Full Performance Study on Mass Concrete of X Nuclear Power Station

Bao-Liang Zhang and Xiu-Jun Yi

ABSTRACT: In this paper, based on the X nuclear power nuclear reactor, the mixture ratio of the nuclear base plate concrete was designed. And the mechanical property test, adiabatic temperature rise test, concrete shrinkage test and durability test were performed. Basic mechanical property and the thermal performance of the nuclear base plate concrete were investigated. The results show as follows: The compressive strength of 28 days was 38.6 MPa. The derived relationship between specific heat \( c \) and temperatures \( \theta \) was: \( c = 0.0003322 \theta^2 - 0.2463580 + 1.4571 \). The derived relationship between adiabatic temperature-rise and age was: \( \Theta_{n} = 45.45 - 45.75 / (1 + 0.00186n) \) \( (100/9) \). The chloride ions migration coefficient was \( 5.5 \times 10^{-12} \text{m}^2/\text{s} \) less than \( 7 \times 10^{-12} \text{m}^2/\text{s} \). All in all, the mixture ratio of the concrete is suitable for pouring the nuclear base plate of Hainan nuclear power plant nuclear reactor.

KEYWORD: Reactor, Mass Concrete, Full Performance

1 GENERAL INSTRUCTIONS

The radius of X nuclear power reactor bottom is 19.0m with largest casting thickness was 3 meters and maximum casting volume 3800m\(^3\). In that region, the annual average temperature was 24.3 °C, extreme maximum temperature is 41.5 °C. High temperature weather has great influence on the crack control of mass concrete. Nuclear reactor plants has the strict request for concrete strength and durability of concrete. The concrete for nuclear plate must been have high strength and low concrete chloride ion diffusion coefficient. But it was the most difficulty for the concrete crack control which the contradiction between high strength and maximum temperature control \(^{[1-2]}\). Based on the temperature and stress model, test data of the mechanical performance and durability was analyzed. The model analysis results proved that the feasibility of the mass concrete crack resistance. Thus it’s could provide the effective reference for the concrete designer of nuclear reactor plants. In domestic the most of designer used assumptions numerical about mechanical properties and thermal properties when they simulated the temperature changing of nuclear power mass concrete \(^{[3]}\). But still did not appear with concrete whole performance testing data for researching. In this paper, through testing the concrete performance and verified the temperature model, we could effectively reduce the risk of concrete crack when in the concrete mixture ratio design stage.

China Nuclear Building Materials Co. Ltd. Wuhan city, Hubei province
2 RESEARCH CONCENTS

2.1 Preparing the new file with the correct template

The principle of designing was using high performance water reducer, reducing the concrete unilateral water, increasing the dosage of mineral admixture and reducing unilateral cementitious material of the concrete \(^{[4]}\). Based on those principles, the effect of reducing the unilateral concrete hydration heat been achieve. So as to effectively reduce the highest temperature which in the center of the mass concrete. Furthermore it’s could improve unilateral concrete aggregate volume ratio.

That could reduce the risking of the mass concrete crack. Where the cement was low heat PII42.5, fly ash was I class, medium sand, HPC poly carboxylic acid water reducer which provided by Shanxi Huang teng. Through many test and screening, eventually we selected the following concrete mix ratio, as shown in table 1.

Table 1. Concrete mixture ratio of C35P8.

<table>
<thead>
<tr>
<th>Material name</th>
<th>Water</th>
<th>Cement</th>
<th>Fly ash</th>
<th>Sand</th>
<th>Aggregate (mm)</th>
<th>Admixture</th>
</tr>
</thead>
<tbody>
<tr>
<td>kg/m³</td>
<td>160</td>
<td>280</td>
<td>117</td>
<td>76</td>
<td>376</td>
<td>696</td>
</tr>
</tbody>
</table>

2.2 Mechanical test of concrete

According to JGJ 50081-2002 Ordinary Concrete Mechanics Performance Test Method Standard, the nuclear concrete have to be test compressive strength (the size of the specimen was 100mm*100mm *100mm) and Poisson’s ratio (sample size was 100mm*100mm *300mm). Test results were shown in table 1. We tested the splitting tensile strength (sample size for 150mm*150mm*150mm) and static compression elastic modulus (specimen size was 100mm*100mm*300mm). As the data shown in fig.1 and fig.2.

Table 2. Mechanical properties of concrete.

<table>
<thead>
<tr>
<th>Test item</th>
<th>Age</th>
<th>Test result</th>
</tr>
</thead>
<tbody>
<tr>
<td>Compressive strength, MPa</td>
<td>3d</td>
<td>18.0</td>
</tr>
<tr>
<td></td>
<td>7d</td>
<td>27.0</td>
</tr>
<tr>
<td></td>
<td>28d</td>
<td>38.6</td>
</tr>
<tr>
<td>Poisson’s ratio</td>
<td>28d</td>
<td>0.19</td>
</tr>
<tr>
<td></td>
<td>60d</td>
<td>0.19</td>
</tr>
</tbody>
</table>

According to data from the figure 1, the early tensile strength of 3days was 1.9MPa. That was better tensile strength of ordinary concrete. The early strength of concrete can effectively improve the early crack resistance. The dosage of fly ash was 28% in the mixture ratio so that the later strength grows larger. The splitting tensile strength was 4.95 for 60d. As the fig.1 shown the late strength grow trends was obviously.
2.3 Thermal performance of concrete

In the mass concrete temperature model, it’s included thermal parameters such as temperature conductivity, thermal conductivity and thermal expansion coefficient. Because of concrete using different raw materials the thermal properties of concrete were different. The designer could not find the accurate number when they selected the parameters. So they only could be used to assume the parameters or reference value. Which lead to the results of the model deduction of certain bias. According to the requirements of The Hydraulic Concrete Experiment Regulations (DL/5150-2001). We measured the data which included coefficient of thermal conductivity, temperature conductivity and linear expansion coefficient. As the Data shown, we can see coefficient of thermal expansion was $9 \times 10^6/\degree C$. The coefficient of thermal conductivity was 0.003540/m$^2$/h and the thermal conductivity was 7.86 KJ/(m.h. $\degree C$).

According to the test data, we deduced the relationship between the specific heat ($c$) and temperature ($\theta$). Such as formula 1 shown below:

$$c = 0.0003322\theta^2 - 0.246358\theta + 1.45710$$  \hspace{1cm} (1)
Table 3. Mechanical properties of concrete.

<table>
<thead>
<tr>
<th>Test item</th>
<th>Test result</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Temperature coefficient m²/h</td>
<td>0.003540</td>
<td>----</td>
</tr>
<tr>
<td>Thermal conductivity KJ(m.h.℃)</td>
<td>7.86</td>
<td>----</td>
</tr>
<tr>
<td>Coefficient of thermal expansion ×10⁶/℃</td>
<td>9</td>
<td>----</td>
</tr>
<tr>
<td>Specific heat KJ(kg.℃)</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>1.021</td>
<td>22.8℃-38.5℃</td>
</tr>
<tr>
<td></td>
<td>1.033</td>
<td>38.5℃-53.5℃</td>
</tr>
<tr>
<td></td>
<td>1.190</td>
<td>53.5℃-67.7℃</td>
</tr>
</tbody>
</table>

2.4 Adiabatic temperature rise test of concrete

On the basis of DL/T5150-2001 Hydraulic Concrete Experiment Regulations, the cementitious material of the concrete in the hydration temperature changing under the adiabatic condition were measured.

![Figure 3. Experimental results of adiabatic temperature rise of concrete.](image)

The data of highest temperature which in the center of mass concrete structure were shown in figure 3. The determination results were tested when the initial temperature of concrete mixture was 20.2 ℃. As the detection results shown, temperature rose quickly that the adiabatic temperature within 3 days. While temperature increased slowly after 7 days. Based on the results of the test data, a large-scale regression analysis and the adiabatic temperature-rise data fitting hyperbolic expressions was obtained. As formula 2 shown:

\[ \Theta_n = 45.45 - 45.75 / (1 + 0.00186n)^{100/9} \]  \hfill (2)

Where, correlation coefficient r=0.981; \( \Theta_n \) = n day age concrete adiabatic temperature rise, ℃; N= concrete age, days.

2.5 Concrete shrinkage test

According to GB/T50082-2009 Test Method Standard Long Term Performance and Durability of Ordinary Concrete. We detected the concrete shrinkage with the specimen size was 100mm*100mm*515mm. Test results were shown in figure 4. As the data showed that the temperature shrinkage value growth faster within 14 days. While
after 60 days the shrinkage of concrete increased slowly. Early shrinkage of concrete influenced on mass concrete crack control. So it’s particularly important to the concrete curing in the process of construction and the curing time should be more than 14 days at least.

![Shrinkage Value Curve of Concrete](image)

**Figure 4. Shrinkage value curve of concrete.**

### 2.6 Durability test

#### 2.6.1 Carbonation test of concrete

According to the GB/T50082-2009 Ordinary Concrete Long-term Performance and Durability Test Method Standard, the carbonization depth of concrete was be detected. Where the testing conditions included the following aspects: CO₂ concentration: 17%~23%; temperature:18 °C~22 °C, relative humidity: 65% ~75%, the specimen size was 100mm*100mm*100mm. The test results as in table 4 shown:

<table>
<thead>
<tr>
<th>Specimen age(d)</th>
<th>Average carbonation depth of each carbonization age</th>
</tr>
</thead>
<tbody>
<tr>
<td>28d</td>
<td>13.8mm</td>
</tr>
<tr>
<td>60d</td>
<td>25.0mm</td>
</tr>
</tbody>
</table>

#### 2.6.2 Resistance to chloride ion penetration test

In the technical specification of concrete, it was required that the chloride ion permeability coefficient was not more than 7*10⁻¹²m²/s. Based on the GB/T50082-2009 Ordinary Concrete Long-term Performance and Durability Test Method Standard, we used the rapid chloride migration coefficient method (RCM method) and detected the unstable state chloride migration coefficient. The test results were shown in Table 5.

<table>
<thead>
<tr>
<th>Inspection items</th>
<th>Test result</th>
<th>Explain</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unstable chloride ion migration coefficient ×10⁻¹² m²/s</td>
<td>Specimen age 56d</td>
<td></td>
</tr>
</tbody>
</table>

### 2.7 Temperature simulation analysis

Based on the data of the full performance test, we took the data input the temperature evolution model. The input data included some aspects such as the concrete compres-
sive strength, splitting tensile strength, elastic modulus, Poisson's ratio, temperature coefficient, thermal conductivity coefficient, linear expansion coefficient, specific heat, shrinkage, creep coefficient, the external environment factors, casting temperature and the weather temperature. Through the model, we analyzed the mass concrete temperature field and stress field changing rule and verified the accuracy by the actual testing data.

![Center Temperature Curve](image)

Figure 5. Model output of center temperature curve.

As the figure 5 shown, the maximum center of mass concrete structure temperature curve. The highest temperature was 61.5 degrees Celsius by the model analysis when the casting temperature was 24 degrees. The highest temperature is reached when the curing time in 51 hours. As construction monitoring shown that the maximum temperature of 62.4 degrees Celsius, the highest temperature appeared in the pouring 52h.

According to the design requirements, the mass concrete temperature difference between inside and outside was not more than 25 degrees Celsius. As the model calculated results shown the maximum temperature was 24.4 degrees Celsius. As shown in Figure 5. We found that monitoring data was shown 24.6 degrees Celsius. As actual data shown in Figure 6.

![Model calculation of internal and external temperature difference](image)

Figure 6. model calculation of temperature difference between inside and outside.
3 CONCLUSION

The results show as follows:
1. The compressive strength of 28 days is 38.6 MPa;
2. The derived relationship between specific heat (c) and temperatures (θ) was: 
   \[ c = 0.0003322\theta^2 - 0.2463580 + 1.4571 \];
3. The derived relationship between adiabatic temperature-rise and age was: 
   \[ \Theta_n = 45.45 - 45.75/(1+0.00186n)^{(1000N)} \];
4. Although the concrete shrinkage value will significantly increase before the age of 14 days, it will do slowly after 60 days;
5. The concrete carbonization depth was 25.0mm. The chloride ions migration coefficient was \( 5.5 \times 10^{-12} \text{m}^2/\text{s} \) less than \( 7 \times 10^{-12} \text{m}^2/\text{s} \);
6. All in all, the mixture ratio of the concrete is suitable for pouring the nuclear base plate of Hainan nuclear power nuclear reactor.

4 REFERENCES