Research and Application of Non-autoclaved PHC Pipe Pile Concrete

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Abstract. This paper studies the influence factors on the strength performance of Non-autoclaved PHC pipe pile concrete, such as the types and dosage of glue materials, water-binder ratio, pipe pile steam curing system, types of polycarboxylate superplasticizer, in view of the low temperature climate conditions in northwest China. The research results show that it is feasible to produce PHC pipe piles with single exemption process in terms of technology, process, cost and regional environment, and realize the application of single autoclaved PHC pipe piles industrial production in northwest China.

1. Foreword
With the market demand brought about by the rapid development of China's economy and the call for national low-carbon environmental protection, PHC-free steam-pressed pipe piles have formed an industrialization trend, which is imperative. At present, in the domestic industrial production of steam-free pipe piles, the Yangtze River Delta and the Pearl River Delta are the main products. Due to the climatic environment restrictions, the northwestern region of China still produces pipe piles in a traditional two-step production process. After high-temperature steaming, steaming in the autoclave can reach the strength of the C80 pipe pile which is common in the market. This traditional process is cumbersome, consumes a lot of energy such as natural gas, and at the same time, the production efficiency of the pipe factory is low due to the two-step production, which directly affects Enterprise productivity and profitability.

Based on the unique climatic characteristics of Northwest China, this paper studies various influencing factors of PHC pipe piles in the single-free process. Starting from the technical process and cost factors, the design of a single-free autoclaved PHC pipe pile process has been successfully designed. And achieved industrial production in the first Xi'an area.

2. Test raw material

2.1. Admixture
(1) Mineral powder. Datang Shenglong produces S95 mineral powder, density: 2.6g/cm3, ratio table: 390m2/kg, loss on ignition: 2.6%, activity: 7d (78%), 28d (97%);
(2) Ultrafine powder. Industrial products, produced in Henan, density: 3.4g/cm3, ratio table: 437m2/kg, loss on ignition: 0.22%.

2.2. Cement
JidongP.O 52.5R cement, 80Um square hole sieve residue: 7.5%, standard consistency: 28.8%, strength: 3d-28.0MPa, 7d-59.8MPa.
2.3. Aggregate
(1) River sand (Mx=2.0~2.4), mud: 3%, MB value: 0.1, crush value: 5.8%;
(2) Double-grade basalt, (Small stone 5 ~ 16mm, Dashi 5 ~ 31.5mm), mud: 1.0%, apparent density: 2800kg / m2, bulk density: 1680kg / m2, crush value: 9.8%.

2.4. Polycarboxylate water reducer
Kezhijie Group produces early-stage polycarboxylate water reducer PC-ZQ1, water reduction rate: 31%, density: 1.108g/cm3, PH value: 6.0.

3. Test methods and results discussion
3.1. PHC pipe pile concrete mix design
3.1.1 Selection of glue type and dosage
Considering the curing system of single steam-free pipe pile and the hydration mechanism of concrete glue, the fixed bulk density (2500kg), fixed water-to-binder ratio (0.28), fixed sand ratio (0.34), fixed single curing system, fixed concrete slump (80-100mm, to adjust the amount of admixture to control slump), for cement cement (320kg, 340kg, 360kg), mineral powder (60kg, 90kg, 120kg), ultrafine powder (20kg, 40kg, 60kg) Three-factor and three-level orthogonal tests were conducted to determine the type and amount of gelation material. The orthogonal test design and results of the gelation material are shown in Table 1 below.

| Serial number | cement (kg) | Mineral powder (kg) | Ultrafine powder (kg) | Single intensity (MPa) |
|---------------|-------------|---------------------|-----------------------|------------------------|
| 1             | 320         | 60                  | 20                    | 78.8                   |
| 2             | 320         | 90                  | 40                    | 81.2                   |
| 3             | 320         | 120                 | 60                    | 82.0                   |
| 4             | 340         | 90                  | 60                    | 85.5                   |
| 5             | 340         | 120                 | 20                    | 83.0                   |
| 6             | 340         | 60                  | 40                    | 84.5                   |
| 7             | 360         | 120                 | 40                    | 88.2                   |
| 8             | 360         | 90                  | 20                    | 87.0                   |
| 9             | 360         | 90                  | 60                    | 89.2                   |

It can be seen from Table 1 that with the increase of the amount of cement in the concrete gelation material, the strength of the concrete is obviously improved. The increase of the amount of mineral powder increases the early strength of the single autoclaved pipe pile concrete better than that of the ultra-fine powder. Preferably, cement (360 kg), mineral powder (90 kg), and ultrafine powder (20 kg) are used as the components of the gelation material, and the total amount is 470 kg.

3.1.2. Water-to-gel ratio adjustment test
On the basis of the test of 3.1.1, determine the amount and proportion of the gelation material, fix the concrete slump (80 ~ 100mm, adjust the slump of the admixture dosage), adjust the water-to-binder ratio, optimizing mix proportion of concrete, increasing the Strength of single autoclaved PHC pipe piles. The water-to-gelation material ratio adjustment test is shown in Table 2 below.

| Serial number | Plastic material (kg) | Water consumption (kg) | Water to glue ratio (%) | Single intensity (MPa) |
|---------------|------------------------|------------------------|-------------------------|------------------------|

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From the analysis of the experimental results in Figure 1, when the ratio of water to the gelation material is greater than 0.26, the strength begins to decrease. When the ratio of water to the gelation material is less than 0.24, the strength of the concrete is gradually decreased. The optimum water-to-gelation material ratio is between 0.24 and 0.28. The construction performance of the concrete and the centrifugal effect of the pipe piles finally set the water-to-gelation material ratio to 0.26.

3.2. Polycarboxylate water reducer
This experiment selects Kezhijie Group's early-strength polycarboxylate water reducer PC-ZQ1, PC-1, PC-2 Special Water Reducing Agent for Autoclaved Pipe Pile of a Manufacturer in Guangdong Province, PC-3 Water Reducing Agent for Precast Concrete Made by a Manufacturer in Hebei Province, contrast experiment of PHC pipe pile concrete under the same slump is carried out, the strength of single autoclaved PHC pipe piles is compared. The test data and results are shown in Table 3 below.

| Serial number | Slump (mm) | Admixture dosage (%) | Single intensity (MPa) |
|---------------|------------|----------------------|------------------------|
| PC-ZQ1        | 90         | 1.1                  | 91.5                   |
| PC-1          | 90         | 1.3                  | 86.6                   |
| PC-2          | 90         | 1.3                  | 92.2                   |
| PC-3          | 90         | 1.1                  | 88.6                   |

In this test, different manufacturers were selected for the precast concrete special admixtures. It was found that different admixtures had different effects on the early strength of precast concrete. Finally, PC-ZQ1 and PC-2 are chosen as water reducing agents for concrete of PHC pipe piles.

3.3. Comparative test of curing time of PHC pipe pile concrete
This test is based on the single-free maintenance system of PHC pipe piles, the final results of 3.1.1, 3.1.2 and 3.2 optimization of the gelation material, water-binder ratio and admixtures are used as
concrete mix ratio and admixture types, to verify the strength change of concrete of pipe piles under the condition of 55 steam for one hour and 90 steam for one hour, two hours, three hours, four hours, five hours, six hours and seven hours respectively. The experimental data are shown in Table 4.

| Serial number | 55℃ Rest time (h) | 90℃ Rest time (h) | Single intensity (MPa) |
|---------------|-------------------|-------------------|------------------------|
| 1             | 1                 | 1                 | 56.8                   |
| 2             | 1                 | 2                 | 70.2                   |
| 3             | 1                 | 3                 | 82.6                   |
| 4             | 1                 | 4                 | 91.8                   |
| 5             | 1                 | 5                 | 93.2                   |
| 6             | 1                 | 6                 | 93.8                   |
| 7             | 1                 | 7                 | 95.0                   |

Figure 2. Relationship between rest time and intensity

It can be seen from Fig. 2 that when the PHC pipe pile concrete is maintained at a low pressure of 90 °C, the concrete strength increases rapidly within 1-4 h with the extension of the standing time, and the strength rises slowly and close to stability after 4-7 hours. Considering the production cost of the pipe pile, the final single-free low-pressure static curing time of the PHC pipe pile is set to 4h.

3.4. PHC pipe pile concrete optimization ratio industrialized trial production

After the concrete mix proportion and process optimization test of 3.1, 3.2 and 3.3 in this paper, Finally, the concrete ratio of C80PHC autoclaved pipe pile is set as follows: 470kg of the gelation material, the ratio of water to cementitious material is 0.26%, the dosage of water reducing agent PC-ZQ 1 is 1.1%, concrete The bulk density is 2500kg, the proportion of sand can fluctuate appropriately according to the operability of concrete construction; the pipe pile maintenance system is set to 55 °C low pressure for 1 h, and 90 °C for 4 h. Finally, industrial trial production was carried out in a pipe pile factory in Shaanxi. This industrial production trial produced 10 PHC pipe piles. The test results are shown in Table 5 below.

Table 5. Pipe Pile Production Test Data

| Numbering | Test block single strength (MPa) | Single exemption pile rebound strength (MPa) |
|-----------|---------------------------------|---------------------------------------------|
| 1         | 88.6                            | 92.3                                        |
| 2         | 85.3                            | 91.2                                        |
| 3         | 89.6                            | 94.6                                        |
| 4         | 88.2                            | 94.8                                        |
|   | 5  | 6  | 7  | 8  | 9  | 10 | Mean |
|---|----|----|----|----|----|----|------|
|   | 90.2 | 88.9 | 91.6 | 90.5 | 88.8 | 89.4 | 89.1 |
|   | 93.2 | 95.0 | 96.3 | 95.4 | 91.2 | 92.8 | 93.7 |

It can be seen from the test data of Table 5 that the trial production of the single-free autoclaved C80 PHC pipe pile is better, the strength of the test block and the rebound strength of the pipe pile all meet the national standard requirements of the C80 pipe pile, and it is considered that the single-free autoclaved PHC pipe The pile test was successful and the feasibility of industrialization was up to standard.

3.5. Discussion of results

3.5.1 Discussion on the effect of PHC pipe pile concrete admixture
PHC pipe pile concrete realizes the low-pressure single-free maintenance from the original low-pressure two-step steam curing to the present, which requires high early hydration speed of the gelation material. This paper selects high quality and high activity mineral powder as the main admixture to quickly inspire concrete Early hydration speed, improve the early strength of concrete; at the same time, the auxiliary ultrafine powder can stimulate the hydration of the gelation material and increase the compactness of the pipe pile during the centrifugation process, which is beneficial to increase the centrifugal water volume and reduce the water-cement ratio. Through orthogonal test and analysis and comparison, this paper finds the saturation point of high-active mineral powder, which accounts for about 20% of the gelation material, avoiding the excessive proportion of the gelation material and affecting the strength of the concrete. In the early stage of the experiment, the quartz powder and fly ash were abandoned to affect the early hydration rate of the gelation material, and even the early blending materials which failed to provide concrete strength, shortened the test process in the selection of the gelation.

3.5.2. Discussion on the water-to-binder ratio of PHC pipe pile concrete and the role of admixture
In this paper, a gradient test of 5 groups of water-to-gelation material ratios between 0.22 and 0.30 was carried out, and the slump of the five groups of concrete was controlled by the addition of the water reducer, and then concrete maintenance strength of the concrete was compared. As the water-to-the gelation material ratio increases gradually, the strength decreases significantly. When the water-to-the gelation material ratio is too low, the concrete strength will decrease slightly. The reason for the analysis is that the water-to-gel ratio is too small, the concrete state is poor, and the homogeneity is not good. As a result, the centrifugal effect of the pipe pile is not ideal, so the strength is reduced slightly, and the water-to-the gelation material ratio has an optimal water-to-the gelation material ratio according to the construction property and state of the concrete.

At the same time, the strength of pipe piles is different under the same slump of concrete controlled by different admixtures, the strength of the pipe pile is improved by the concrete and water reducer, the strength of special early strength admixtures for pipe piles is relatively high under the condition of single exemption of pipe piles, therefore, it is considered that the influence of additives on the strength of PHC pipe piles is mainly manifested in the adaptability of additives and the early strength effect of additives.

3.5.3 Discussion on curing conditions of PHC pipe pile concrete
In this paper, gradient tests of pipe piles with different static curing time under low pressure at 90°C are carried out. It is found that the strength of concrete increases rapidly with the prolongation of the static curing time before 5 hours, and slowly with the prolongation of the static curing time after 5
hours. Considering the factors of economic benefit and energy saving and environmental protection, the author considers that finding the highest point of rapid increase of concrete strength is the best maintenance time of PHC single autoclaved pipe pile, so as to avoid prolonging the maintenance time and wasting resources to destroy the environment for the weak increase of concrete strength in the later period.

4. In conclusion
This paper optimizes the concrete admixture, finds the best water-to-binder ratio of concrete, selects the special admixture for pipe piles, adjusts the curing conditions, ultimately realize the first application of C80 single autoclaved PHC pipe pile technology in Northwest China. Research influencing factors of PHC pipe pile production process, paving the way for the promotion and application of single-free PHC pipe piles in the northwest region.

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