The Analysis and Research on Durability of Super-high Strength Concrete Poles

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Abstract. Compared to ordinary concrete, super high strength concrete has the characteristics of high strength and excellent durability. But it has higher requirements for materials and conditions for maintenance, as a result, its application in actual engineering is less. Based on actual project, this paper analyzed and summarized its durability, including compressive strength, frost resistance, carbonation resistance, anti-chloride ion permeability and water resistance, so as to provide a reference for the research and development of super-high performance concrete poles.

1. Introduction
Concrete poles have irreplaceable advantages of low production cost, convenient production, long service life, maintenance-free, convenient construction and strong environmental adaptability, etc. At present, it plays an active role, and is widely used in agricultural distribution network transmission lines, broadcasting communications, railway contact network pillars and other fields\textsuperscript{[1]}. Especially in the past ten years, with the implementation of China's urban and rural network transformation and the growing development of grid, transmission line is developing to a large diameter and multiple circuits, and it has high requirements on the structure and load of the tower. It has been unable to meet the load carrying capacity requirements of some lines, if using ordinary reinforced concrete ring poles. These problems of durability, safety, transportation, installation cost, and cable footprint of transmission line pole are becoming increasingly prominent\textsuperscript{[2]}. The drawing line of ordinary concrete poles covers a large area, has high compensation costs and is difficult to implement on site, in restricted areas of the corridor\textsuperscript{[3,4]}. It increases the difficulty and quantity of transportation, lifting, assembly, as the pole has a relatively large weight, if ordinary concrete large moment poles are used instead of the pull rods\textsuperscript{[5,6]}

Relying on a 35kV line project, this paper have proposed new technologies and processes for ultra-high strength concrete poles. This paper Studied the mechanical properties of super-high strength concrete, such as compressive strength, frost resistance, carbonation resistance, chloride ion permeability and water permeability resistance, and then summarized the test results. It provides certain reference and recommendations for the later application of ultra-high strength concrete poles.

2. Test overview

2.1. Raw materials and mix ratio
The cement used ordinary Portland cement. The stone are made of hard gravel. The water used clean neutral water and drinking tap water. The water-cement ratio of concrete construction is 0.20, Considering the hydration water consumption of cement and guaranteed water consumption of construction under the action of water reducing agent.
2.2. Test piece maintenance process

The super-high strength concrete pole maintenance system is divided into three stages: atmospheric steam curing, high pressure and high pressure damp heat secondary curing and natural curing.

2.2.1 Atmospheric pressure steam maintenance

In order to accelerate the hardening of concrete and improve the turnover of steel mould, the saturated steam curing at normal pressure and temperature is adopted, and the prepared specimens will be put into the steam curing tank.

2.2.2 Demoulding

After steam curing, the steam curing pool is lifted out to demould. Fixed plate bolts are loosened before demoulding, and the prestressing force is transferred to the pole. The prestressing force is assumed by concrete. After demoulding, the appearance and size deviation are checked one by one, and the quality grade is calibrated, the qualified seal is affixed, and the quality inspection record is made.

2.2.3 Secondary maintenance of high Temperature, high pressure, humidity and heat in high pressure autoclave

The appearance and dimension quality of the tested pole are maintained in the autoclave under high temperature and high pressure, which promotes the recrystallization of the active admixture and free calcium dioxide in concrete, makes the internal structure of concrete more compact, thus improving the concrete label and curing quickly.

2.2.4 Storage and natural conservation

After leaving the reactor, the specimens are put into the yard for natural maintenance until 28 days. The specimens need to be sprinkled with water for natural maintenance within 7 days. The water should be sprinkled at least four times a day, and the top section should be sealed.

2.3. Compressive strength test

The compressive strength test was carried out with 150 mm × 150 mm × 150 mm cubic specimens, consisting of two groups, three in each group. The press uses WHY-5000 microcomputer-controlled electro-hydraulic servo ring expander.

The compressive strength of concrete cube is calculated as follows: (1):

\[
 f_{cc} = \frac{F}{A}
\]

Formula: \( f_{cc} \) is the compressive strength (MPa) of concrete cube specimens; \( F \) is the failure load (N); and \( A \) is the compressive area (mm\(^2\)) of specimens.

2.4. Frost resistance test

The frost resistance test was carried out with 100 mm × 100 mm × 400 mm specimens. There were 1 group of specimens with 3 specimens in each group.

(1)Relative dynamic modulus of elasticity should be calculated as follows:

\[
 P_i = \frac{f_{ni}^2}{f_{oi}^2} \times 100
\]

Formula: \( P_i \) is the relative dynamic modulus of elasticity (%) of the \( i \) concrete specimen after \( n \) freeze-thaw cycles, accurate to 0.1; \( f_{ni} \) is the transverse fundamental frequency (Hz) of the \( i \) coagulation specimen after \( n \) freeze-thaw cycles. \( f_{oi} \) is the initial transverse fundamental frequency (Hz) of the \( i \) coagulation specimen before freeze-thaw cycle test.
3

\[ P = \frac{1}{3} \sum_{i=1}^{3} P_i \]  \hspace{1cm} (3)

Formula: \( P \) is the relative dynamic elastic modulus (%) of a group of concrete specimens after \( n \) freeze-thaw cycles, accurate to 0.1.

The relative dynamic elastic modulus \( P \) shall be the measured average value of the test results of the three test pieces. When the difference between the maximum or minimum value and the intermediate value exceeds 15% of the intermediate value, this value should be eliminated, and the arithmetic mean of the remaining two values should be taken as the measured value. When it exceeds 15% of the intermediate value, the intermediate value shall be taken as the measured value.

(2) The mass loss rate of a single test piece shall be calculated as follows:

\[ \Delta W_{ni} = \frac{W_{ni} - W_{ni}}{W_{ni}} \times 100 \]  \hspace{1cm} (4)

Formula: \( \Delta W_{ni} \) is the mass loss rate (%) of the first concrete specimen after \( n \) freeze-thaw cycles, accurate to 0.01. \( W_{ni} \) is the mass of the first concrete specimen before the freeze-thaw cycle test (g). \( W_{ni} \) is the mass (g) of the ten coagulated ten test pieces after \( n \) freeze-thaw cycles.

(3) The average mass loss rate of a group of test pieces shall be calculated as follows:

\[ \Delta W_n = \frac{\sum \Delta W_{ni}}{3} \times 100 \]  \hspace{1cm} (5)

Formula: \( \Delta W_n \) is the average mass loss rate (%) of a group of concrete specimens after \( n \) freeze-thaw cycles, accurate to 0.1.

2.5. Carbonization resistance test

The average carbonization depth of concrete at each test age should be calculated as follows:

\[ \bar{d}_t = \frac{1}{n} \times \sum_{i=1}^{n} d_i \]  \hspace{1cm} (6)

Formula: \( \bar{d}_t \) is the average carbonization depth (mm) after the carbonization of the test specimen for \( t \) days, accurate to 0.1mm; \( d_i \) is the carbonization depth (mm) of each measurement point; \( n \) is the total number of measurement points.

2.6. Resistance to chloride ion permeability test

The total electric flux of each test piece is calculated as follows:

\[ Q = 900I_0 + (I + 2I + 3I + \cdots + 10I) \]  \hspace{1cm} (7)

Formula: \( Q \) is the total electric flux (C) through the diameter of the test piece; \( I_0 \) is the initial current (A), accurate to 0.001A; \( I_i \) is the current (A) at time \( t \) minutes, accurate to 0.001A.

According to formula (8), the electric flux of the test piece is converted into a electric flux value of a test piece having a diameter of 95 mm.

\[ Q_i = Q \times \frac{x}{95} \]  \hspace{1cm} (8)

Formula: \( Q_i \) is the electric flux (C) through the test piece with a diameter of 95mm; \( Q_i \) is the electric flux (C) through the test piece with a diameter (mm); \( x \) is the actual diameter of the test piece (mm). In this experiment, \( x = 100 \)mm.

2.7. Water penetration resistance test

The impermeability grade of concrete should be calculated as follows:

\[ P = 10H - 1 \]  \hspace{1cm} (9)
Formula: $P$ is the concrete impermeability grade; $H$ is the water pressure (MPa) when 3 of the 6 specimens seep into water.

3. Results and Analysis of Durability Test of Ultra High Strength Concrete

3.1. Compressive strength test

3.1.1 Maintenance of super-high strength concrete poles
When the load reaches 80% to 90% of the maximum load, there is an obvious cracking sound in the concrete specimens of the ultra-high-strength concrete poles cured at the same time. Before the failure, the cracking sound continued for a long time, and cracks appeared on the side surface of the test piece. After the cracks were formed, the steel fibers between the bridges began to work, delaying the expansion of the cracks. In addition, the steel fibers needed to be pulled out from the base concrete. A large amount of deformation energy is consumed. Noisy and tearing sounds can be heard before the fiber is pulled out before the destruction. When broken, there are fragments and cracks, which then become a huge sound and eventually destroy, but the test piece remains basically the same. After compression and failure, the test piece was cracked and not scattered, and it was not broken but broken, and basically maintained the shape of a regular parallelepiped. The failure morphology and test data of concrete specimens cured by Super-high strength concrete poles are shown in Table 1.

| serial number | Ultimate load / kN | Compressive strength /MPa | Mean compressive strength/MPa |
|---------------|--------------------|---------------------------|-------------------------------|
| 1             | 2633.2             | 117.03                    |                               |
| 2             | 2354.3             | 104.64                    | 109.39                        |
| 3             | 2396.3             | 106.50                    |                               |

It can be known from Table 1 that the compressive strength of the concrete specimens for super-high strength concrete poles cured at the same time was 109.39 MPa, which reached the C100 concrete mark, which was significantly higher than the current highest pole concrete C80.

3.1.2 Normal curing for 28 days
In order to analyze the effect of different curing systems on the strength of concrete, a compressive strength test of standard curing 28d concrete was carried out. The failure morphology and compressive strength data of standard cured 28d concrete specimens are shown in Table 2.

| serial number | Ultimate load /kN | Compressive strength /MPa | compressive strength/MPa |
|---------------|-------------------|---------------------------|--------------------------|
| 1             | 2596.1            | 115.38                    |                          |
| 2             | 2212.3            | 98.32                     | 98.32                    |
| 3             | 1959.7            | 87.10                     |                          |

It can be known from Table 2 that the compressive strength of the standard cured 28d concrete test piece is 98.32MPa, which is less than the compressive strength of the concrete test piece cured by the super-high-strength concrete poles during the same period of 109.39MPa. It can be seen that atmospheric pressure steam curing and autoclave high temperature and high pressure wet secondary curing promote the recrystallization of the added active admixture and the free calcium dioxide in the concrete, making the concrete internal structure more dense. Therefore, the compressive strength of the super-high strength concrete poles cured in the same period is relatively high, which meets the acceptance criteria of ultra-high-strength concrete.

3.2. Antifreeze test
Antifreeze test results are shown in Figure 1.
Figure 1 Curves of relative dynamic elastic modulus and mass loss rate with the number of freeze-thaw cycles

It can be seen from Fig. 6 that the relative dynamic elastic modulus of the concrete specimen decreases with the increase of the number of freeze-thaw cycles. It decreases slowly in the early stage (0 to 100 times) and decreases rapidly in the later stage (100 to 200 times). With 200 freeze-thaw cycles, the relative dynamic elastic modulus decreased to 89.8%, but it was still much greater than 60%. With the increase of the number of freeze-thaw cycles, there was almost no loss in the quality of the concrete specimens. At 200 freeze-thaw cycles, the test specimens the mass loss rate is still 0.

The super-high strength concrete poles cured in the same period of time have a relatively small loss of the relative elastic modulus after 200 freeze-thaw cycles, and at the same time, there is almost no loss in mass. The super-high strength concrete poles, due to their excellent anti-freezing performance, can be protected from diseases such as frost damage and rebar corrosion, ensuring that the super-high strength concrete poles will be in service during their design life.

3.3. Carbonization test

After the carbonization of the concrete test piece for 28 days, the test phenomenon after spraying the phenolphthalein alcohol solution on the cross section of the test piece

The carbonization depth of the three concrete specimens after carbonization for 28 days is 0, which indicates that the concrete cured by the super-high strength concrete poles at the same time has excellent carbonization resistance and can effectively protect the steel bars in the concrete from corrosion. It guarantees the normal use of super-high strength concrete poles in complex service environments.

3.4. Resistance to chloride ion penetration test

The electric flux test data are shown in Table 3.

| specimen number | total electric flux/C | converted electric flux/C | measured electric flux /C |
|-----------------|----------------------|---------------------------|--------------------------|
| 1-1             | 48.7                 | 44.0                      |                          |
| 1-2             | 27.5                 | 24.9                      | 37.9                     |
| 1-3             | 42.0                 | 37.9                      |                          |
| 2-1             | 51.5                 | 46.4                      |                          |
| 2-2             | 100.9                | 91.1                      | 46.4                     |
| 2-3             | 41.5                 | 37.5                      |                          |

Note: In the specimen number \( x - y \), \( x \) refers to the group and \( y \) refers to the serial number of the test piece.
It can be seen from Table 3 that the measured flux values of the two test specimens are 37.9C and 46.4C, respectively. It shows that the concrete specimens of super-high strength poles have excellent resistance to chloride ion penetration.

3.5. Water penetration resistance test
During the test, when the water pressure reached the maximum water pressure of the concrete impermeability meter of 2.1 MPa, no water seepage occurred in the six specimens, indicating that the concrete cured by the super-high strength poles at the same time has very good resistance to water penetration, ensuring the normal service of super-high strength concrete poles in complex environments was achieved.

4. conclusion
(1) The 28-day compressive strength of the super-high strength concrete of this technology has reached 109.39 MPa, reaching the C100 concrete grade, which is significantly higher than the highest grade C80 of existing pole concrete.
(2) The loss of the relative dynamic elastic modulus of the super-high strength concrete specimen after 200 freeze-thaw cycles is small, and at the same time, there is almost no loss in mass. It is foreseeable that super-high strength concrete poles that are used in severe and complex service environments such as severe cold regions can be protected from frost damage and rebar corrosion due to their excellent frost resistance.
(3) Ultra-high-strength concrete has very good resistance to carbonization, resistance to chloride ion penetration, and resistance to water penetration.
(4) The use of this technology can reduce the root diameter and weight of concrete poles, and can effectively reduce the investment in transmission line engineering.

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