Simulation Analysis of Temperature Field in the Curing Process of Precast Concrete Wall Panels

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Abstract: To investigate the temperature field change law of the steam curing process of precast concrete elements, this paper takes precast concrete wall panels as the research object.Combining the field production process with the theory of temperature field calculation, ANSYS is used to simulate the temperature field of the maintenance process and to compare the maintenance effect under different maintenance systems.The simulation analysis shows that the steam curing effect gradually decreases with the increase of the thickness of the prefabricated components of the slab.The poor thermal conductivity of the concrete and the rapid temperature rise in the warming stage will lead to a large temperature difference between the inside and outside of the wall panels.The curing effect can be improved by adjusting the curing system.

Keywords: *Precast Concrete Wall Panels; Steam Curing; Temperature Field; Curing Regime*

I. INTRODUCTION

Curing is an important part of the PC component production line, mostdomestic factories use the steam curing process.Compared with the natural curing process, the steam curing process can improve the early strength of PC components in aperiod, to achieve rapid demolding requirements, and greatly improve the production efficiency of PC components[1]. Zhang et al[3], experimentally tested the mechanical properties of concrete under different curing regimes and found that different preconditioning times, heating rates, constant temperatures, and cooling rates would all have an effect on the strength of concrete, and curing strength prediction model was established.Using self-compacting concrete as a raw material, Zhao et al [4], an experimental comparison of the strength of concrete blocks in standard and high-temperature curing methods revealed that high-temperature curing can improve the early mechanical properties of self-compacting concrete.

Current research has focused on the effect of the curing regime on the overall mechanical properties of the concrete at a later stage, with very little research on the temperature field distribution of PC components during curing. In the actual production process, PC components often have appearance defects such as non-penetrating cracks and peeling of the skin, which arise due to the poor thermal conductivity of concrete, the large temperature difference between the internal and external surfaces of concrete during the curing process, and the local fine deformation caused by the different thermal expansion[5]. Based on the theory of temperature field analysis, this paper simulates and analyzes the temperature field in the curing process of precast concrete wallboard by Ansys finite element software.

I. BASIC THEORY OF TEMPERATURE FIELD ANALYSIS

A. Heat Conduction Equation

The heat conduction equation based on the heat of concretehydration is:

$$\frac{\partial T}{\partial \tau} = \frac{\lambda}{\rho c}\left(\frac{\partial^2 T}{\partial x^2} + \frac{\partial^2 T}{\partial y^2} + \frac{\partial^2 T}{\partial z^2}\right) + \frac{\partial \theta}{\partial \tau} \tag{1}$$

Where τisthe curing time(h), $\rho$is density(kg/m^3), $c$is the specific heat capacity(kJ/(kg·℃)),$\lambda$is the thermal conductivity w/(m·℃), θisthe final amount of the adiabatic temperature rise(℃).

The adiabatic temperature rise of concrete depends on the heat of hydration of the hydratable complexes in the concrete, and the formula for rising adiabatic temperature rise is：

$$\theta(\tau) = \frac{(W + kF)Q(\tau)}{c\rho} \tag{2}$$

Where Q(τ) is the total heat release per unit mass of concrete at curing timeτ(kJ/kg),$W$is the amount of concrete used (kg/m^3), k is the discount factor, which is related to the type of blending material, F is the amount of blending material used (kg/m^3).

B. Initial and Boundary Conditions

To obtain the temperature distribution of PC components during curing, the initial and boundary conditions need to be known. After the concrete is poured, the temperature entering the kiln is the initial condition, and the heat exchange between the component and the curing environment is the boundary condition.

It is assumed that the temperature distribution of the components is uniform before they enter the kiln. The initial conditions for solving the temperature field of the PC componentsare:

$$T(x,y,z,\tau)_{\tau=0} = T_0(x,y,z) = const \tag{3}$$

The heat convection between the concrete surface and the curing environment is treated according to the third type of boundary conditions, and its expression is:

$$-\lambda \frac{\partial T}{\partial n} = \beta(T - T_\alpha) \tag{4}$$

Where β is the concretesurface heat release coefficient (kJ/(m2·h·℃)),e is the known time-dependent curing temperature.

In the process of steam curing, the flow rate of hot steam is large, and the steam is in an uninterrupted state, so the temperature of the surface of the concrete precast components can be approximately equal to the temperature in the curing kiln.

The heat release of concrete through the formwork can be converted into the effect of the equivalent surface heat release coefficient on heat conduction [6], and the equivalent heat release coefficient expression is:

$$\beta_s = \frac{1}{(1/\beta) + h/\lambda} \tag{5}$$

II. FINITE ELEMENT ANALYSIS

A. Project Overview

The precast concrete wall panel produced by a precast component factory has a cross-sectional size of 3.2m×2.8m, and its thickness can be produced by a flat die process according to the actual engineering needs. The four sides of the wall panel are made of steel formwork. The concrete of C30 strength grade is used in the production. The curing method is the common straight-through water steam shaft kiln curing, and the temperature in the curing kiln is evenly distributed during the steam curing process.

C. Establishment of a curing regime

The curing process of precast concrete wall panels is dividedinto 4 stages: the pre-curing stage, heating stage, constant temperature stage, and cooling stage [7]. Pre-curing of concrete can reduce the thermal damage of post-curing. The pre-curing time is mainly determined by the initial setting time of concrete, usually 1 to 3 hours; PC components are heated continuously at the beginning of the warming phase until the maximum curing temperature is reached. To reduce the thermal damage effect of concrete, the temperature rise rate should be limited to less than 20°C/h, often taken from 1 to 3 hours.

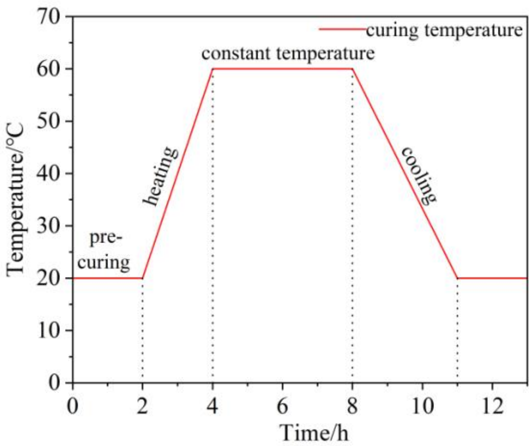

Fig.1 Schematic diagram of curing regime S_1

In the constant temperature stage, a stable high temperature is maintained in the curing kiln, so that the concrete can obtain high early strength. The curing time is usually 4 to 6 hours. For plate components, the constant temperature is usually maintained between 50 °C and 70 °C. After constant temperature curing, if the component is directly removed from the curing kiln, the temperature difference between the component body and the external environment will cause temperature cracks. Therefore, cooling treatment is required, and the cooling rate should not be higher than 20℃/h. Considering the production efficiency, the curing system S1 established in this paper is shown in Fig 1. The pre-curing temperature is 20°C, and the constant temperature is 60 °C. The pre-curing is over in the second hour, the heating stage is over in the 4th hour, the constant temperature stage is over in the 8th hour, and the 11-hour cooling phase ends.

D. Finite element model

Based on the project profile, four common thicknesses of precast concrete wall panels of 0.3m, 0.24m, 0.2m, and 0.15m are selected for temperature field analysis in this paper, and the above three wall panels are abbreviated as component A, component B, component C and component D for subsequent result analysis. Wall panels of different thicknesses are meshed in the same way, taking a 0.2m thick wall panel as an example, the finite element model is shown in Fig. 2.

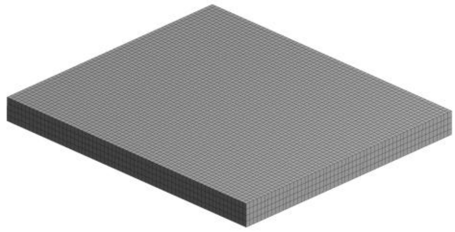

Fig.2 Finite element model

E. Loading working conditions

During the curing process, the components and the steam in the curing kiln continuously transfer heat through thermal convection, and the convective heat exchange is applied to the surface of the components as a surface load, The equivalent surface heat release coefficient of the steel formwork is calculated according to Eq.(5), and the material parameters required for the calculation are shown in Table 1.

TABLE. 1 Material parameters

Parameter Name	Parameter Value	
	C30	Q235
Density(kg/m^3)	2436	7800
Specific heat capacity (J(kg·°C))	917	460
Thermal conductivity(W/(m·℃))	2.23	60.40
Surface heat convection coefficient(KJ/(m^2·h·℃))	82.23	76.70

For the expression of the heat of hydration of cement, this paper uses the exponential formula[8]:

$$Q(\tau) = Q_0(1 - e^{-m(\frac{\tau}{24})}) \tag{6}$$

Where Q0is the final cumulative heat of hydration atτ→∞, m is a constant, which is determined by the pouring temperature.

In ANSYS, the heat of hydration of cement is applied to the model as a body load through the heat generation rate Hgen[9], which is expressed as:

$$H_{gen} = (W + kF)\frac{dQ(\tau)}{d(\tau)} \quad (7)$$

III. FINITE ELEMENT CALCULATION RESULTS AND ANALYSIS

In the steam curing process, the internal center point temperature and surface center point temperature change trend of different thickness components is the same, due to the short period of static curing stage, the temperature rise of the concrete hydration zone is less obvious; A gradual increase in temperature at both points during the warming phase and the constant temperature phase; After the beginning of the cooling phase, the temperature of the surface center point gradually decreases, due to the poor thermal conductivity of concrete, the internal heat conduction to the outside is slow, and the heat of hydration continues to occur, the temperature of the internal center point continues to rise for some time before it begins to fall.

As can be seen from Fig. 3 and Fig. 4, the thickness will have a greater impact on the internal temperature variation of the components, the thicker the components the smaller the temperature peak in the internal center, and the delay in the appearance of the peak, the specific changes are shown in Table 2. Compared with component A, the peak appearance time of component D is 1.5h earlier and the peak is 9.08°C higher.

TABLE.2 Internal center point temperature variation parameters

Name	Thickness (m)	Peak occurrence time (h)	Peak (˚C)	Peak increase
componentA	0.3	10	46.88	0
componentB	0.24	9.5	50.25	7.1%
componentC	0.2	9	52.67	12.4%
componentD	0.15	8.5	55.96	19.4%

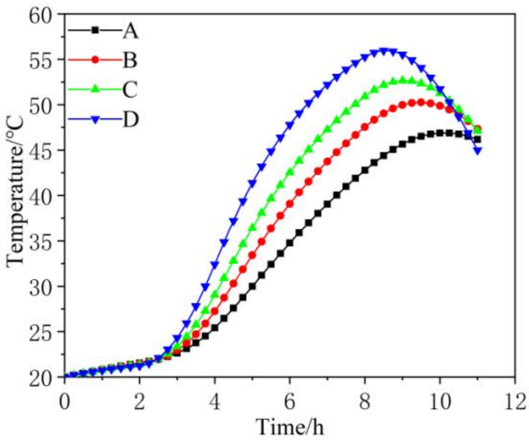

Fig.3 Internal center-point temperature

The temperature difference between the center point of the surface and the center point of the interior of the components of different thicknesses is shown in Fig. 5. After the beginning of the warming stage, the surface temperature of the components rises rapidly, and the temperature difference between the interior and exterior gradually increases and reaches a peak at the beginning of the constant temperature stage, which gradually decreases with the constant temperature curing. The temperature difference disappears after the cooling stage is carried out for some time, after which the surface temperature drops rapidly and the temperature difference appears negative. With the increase of thickness, the temperature difference at 2 points gradually increases and the duration of the larger temperature difference grows.

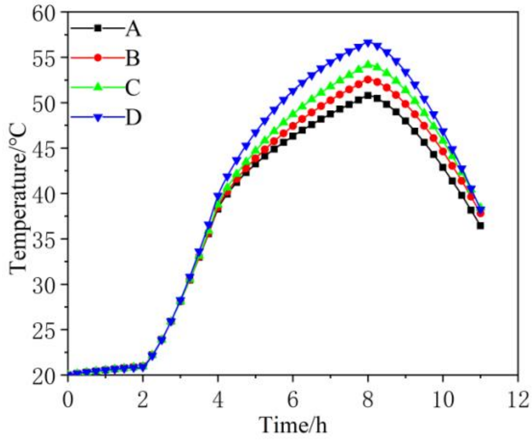

Fig. 4 Surface center-point temperature

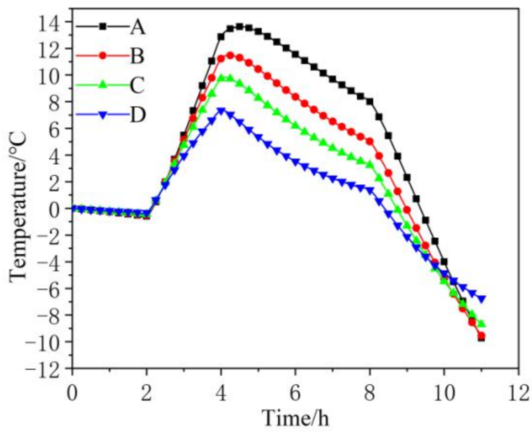

Fig. 5 Inner surface temperature difference

From the above analysis, it can be seen that the size of the temperature difference between the surface and the interior of the plate components in the curing process is related to the rate of temperature rise, and the peak internal temperature is related to the duration of the constant temperature phase.

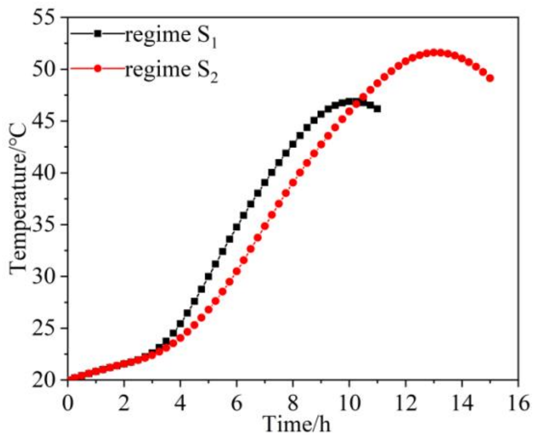

Fig. 6 Temperature at the internal center of component A

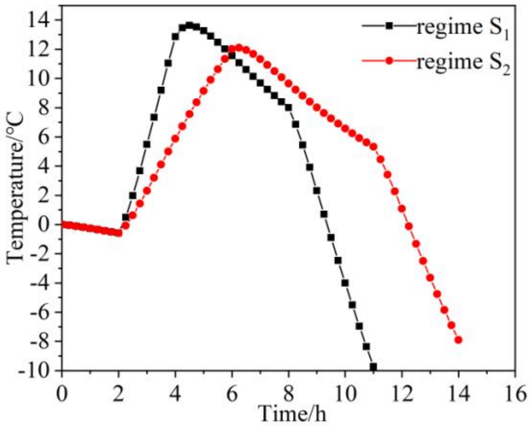

Fig. 7Tow-point temperature difference of component A

Under the action of curingregime S1, the curing effect of component A is significantly lower than that of components D. Establish a curing regime for component A. S2：The heating rate V=10℃/h, constant temperature curingfor 5h, other parameters are consistent with the curingregime S1. Fig.6 and Fig.7 show that the peak internal center point temperature of component A increases, and the internal surface temperature difference decreases significantly under the effect of the curing regime S2. Therefore, different curing regimes should be used for components of different thicknesses.

CONCLUSION

This paper takes precast concrete wall panels of different thicknesses as the research object, combines the field production process with the theory of temperature field calculation, and uses ANSYS finite element analysis software to simulate and analyze the temperature field of the wall panel curing process, and obtains the following conclusions:

(1) Concrete is a poor conductor of heat, with the increase in the thickness of the slab-type precast concretecomponents, the internal temperature rise of the components is slower, and the effect of steam curing gradually decreases.

(2) Reducing the heating rate can reduce the temperature difference between inside and outside, extending the constant temperature time can improve the internal temperature of the components, and different thicknesses of precast concrete slabs should use different curing regimes.

(3) When developing the curing system, simulation analysis can be performed with ANSYS finite element software, and the curing program can be adjusted according to the analysis results to improve the curing effect.

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