Influence of additives on hydration heat of mass concrete

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Abstract. In this paper, the development of early hydration heat and the performance of large temperature difference of mass concrete structures are studied. Five mass concrete samples with two strength grades and five mixing ratios were made. The size of samples is 1000mm*1000mm*1400mm. Temperature sensors are embedded in the component while the components are constructed. Temperature of early hydration heat temperature rise and instant heating on one side are tested by the sensors. It is found that the early hydration heat temperature rise of self-made crack resistance concrete with internal curing agent or shrinkage reducing agent is lower than that of common commercial concrete. The results of single-side instantaneous temperature rise test show that the temperature changes least on the heating surface of concrete and most in the middle position.

1. Introduction
Due to the large amount of hydration heat generated during hydration of cement, cracks will occur in the process[1, 2]. Therefore, in order to ensure the safety and durability of mass concrete structure[3], it is particularly important to test and analyze the temperature changes during the design and construction stages[4]. For concrete, besides water cement ratio, cement dosage and mineral admixture[5, 6], admixture also has certain influence on the hydration heat of concrete. In the early stage of hydration, the superplasticizer can inhibit the hydration of cement[7, 8]. At the same time, the expansion agent, shrinkage reducing agent and internal curing agent can also reduce the hydration heat of cement in varying degrees[9].

It can be seen from the above that most of the research on the hydration heat of concrete is still focused on the water cement ratio, cement dosage, mineral admixtures and other fields. The existing research on the influence of admixtures on the hydration heat of cement is mostly confined to the level of the hydration heat of cement. At present, there is little research on the effect of admixtures on the hydration heat of mass concrete. This paper makes experimental measurements and theoretical
calculations on the temperature changes of large-scale concrete members with different proportions, so as to study the development process of early hydration heat of mass concrete structures. In addition, by analyzing the temperature gradient in the single-side instantaneous heating test, the large temperature difference resistance of concrete members with different proportions is studied.

2. Test conditions

2.1 Mix ratio and materials

The cement is P.O42.5R ordinary Portland cement with a density of 3100 kg/m³. The fly ash is F class II grade. The slag powder is S95 grade high performance slag powder. The gradation of gravel is 5-20mm, the sand is II grade medium sand. The superplasticizer is JK-5 naphthalene series superplasticizer with a 23% water reduction rate. Shrinkage reducing agent is SBT-SRAI concrete shrinkage reducing agent. Internal curing agent is a kind of composite polymer water-absorbing and water-retaining composite material made by China Academy of Railway Sciences. The mix proportions are shown in table 1.

| Mix type | Cement | Fly ash | Sand | Gravel | Water | Super plasticizer | Shrinkage reducing agent | Internal curing agent |
|----------|--------|---------|------|--------|-------|-------------------|-------------------------|----------------------|
| C50-S    | 280    | 88      | 582  | 1237   | 144   | 6                 | 0                       | 0                    |
| C40-N    | 280    | 88      | 582  | 1237   | 180   | 4                 | 0                       | 32                   |
| C50-N    | 280    | 88      | 582  | 1237   | 144   | 6                 | 0                       | 32                   |
| C40-J    | 280    | 88      | 582  | 1237   | 180   | 4                 | 6                       | 0                    |
| C50-J    | 280    | 88      | 582  | 1237   | 144   | 6                 | 6                       | 0                    |

2.2 Design of concrete specimen

In order to simulate the actual situation and test the internal temperature of concrete, rectangular members with length of 1000mm, width of 1000mm and height of 1400 mm were made. Components of this size basically conform to the definition range of mass concrete size in 《Specification for mix proportion design of ordinary concrete ( JGJ55-2011, J 64-2011)》.
As shown in figure 1, the sensors are arranged from the outside of the concrete member to the inside according to the spacing of 80 mm, 7*120 mm, 80 mm, and all the sensors are at a plane height. The sensor wire is fixed on the steel bar of the specimen. When the concrete is constructed the sensor is wrapped in concrete and fixed in place according to the design.

2.3 Experimental programme
The flash concrete and the specimen model are formed at the same time, and the concrete is vibrated while constructing to ensure the compactness of the specimens. The test of the hydration temperature begins after the specimens are constructed. The hydration heat is tested after modeling. The adiabatic temperature rise at the center of the concrete specimen was measured at 0.1d, 0.2d, 0.3d, 0.4d, 0.5d, 0.6d, 0.7d, 0.8d, 0.9d, 1d, 2d, 3d and 5d. Respectively, the environmental temperature was recorded. The field test is shown in figure 2. The hydration heat test is completed on the 5 day of the specimen formation, and after the test sample was dismantled, the temperature gradient under the simulated temperature condition was tested. When the surface temperature of each specimen reaches 55℃, the temperature is kept constant and the internal temperature is recorded.

3 Results and discussion

3.1 Early hydration heat

3.1.1 Calculation of early hydration heat. The adiabatic temperature rise of mass concrete specimens is estimated by the double exponential equation of cement hydration heat and the adiabatic temperature rise estimation formula of concrete. The maximum adiabatic temperature rise of each proportion of concrete 1d~3d is calculated by equation (1) and (2).

\[
Q(\tau) = Q_0 (1 - e^{-a \tau^b})
\]  

(1)

Where: \(a\) , \(b\) — Calculating coefficients

\(Q_0\) — Total amount of hydration heat of cement (kJ/kg)
\[ \tau \rightarrow \text{Age of concrete (d)} \]

for ordinary Portland cement: \( a=0.69, b=0.56, Q_0=330 \)

\[ \theta(\tau) = \frac{Q(\tau)(W + kF)}{c\rho} \quad (2) \]

Where:
- \( \theta(\tau) \rightarrow \text{Adiabatic temperature rise of concrete (°C)} \)
- \( Q(\tau) \rightarrow \text{Cumulative hydration heat of cement (kJ/kg)} \)
- \( W \rightarrow \text{Cement consumption per cubic metre of concrete (kg/m}^3) \)
- \( c \rightarrow \text{Specific heat of concrete (kJ/kg⋅°C)} \)
- \( \rho \rightarrow \text{Concrete density (kg/m}^3) \)
- \( k \rightarrow \text{Reduction coefficient, for concrete with fly ash } k = 0.25 \)
- \( F \rightarrow \text{Mineral admixture per cubic metre of concrete (kg/m}^3) \)

3.1.2 Test results and analysis of hydration heat. The hydration heat of mass concrete specimens with different proportions are tested, the measured results are shown in figure 3. At the same time, the calculation results are also placed for comparison.

(a) Adiabatic temperature rise of C50-S

(b) Adiabatic temperature rise of C40-N
By comparing the internal heat of hydration between commercial concrete and mass concrete specimens with internal curing agent and shrinkage reducing agent, it is found that the temperature rise of internal heat of hydration is positively related to the age of concrete. That is, with the advancing of age, the hydration heat and temperature of concrete will gradually increase. At the same time, it is found that the hydration heat temperature rise of mass concrete specimens with internal curing agent and shrinkage reducing agent in 5 days is lower than that of ordinary mass concrete specimens in 5 days. Comparing the test results with the calculation results, it is found that the test results of the hydration heat rise of the ordinary mass concrete specimens are higher than the calculation results, while the test results of the hydration heat rise of the mass concrete specimens with internal curing agent and shrinkage reducing agent are lower than the calculation results.

Shrinkage reducer can reduce the surface tension of porous solution, cause the change of ion concentration in porous solution, and then slow down the transformation of ettringite to calcium sulfonate monosulfate, which has a certain retardation effect on hydration reaction\textsuperscript{10}. Internal curing agent can react with water to form hydrogel, which can hinder the contact between cement and water, thus inhibiting the hydration reaction of cement\textsuperscript{11}. 

**Figure 3.** Adiabatic temperature rise
3.2 Results and analysis of the single side momentary heating test
After form removal, the temperatures of the specimens’ surface are simulated. The simulation uses a one-sided instantaneous heating method, while the internal temperature of the specimen is tested. The test results are shown in Figure 4. It can be seen that the temperature change is the smallest in the concrete heating surface and the largest change occurs in the middle position. At the same time, there is little difference between the temperature gradients of different proportions of concrete at the same measuring point. And the influence of the change of measuring point position on the temperature difference of concrete with different proportions is similar. The results of remote monitoring on the heating surface show that the temperature variation trend of different test points is similar, the temperature difference is small, the temperature difference between the inside and outside of the concrete sample is small too, which means the volume stability of the concrete is good, and there is little possibility of cracking of the concrete. The temperature difference between the surface temperature and the ambient temperature of the mega-cylinder is large, which agrees with the calculation results and accords with the law of heat conduction.

![Figure 4. Temperature distribution of specimens](image)

Conclusions
(1) The hydration heat temperature rise of concrete is positively related to the early age of concrete. The smaller the age is, the faster the hydration heat of concrete develops.
(2) The test results of the temperature rise of hydration heat of mass concrete with internal curing agent or shrinkage reducing agent are lower than the ordinary mass commercial concrete.
(3) The temperature rise of hydration heat in 5 days of mass concrete with internal curing agent or shrinkage reducing agent is lower than that in 5 days of ordinary mass concrete.
(4) In the single-side instantaneous heating test, the temperature change is the smallest on the concrete heating surface and the biggest on the middle part. There is little difference between the temperature gradient of concrete with different proportions at the same survey point.

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