

An Approach to Determine the Coefficient of Thermal Expansion of Road Concrete Using Optical Lever

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Abstract—The approach to determine the coefficient of thermal expansion (CTE) of road concrete using optical lever system was introduced. CTE of 144 concrete specimens was determined with it. The coarse aggregate in these specimens contains 8 kinds of stones from 19 origins. Measured data was satisfactory verified by AASHTO TP60. The results showed that: CTE of road concrete was between $4.76 \times 10^{-6}/^{\circ}\text{C}$ and $12.1 \times 10^{-6}/^{\circ}\text{C}$. Coarse aggregate type had a great influence on CTE. When aggregate content was equivalent, the higher CTE of the aggregate, the higher CTE of concrete contained that aggregate. The sensitivity of concrete for different temperature ranges and the same temperature gradient has no significant difference, such as 20°C to 30°C and 30°C to 40°C . Meanwhile, amount of concrete expanse when temperature increment was equal with concrete shrinkage when temperature reduction.

Keywords—coefficient of thermal expansion; road concrete; measurement approach optical lever; aggregate

I. INTRODUCTION

The coefficient of thermal expansion (CTE) has been recognized as an important parameter of Portland cement concrete for long time. It is known as a key factor influencing cement concrete pavements' early-age behaviors, which require saw-cutting at the joints just before cracks were formed. The CTE values between different layers in the Portland cement concrete pavement should be compatible to adjacent layers, otherwise, thermal instability between two layers causes delaminating such as splitting cracks and spall. In fact, the CTE values both for the overlaying or patching materials and their underlying substrate concrete material were to be determined for the quality control in the laboratory [1]-[3]. In order to predict cracking response and prepare for its way to cope with it, a systematic way to determine the coefficient of thermal expansion of cement concrete is needed. Therefore, it has been a big issue for concrete pavement engineers to precisely determine the CTE value for Portland cement concrete.

The CTE is measured as the change in length per change in temperature. The CTE is directly used for thermal curling stresses design under highest temperature gradient in jointed plain concrete pavements and average distance of transverse joint and longitudinal reinforcement ratio design in continuously reinforced concrete pavements in Specifications of Cement Concrete Pavement Design for

Highway (JTG D40-2011) [4]. In American the CTE is used for transverse joint sealant design in jointed plain concrete pavements and longitudinal reinforcement design in continuously reinforced concrete pavements in the 1993 edition of the American Association of State Highway and Transportation Officials Guide for the Design of Pavement Structures (AASHTO 1993) [5]. However, it is not a direct input for structural pavement design. In the new Mechanistic-Empirical Pavement Design Guide developed under National Cooperative Highway Research Program (NCHRP) Project 1-37A (ARA 2004) [6][7], the CTE value is required as a direct input for structural pavement design procedures. It is used to determine joint and crack openings as well as critical Portland cement concrete slab distresses directly or indirectly [8]-[10]. Besides concrete ages, there are many factors known for affecting the CTE of concrete, including the types of coarse aggregates, relative humidity, admixtures, outline of specimen [11]-[17], etc.

In this study the influencing factor of different coarse aggregates on thermal coefficient of concrete were just quantitatively investigated.

II. TESTING EQUIPMENT AND TESTING METHOD

A. Testing Equipment

Currently, there are many measurement methods for minimal deformation and their principle was almost similar. The specimen was expansion in the heating process. The expansion was transferred to the detection system through a bar that connected the surface of specimen. The difference was the equipment that measured the expansion. Common methods include dial indicator method, thermo-mechanical method (optics method, electromagnetic induction method, electrical resistance method) and volume method.

In this study, temperature-controlled water bath was used to heat the prism concrete specimen. Then, the deformation transferred to optical lever system through a fused quartz bar. We can record the determination reflecting to vernier caliper through optical lever when temperature in center concrete specimen increased from 10°C to 50°C and determine the thermal expansion coefficient of concrete ultimately. Testing equipment is shown in Figure 1.



Figure 1. CTE test equipment

The test equipment includes CTE test box (temperature-controlled water bath, 0.1°C), optical lever system, fused quartz rod, temperature recorder (0.1°C) and vernier caliper (0.02 mm). The CTE container makes concrete specimen warm evenly through heating water in container. The temperature of water should keep between 10°C and 50°C. The water level in the container should be 5cm higher than the vertical height of the concrete specimen. Test box cover reserved a round hole 1.5 cm in diameter. So that fused quartz bar can connect the specimen in the bath vertical through it, and specimen deformation can transfer to optical lever.

B. Testing Method

There are variety of testing equipment and the corresponding methods for the measurement of thermal coefficient of concrete. Engineers in U.S. DOT invented a decent measuring device which was adopted in the AASHTO TP 60 [3] - serving as the standard test method for the coefficient of thermal expansion of concrete. In this study, the CTE was measured with improved optical lever system and the test conditions were same with TP 60.

Test steps as follows:

1. Put the prismatic specimen (10cm×10cm×40cm) on the floor of test box vertically, making sure it can completely soaked in water. The specimen connects with the floor of box by a quartz glass mesh which also effectively limit the disturbance of concrete specimens because of temperature rising.
2. Connect molten quartz rod to the upper surface of the specimen with glue stick, and make quartz rod vertical through the cover of box.
3. Inject the test box with water, and make sure the water higher than the specimen surface 5cm.
4. Set up optical lever, put the rear leg of optical lever on the upper surface of quartz bar, and make optical lever base level, mirror vertical.
5. Adjust the telescope, and make sure the telescope axis horizontal. Make the telescope axis perpendicular to the upright ruler. Make the telescope's mirror and optical lever reflective surface parallel to the caliper and the telescope at the same height with the optical lever reflective surface.
6. Fine-tune the telescope, find the clear reading of calipers in the telescope window, and record the distance between fore leg and the rear leg of optical lever and the

distance between caliper and the optical lever reflective surface.

7. Connect the temperature sensor in the center specimen to temperature recorder.

8. Heat the water to 10°C. When the temperature recorder shows 10°C, keeping 4 hours, write down the caliper readings h_1 . Heat the water to 50°C, the temperature recorder shows 50°C, keeping 4 hours, write down the caliper readings h_2 , re-set the water temperature to 10°C, when the temperature recorder shows 10°C, keeping 4 hours, write down the caliper readings h_1 .

9. For one type of aggregates, do step 1 to step 8 three times and get the average value.

The measurement principle of optical lever method is based on this basic hypothesis that superimposing straightedge on partition board of the telescope, but actually there is some space between partition board and straightedge. The incident diagonal light from straightedge is reflected through plane mirror, then enters lens barrel, at this time, the incident light and reflecting light don't overlap, and there is an angle between them. This angle undoubtedly increases the error. In analytic geometry method we can find the motion trajectory of original image of image point in a telescope. The map of light path is shown in Fig.2.

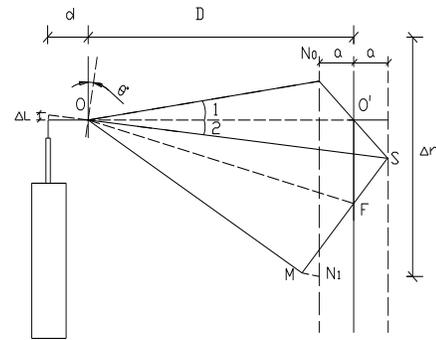


Figure 2. Light path

Thus the true value of referred with Eq.1.

$$\Delta L = \frac{(h_2 - h_1) \times d}{\sqrt{2 \left[\left(D^2 + (h_2 - h_1)^2 \right) + D \sqrt{D^2 + (h_2 - h_1)^2} \right]}} \quad (1)$$

Where: ΔL is expansion size of specimen (m), D is space between vernier caliper and reflection mirror (m), d is space between fore foot and back foot in optical lever (m), h_1 is vernier caliper reading when the temperature is 10°C (m), h_2 is vernier caliper reading when the temperature is 5°C (m).

Therefore, a more precise concrete expansion coefficient is obtained as Eq.2.

$$CTE = \frac{\Delta L}{\Delta T \times L} \quad (2)$$

Where: ΔT is 40, [°C], Temperature variation, L is the size in the specimens' expansion direction [m].

III. EXPERIMENTAL STUDY

TABLE I. PROPERTIES OF COARSE AGGREGATE

Name	Source	Crushing Value [%]	Abrasion value [%]	Coefficient of Expansion [$10^{-6}/^{\circ}\text{C}$]
granite	Heilongjiang	12~29	14~31	5~11.9
diorite	Hebei	13~30	15~36	4.1~10.3
sandstone	Heilongjiang	15~35	14~36	8~12
basalt	Beijing	10~27	9~25	4~12.5
limestone	Guangxi	14~34	13~29	3.06~12.1
dolerite	Guangxi	15~33	12~40	3.6~7
quartzite	Gansu	11~18	15~20	10~11
dolomite	Gansu	6.66~10.44	12~22	5.5~10.8

Several different types of primary rocks were used to obtain the coarse aggregates for this study. The coarse aggregates were obtained from 8 sources that included basalt from 4 sources, granite from 3 sources, limestone from 5 sources, sandstone from 2 sources, dolomite, quartzite, dolerite, diorite each from one source respectively. Table 1 presents the sources and main properties of these coarse aggregates.

In this study, Lafager cement 425 made in Beijing was used. The source of sand in the experiment is Qinhuangdao and its fineness modulus is 2.8. For different kinds of aggregates, same cement, sand, admixture, same proportion were used. Water-cement ratio is 0.42 and sand ratio is 0.56.

IV. RESULTS AND ANALYSIS

Fresh properties tests for concrete mixtures were conducted in accordance with the ASTM standards and the

results are given in Table 2. The target slump was 30 mm to 55 mm. The percentage of air content of the mixtures varied between 1.1% and 2.2%. The fresh density of concrete decreased with increase of the air content and varied between 2426 kg/m^3 and 2466 kg/m^3 depending on the air content.

The thermal expansion coefficients of different coarse aggregates concretes measured by optical lever are shown in table 2. In order to verify the reliability of the results measured by optical lever, these specimens were measured again with the method TP60. The results are shown in table 2 too. The results showed that: measured data by optical lever was satisfactory verified by AASHTO TP60.

Concrete expansion amount as the temperature increasing is in good agreement with concrete shrinkage as the temperature is reduced, as shown in Fig.3.

TABLE II. SPECIFICATIONS OF FRESH CONCRETE AND CTE OF CONCRETE CAME FROM VARIETY OF AGGREGATES

Name	Slump [mm]	Density [kg/m^3]	gas content [%]	CTE [$10^{-6}/^{\circ}\text{C}$]	
				Optical lever	TP60
diorite concrete	40	2426	2.0	8.59	8.56
sandstone I concrete	30	2441	2.1	12.1	11.90
granite I concrete	40	2440	1.8	7.90	7.91
basalt I concrete	35	2461	1.6	6.09	6.22
limestone I concrete	35	2457	1.6	9.01	9.05
quartzite concrete	40	2441	2.0	9.27	9.27
dolerite concrete	50	2426	2.2	8.59	8.62
dolomite concrete	55	2442	1.8	9.43	9.31
limestone II concrete	30	2453	1.5	9.25	9.22
granite II concrete	35	2450	1.6	9.45	9.43
limestone III concrete	35	2453	1.4	7.71	7.80
sandstone II concrete	35	2461	1.1	10.80	10.89
limestone IV concrete	40	2458	1.4	9.06	9.07
basalt II concrete	40	2466	1.5	8.20	8.20
basalt III concrete	45	2447	2.0	6.65	6.69
granite III concrete	35	2464	1.4	6.66	6.69
basalt IV concrete	30	2465	1.4	4.76	4.77
limestone V concrete	50	2445	2.2	8.40	8.53

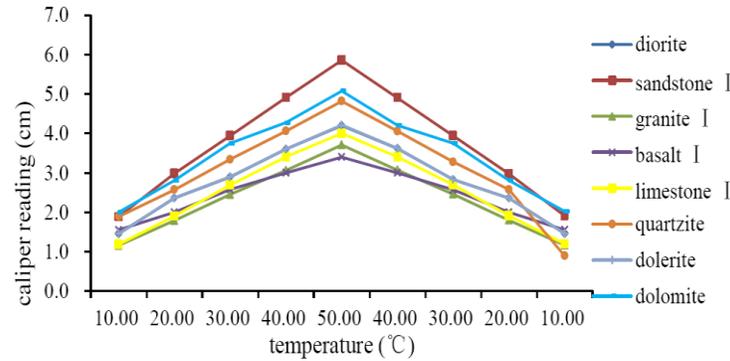


Figure 3. The changes of caliper reading with temperature

The sensitivity of concrete with different temperature ranges and the same temperature gradient is not significant. Compared with thermal expansion coefficient of different coarse aggregates itself, it is easy to tell that the higher thermal expansion coefficient of the aggregate, the higher thermal expansion coefficient of concrete contained the same aggregate, when coarse aggregate content is roughly the same.

V. SUMMARY

The approach to determine the coefficient of thermal expansion (CTE) of road concrete using optical lever system was introduced. CTE of 144 concrete specimens was determined with it. Measured data was satisfactory verified by AASHTO TP60. The results showed that: CTE of road concrete was between $4.76 \times 10^{-6}/^{\circ}\text{C}$ and $12.1 \times 10^{-6}/^{\circ}\text{C}$. Coarse aggregate type had a great influence on CTE. When aggregate content was equivalent, the higher CTE of the aggregate, the higher CTE of concrete contained that aggregate. The sensitivity of concrete for different temperature ranges and the same temperature gradient has no significant difference.

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