylene ether (IPEG, molecular weight 2400); Acrylic acid (AA); Acryloxyethyl trimethylammonium chloride (DAC); 2-acrylamido-2-methylpropanesulfonic acid (AMPS); Ammonium persulfate (APS); Thioglycolic acid (TGA); Sodium hydroxide solution, 30 wt% (30% NaOH).

Conch cement (C), PO 52.5R, the performance indexes are shown in table 1; Ground fine quartz sand powder (GQSP), specific surface area 442 m²/kg, loss on ignition 0.83%; Ground granulated blastfurnace slag, S95 (GGBS), specific surface area 420 m²/kg, 28 days activity index 98%; River sand (S), fineness modulus of 2.7; Coarse aggregate 1 (G1), particle size of 10-31.5 mm; Coarse aggregate 2 (G2), particle size of 5-20 mm; Water (W).
Table 1. Cement performance index

| Specific surface area/(m²/kg) | Setting time/min | Flexural strength/MPa | Compressive strength/MPa |
|-------------------------------|-------------------|-----------------------|--------------------------|
|                               | Initial | Final | 3 d | 28 d | 3 d | 28 d |
| 374                           | 165     | 225   | 6.5 | 9.1  | 34.2| 58.1 |

Sodium dodecyl benzene sulfonate (SDBS); Sodium lauryl sulfate (SDS); Evonik SITREN AirVoid 601 (SA601); Air Products & Chemicals, Carbowet DA740 (DA740); Evonik SITREN AirVoid 321 (SA321); Evonik SITREN AirVoid 322 (SA322); Sodium sulfate (SS); Triethanolamine (TEA); Diethanolmonoisopropanolamine (DEIPA).

2.2. Synthetic Methods

In a four-necks flask with a dropping device, the IPEG and deionized water were added at 60±3°C. a certain concentration of initiator solution and unsaturated acid solution were prepared respectively. The prepared solutions were dropping into the flask seperately for 3 hours. Kept the reaction at 60±3 ºC for 1 h to complete the polymerization. Finally, a sodium hydroxide solution was added to adjust the pH and obtained the polycarboxylate superplasticizer (PCE) with solid content at 50 wt%.

A series of PCEs were designed and synthesized. The molecular structure of PCEs was shown in figure 1. The list of synthetic raw materials for PCEs is shown in table 2.

Figure 1. Molecular structure of PCE (m is hydrogen / alkali metal element; a, b, c, d are integers respectively)

| Sample | Macromonomer | Unsaturated acid | Initiator | Chain transfer agent |
|--------|--------------|-----------------|-----------|---------------------|
| PCE-1  | IPEG         | AA              | /         | /                   |
| PCE-2  | IPEG         | AA DAC          | APS       | TGA                 |
| PCE-3  | IPEG         | AA DAC AMPS     | /         | /                   |

2.3. Test Methods

The paste test was in accordance with GB/T 8077-2012 (China Standard). The dosage of PCEs was 0.2%. The water binder ratio of paste was 0.29. The concrete test was in accordance with relevant requirements of GB/T 50080-2016 and GB/T 13476-2009 (China Standard). The dosage of admixture in concrete was 0.5% (solid content) according to the binding material. The concrete mix proportion is shown in table 3.

Table 3. Concrete mix proportion (kg/m³)

| Mix Proportion No. | C   | GGBS | GQSP | S   | G1  | G2  | W   |
|--------------------|-----|------|------|-----|-----|-----|-----|
| M-1                | 320 | 130  | 130  | 802 | 776 | 320 | 145 |
| M-2                | 284 | 116  | 116  | 700 | 880 | 470 | 125 |
| M-3                | 301 | —    | 129  | 768 | 809 | 347 | 132 |
| M-4                | 308 | 44   | 88   | 768 | 806 | 345 | 141 |
The concrete blocks were kept at 20±2 °C for 30 min, and then moved into the curing pool (80 °C) for steam curing for 5 h. And the concrete blocks were placed in the autoclave (180 °C, 1 MPa) for 8 h in the following. Finally the compressive strength could be tested.

3. Results and Discussion

3.1. Effect of Polycarboxylate Superplasticizer on the Performance of Pump PHC

The paste fluidity of PCEs was tested at the initial time and 30 min later. The test results are shown in table 4.

| Test No. | Sample   | Paste fluidity/mm |
|---------|----------|-------------------|
| A-1     | PCE-1    | 228               |
| A-2     | PCE-2    | 205               |
| A-3     | PCE-3    | 236               |

It can be concluded from table 4 that the initial concrete dispersing performance is PCE-3>PCE-1>PCE-2. The lower fluidity of PCE-2 is due to cationic monomer (DAC) incorporated into the main chain of PCE molecular structure. The dispersing retention of PCE-3 is better than PCE-2 after 30 min.

The concrete mix proportion was employed by M-1 in table 3. The properties of concrete are shown in table 5.

| Test No. | Sample   | Slump/mm | Air content/% | Compressive strength/MPa |
|----------|----------|----------|---------------|--------------------------|
| A-4      | PCE-1    | 190      | 3.5           | 46.3                     |
| A-5      | PCE-2    | 185      | 3.0           | 48.9                     |
| A-6      | PCE-3    | 200      | 3.3           | 49.1                     |

It shows that the initial concrete slump is PCE-3>PCE-1>PCE-2 from table 5. After 30 min, the slump retention is PCE-1>PCE-3>PCE-2. The initial air content of PCE-1 is 3.5%, which higher than PCE-2 and PCE-3. After 30 min, the air content is PCE-1>PCE-3>PCE-2. The compressive strength after steam curing is PCE-1>PCE-2>PCE-3, which is the same conclusion after autoclaved curing process. The PCE-3 is more suitable for PHC. The introduction of DAC and AMPS into the molecular structure of PCE are helpful to improve the performance of PHC.

3.2. Effect of Air Entraining Agent on the Performance of Pump PHC

The air entraining agents such as sodium dodecyl benzene sulfonate (SDBS), sodium lauryl sulfate (SDS) and SITREN AirVoid 601 (SA601) were added into the PCE-3 respectively to form compounding solutions. The air entraining agent dosage was 0.1% according to the weight of PCE-3. The concrete mix proportion was employed by M-1. The properties of concrete are shown in table 6.

| Test No. | Compounding agent | Slump/mm | Air content/% | Compressive strength/MPa |
|----------|-------------------|----------|---------------|--------------------------|
| B-1      | SDBS              | 210      | 4.1           | 38.0                     |
| B-2      | SDS               | 210      | 4.3           | 39.4                     |
| B-3      | SA601             | 200      | 3.8           | 37.4                     |
Using air entraining agent in admixture compounding can improve the workability of concrete. The table 6 illustrates that the initial air entraining capability is SDS>SDBS>SA601. The SA601 can control the retention of air content better than SDBS and SDS after 30 min. The air entraining agent reduces the compressive strength after steam and autoclaved curing. When the pumping performance cannot meet the production requirements, it can be recommended to compound air entraining agent, especially the SITREN AirVoid 601.

3.3. Effect of Defoamer on the Performance of Pump PHC

The defoamers such as Carbowet DA740 (DA740), SITREN AirVoid 321 (SA321) and SITREN AirVoid 322 (SA322) were added into the PCE-3 respectively to form admixture compounding solutions. The defoamer dosage was 0.05% according to the weight of PCE-3. The concrete mix proportion was employed by M-1. The properties of concrete are shown in table 7.

| Test No. | Compounding agent | Slump/mm | Air content/% | Compressive strength/MPa | Steam curing | Autoclaved curing |
|----------|-------------------|----------|---------------|--------------------------|--------------|-------------------|
|          |                   | 0 min    | 30 min        | 0 min                    | 30 min       |                   |
| C-1      | DA740             | 170      | 60            | 2.3                      | 1.5          | 50.2              | 86.9              |
| C-2      | SA321             | 185      | 95            | 2.7                      | 2.0          | 49.9              | 89.1              |
| C-3      | SA322             | 180      | 90            | 2.8                      | 1.9          | 50.3              | 88.2              |

Using defoamer will reduce the workability of concrete. It can be concluded from table 7 that the defoaming capability is DA740>SA321≈SA601. The defoamer increases the compressive strength of steam and autoclaved curing, which is due to the contribution of bubble size and quality. The concrete strength growth is obvious after using SA321 and SA322. Compared with using defoamer or not, the steam curing strength is equivalent. The autoclaved curing process is important to strength growth. In order to get higher compressive strength, it can be recommended to compound defoamer into the admixture, especially the SA321 or SA322.

3.4. Effect of Accelerator on the Performance of Pump PHC

The accelerators, such as sodium sulfate (SS), triethanolamine (TEA), diethanolmonoisopropanolamine (DEIPA) were added into the PCE-3 respectively to form compounding solutions. The accelerator dosages were 1.00%, 0.10%, 0.10% separately, which according to the weight of PCE-3. The concrete mix proportion was employed by M-1. The properties of concrete are shown in table 8.

| Test No. | Compounding agent | Slump/mm | Air content/% | Compressive strength/MPa | Steam curing | Autoclaved curing |
|----------|-------------------|----------|---------------|--------------------------|--------------|-------------------|
|          |                   | 0 min    | 30 min        | 0 min                    | 30 min       |                   |
| D-1      | SS                | 190      | 90            | 3.3                      | 2.1          | 49.8              | 93.8              |
| D-2      | TEA               | 190      | 110           | 3.1                      | 2.0          | 52.1              | 88.2              |
| D-3      | DEIPA             | 185      | 95            | 3.1                      | 2.2          | 51.4              | 91.3              |

From Table 8, it can be seen that the workability of concrete is basically the same by compounding with different accelerators. Using agents like TEA and DEIPA are beneficial for increasing the concrete steam curing strength. The compressive strength after autoclaved curing is SS>DEIPA>TEA. The sodium sulfate is recommended to use in order to guarantee the workability and compressive strength.
3.5. **Effect of Admixture Compound on the Performance of Pump PHC**

The agents including air entraining agent SA601, defoamer SA321 and the accelerator SS were added into the PCE-3 together to form admixture compounding solutions, which the agents dosages were 0.05%, 0.05% and 1.00% according to the weight of PCE-3. The concrete mix proportion was employed by M2, M3, and M4 in Table 3. The properties of concrete are shown in Table 9.

| Test No. | Concrete mix proportion | Compressive strength/MPa | Steam curing | Autoclaved curing |
|----------|--------------------------|--------------------------|--------------|-------------------|
| E-1      | M2                       | 53.3                     |              | 93.3              |
| E-2      | M3                       | 55.9                     |              | 97.4              |
| E-3      | M4                       | 54.1                     |              | 95.5              |

From Table 9, the compressive strength after steam curing is 53.3 MPa, 55.9 MPa and 54.1 MPa, The compressive strength after autoclaved curing is 93.3 MPa, 97.4 MPa and 95.5 MPa. The compressive strength can be achieved favourably and higher through using compounding technology to form admixture by PCEs, air entraining agents, defoamers and accelerators.

4. **Conclusions**

Based on the above test results, the following conclusions can be drawn:

1. The introduction of DAC and AMPS into the molecular structure of polycarboxylate superplasticizer is helpful to improve compressive strength after steam curing and autoclaved curing process.

2. If the pumping performance cannot meet the production requirements, the air entraining agent can be used to improve the workability of PHC

3. The Defoamers and accelerators are beneficial for increasing PHC compressive strength. But the defoamers will hinder the workability of concrete.

4. In order to get excellent performance of PHC, the concrete admixture can be obtained by means of admixture compounding technology through using polycarboxylate superplasticizers, air entraining agents, defoamers, accelerators, and etc.

5. **References**

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