Experimental study on elastic modulus of concrete mortar under high temperature

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Abstract. In order to study the change of elastic modulus of mortar concrete under high temperature, the mortar cube was tested at high temperature. The results show that the elastic modulus of the mortar cube is not linear with the change of temperature. The elastic modulus of the mortar decreases with the increase of temperature. When the temperature rises to 150 °C, the mortar elastic mold will have a situation of slowing down and then falling again.

1. Introduction

As an important performance parameter and structural design parameter of concrete mortar, elastic modulus plays a particularly important role in ensuring the safety of components (1), it is also one of the necessary parameters to calculate the deformation, crack development and thermal stress of concrete structures (2). Cement mortar is used in some high temperature environments due to the impact of building fires (3) and some high temperature production environments. Since in some cold places, concrete mortar is also used in some buildings, the influence of low temperature on mortar elastic modulus should also be considered (4). There are many methods for studying cement-based materials, such as resonance method (5), bending method, and the like. The curing temperature of mortar also has influence on the performance of mortar (6). Bending method, and the like. Experimental research on concrete mortar materials under high temperature shows that this coupling relationship exists. When there is no mechanical force, there is a certain or even significant difference between the free deformation of the concrete specimen due to the temperature rise and the mechanical deformation of the concrete specimen under the same temperature rise conditions. In summary, it is proposed to study the mechanical properties of steel-mixed specimens under high temperature, focusing on the strain variation of the reinforced concrete specimens under the joint action of mechanical force and temperature, and to explore the coupling relationship between mechanical force and temperature induced strain. Study the change of elastic modulus of mortar at high temperature, and then provide a basis for the experimental study of concrete mortar at high temperature.
2. Test overview and method

2.1 Test piece design and production
This experiment aims to investigate the experimental study of the elastic modulus of mortar concrete at high temperature. The test uses 150×150×150mm mortar and stone cube test block. The proportion of water in the mortar test block: cement: sand = 1:2.5:4.65, in which the cement is made of ordinary Portland cement, the mortar is cured for 28 days; the stone is limestone obtained from the processing of Xianning. All test pieces were placed in a high temperature chamber for 24 hours before the formal test, and the temperature was set to 40 °C for drying. The cube test piece is placed at the pressurizing device and subjected to mechanical forces during the test. A high temperature strain gauge is attached to the test points of each test piece, and the thermocouple is fixed by tying. The test piece layout is shown in Figure 1. In the number, h is perpendicular to the direction of force, and s is parallel to the direction of force. For example, sand s1 means that a low temperature strain gauge is attached to the mortar cube test block at a central position along the vertical direction as a measuring point.

Figure 1 Arrangement of measuring points

2.2 Test procedure
(1) The test piece is placed in the box. The test piece which is formed by curing and completes the measuring point arrangement is placed at the loading device of the test box. In addition, in the test, an additional 150×150×150mm reference mortar test block was set up, and a thermocouple was buried inside the test block to test its temperature. Since the thermal conductivity of the mortar is weaker than the stone, it can be considered as a mortar test block shape. When the heart temperature reaches the predetermined temperature, the stone block of the same size has reached the specified temperature. In this way, the temperature at the centroid of the pressed test piece can be obtained indirectly to ensure the effect of the "heat penetration" of the test piece, see Figure 2.

(2) Test system debugging. The connection of the corresponding measuring points is completed in the box, and the corresponding wires are led out through the test box test holes to connect the data acquisition system and the data recording device, and the test system is debugged before loading.

(3) Counterweight installation. First place the bottom steel plate to the predetermined position, then place the jack in the middle of the steel plate, adjust the jack to a certain height, and place the required weights on the jacks in order from large to small, the central hole and the external force transmission device of the test box. The tie rods are aligned. Slowly adjust the jack to raise it. When all the weight passes through the tie rod, screw the bottom end bolt of the rod to fix the weight on the rod.
3. test data processing method

3.1 test data processing method

This test adopts a temperature-mechanical force double loading process, in which part of the effect of temperature and mechanical force is coupled. In order to measure the separation of mechanical deformation and temperature deformation during temperature-mechanical load double loading, an in-situ compensation method was proposed and adopted. At the same time, the method also effectively overcomes the test accuracy problem caused by the uneven temperature field in the test environment box.

(1) The 1/4 bridge is used to test the heat output of each measuring point, and the thermal output signals obtained by connecting the thermocouple and the strain gauge to the data acquisition instrument are:

\[ \varepsilon_t = \varepsilon_R + \varepsilon_\beta \] 

(2.1)

(2) The thermal output signal obtained during the first-level loading test is:

\[ \varepsilon_t = \varepsilon_m + \varepsilon_R + \varepsilon_\beta \] 

(2.2)

Where \( \varepsilon_t \) is the strain obtained by the unstressed test; \( \varepsilon_r \) is the strain caused by the deformation of the strain gauge base material; \( \varepsilon_\beta \) is the strain caused by the difference between the thermal expansion coefficient of the strain gauge and the test member; \( \varepsilon_m \) is The strain produced by the action of external forces. The above two equations are subtracted, thus eliminating the effect of temperature on the heat.
3.2 data processing methods

3.2.1 High temperature elastic modulus treatment method for coagulation mortar

1) Temperature-mechanical load loading process

Figure 3 Heat output curve of mortar cube test piece 3 under temperature and force load

It can be seen that 1) the effect of temperature on the heat output of each measuring point is very obvious; 2) the result of heat output is the combined effect of temperature and mechanical force, not the strain value.3) Obvious small protrusions can be seen on the curve during mechanical loading.4) The four faces on the test piece do not overlap, indicating that the mechanical load is eccentric.5) The temperature load plus/unload curve is basically coincident, indicating that the test is reproducible, and the test piece is not damaged, and the test result is highly reliable.

Figure 4 Mechanical output of the mortar cube No. 3 specimen when the temperature is loaded to 180 °C

When the mortar cube is loaded at 180 °C, it can be seen from the figure: the heat output of each stage is stable, almost on a "platform"; during the loading and unloading process, the heat output data can be basically repeated, indicating that the test is very ideal; The heat output of the upper four quarters is not equal, indicating that the loading is eccentric; the difference between the heat output of each load and the heat output under zero load is the strain of the mechanical load. This value is higher than that of the temperature compensation block method. Compensate itself.
During the test, the temperature at the measurement points on the four elevations of the test piece is different, so it has an impact on the test results. Calculating the elastic parameters of a material directly using test results can introduce certain errors. To this end, the temperature-heat output curve obtained by the test is used to interpolate the test results to give a heat output at the same temperature.

### 4. Analysis of elastic modulus of concrete mortar

The mechanical load has a certain eccentricity. When calculating the elastic parameters of the material, the heat output of the test piece is represented by the average value of the heat output of the measuring points on the four facades. Under the load of all levels, the average heat output of the test piece calculated with the test value and the corrected value is shown in Figure 5. It can be seen from the figure that: 1) the correction value is close to the test value, and the law changes with the temperature; 2) the correction value is smoother than the test value, which is the result of correcting the temperature error, and the correction value is more than the test value. High precision.

Table 1 Stress-strain fitting curve of mortar cube test piece 3 in different temperature environments

| Temperature / °C | Stress/kPa-strain/με relationship | Correlation/ $r^2$ | Bullet / MPa |
|------------------|-----------------------------------|-------------------|-------------|
| 20.0             | $\sigma = -22.176 \epsilon + 59.142$ | 0.9988            | 22.176      |
| 30.0             | $\sigma = -21.926 \epsilon + 50.275$ | 0.9993            | 21.926      |
| 50.0             | $\sigma = -21.608 \epsilon + 33.646$ | 0.9998            | 21.608      |
| 70.0             | $\sigma = -21.484 \epsilon + 18.177$ | 0.9999            | 21.484      |
| 90.0             | $\sigma = -21.506 \epsilon + 3.8342$ | 0.9999            | 21.506      |
| 110.0            | $\sigma = -21.628 \epsilon - 9.118$ | 0.9999            | 21.628      |
| 130.0            | $\sigma = -21.806 \epsilon - 20.17$  | 0.9999            | 21.805      |
| 150.0            | $\sigma = -21.993 \epsilon - 28.613$ | 0.9999            | 21.993      |
| 170.0            | $\sigma = -22.139 \epsilon - 33.592$ | 0.9999            | 22.139      |
| 190.0            | $\sigma = -22.192 \epsilon - 34.199$ | 0.9999            | 22.192      |
| 210.0            | $\sigma = -22.099 \epsilon - 29.606$ | 1                 | 22.099      |
| 230.0            | $\sigma = -21.815 \epsilon - 19.225$ | 1                 | 21.815      |
| 250.0            | $\sigma = -21.309 \epsilon - 2.8688$ | 0.9999            | 21.309      |
270.0  $\sigma = -20.567e+19.138$  0.9999  20.567  
290.0  $\sigma = -19.601e+45.952$  0.9999  19.601  
300.0  $\sigma = -19.044e+60.779$  0.9999  19.044  

Figure 6 Curve of elastic modulus and temperature of mortar specimen

5. Conclusion
The relationship between the elastic modulus obtained by the test of the mortar test block and the temperature is shown in Figure 3.1, and the test values at each temperature are shown in Table 3.1. As can be seen from the figure:

1. The variation of the elastic mode of the mortar material with temperature is not linear.
2. As the temperature increases, the mortar material elastic modulus is in a downward trend. When the temperature rises to about 150 °C, the elastic modulus of mortar will rise slowly and then fall again.
3. The freely deformed body under mechanical load is reduced, and the mechanical load strain on it decreases with the temperature drop. This effect is not caused by temperature strain. For the elastic modulus and temperature relationship model, it can be fitted by multiple items or exponential models.

Three-fit curve model of mortar cube test piece:

$$E = -9E^{-07}T^3 + 0.0004T^2 - 0.0394T + 22.792$$  
$$R^2 = 0.9982$$

Mortar cube exponential curve model:

$$E = 22.341e^{-2E-04T}$$  
$$R^2 = 0.2989$$

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