



Thermal Coefficient of Expansion Test for Aggregates Using Dilatometry

The low durability of concrete is often attributed to the incompatibility between the thermal properties of mortar and aggregate. The coefficient of thermal expansion (CoTE) of aggregates determines the thermal expansion of concrete to a considerable extent. It also governs the degree of physical compatibility of the components and hence affects the durability of concrete. Proper characterization of thermal properties of aggregate allows us to predict the behavior of concrete with greater confidence.

A test apparatus referred to as the dilatometer for determining CoTE of both fine and coarse aggregates was developed under Texas Department of Transportation (TxDOT) Project 7-2992 (1996-1997). The dilatometer is also suitable for determining CoTE of crushed mortar and concrete.

The dilatometer originally devised by Verbeck and Haas in 1951 to measure CoTE of aggregate consisted of a 1-liter flask to which was attached a capillary bulb containing electrical contacts. The flask was filled with aggregate and water, and the apparatus was allowed to equilibrate at one of the controlling electric contacts. The equilibrium temperature was observed by means of a Beckman thermometer. In Project 7-2992 the design of the apparatus was improved to obtain stable conditions, and the

measuring device was fully automated.

The objective of this project was to develop a test method to measure the thermal characteristics of concrete aggregates that could be used to create a database of aggregate thermal properties.

What We Did . . .

The work plan included the following tasks:

- evaluate different temperature ranges in order to establish

the optimal range for measuring CoTE of aggregates,

- investigate the effect of sample size on CoTE,
- test repeatability of the dilatometer and evaluate its accuracy using different materials,
- conduct calibration tests using materials of known CoTE, and
- examine the relationship between CoTE of aggregate and its mineralogical composition.

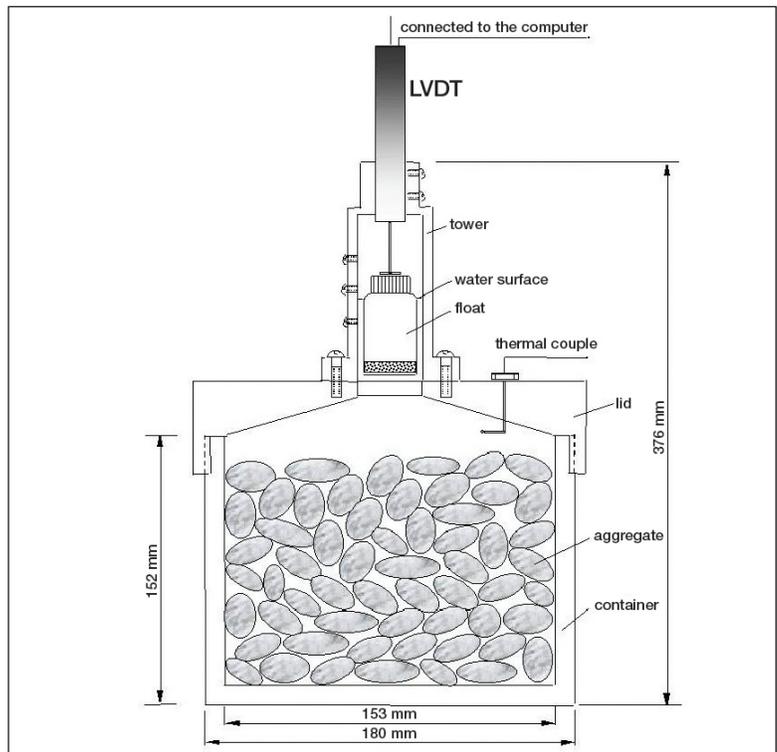


Figure 1. Schematic View of the Dilatometer.



Testing Device

The cross-sectional view of the apparatus developed to measure the coefficient of thermal expansion of aggregate, referred to as the dilatometer, is illustrated in Figure 1. The apparatus used for this research was constructed in-house. It consists of a stainless steel cylindrical container, a brass lid, a hollowed tower standing on the lid, and a float. The inner surface of the lid is configured at a certain angle so that the entrapped air bubbles can easily move along the surface.

To put the dilatometer in use, the container is filled with aggregate sample and water. The water surface is located near the tower access holes. The float moves freely along with the changing water level. A linear variable differential transducer (LVDT) is installed, and its core is connected to the float to measure the rise of the water surface. Electrical signals from the LVDT are generated as the core moves. The signals are acquired and amplified by a signal conditioner and then recorded by a computer data acquisition system.

The LVDT used is Lucas/Schaevitz Model MHR .050, which provides a voltage of 10.00 volts for a displacement of 1.27 mm (0.050 inch). This provides a sufficiently high accuracy in the measurement of a certain volume change in the small area of the water surface in the tower. A guide rod is installed above the core of the LVDT to keep the float/LVDT core assembly vertically aligned. A thermocouple is immersed in the water to monitor the temperature inside the container.

The temperature is recorded along with the LVDT signal continuously by the same computer data acquisition system (Figure 2). Simultaneous recording of the expansion of aggregate and the water temperature makes it possible to study the time effects — including effects of temperature level and temperature change rate on the coefficient of thermal expansion. On the side of the tower, there are ports that can be

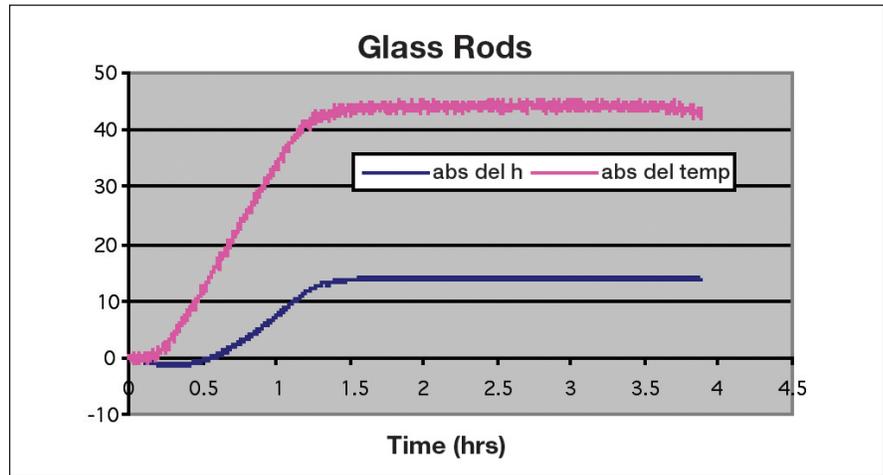


Figure 2. Example of Temperature and Float Test Data.

individually sealed by screws. These screws are used to adjust the initial water surface level to the desired height.

In operation, the container is placed in the water bath and heated by the water surrounding it. When the temperature is raised from T_1 to T_2 , the aggregate, the water, and the container all expand as indicated in Figure 2 for glass rod specimens shown in Figure 3. In operation, the dilatometer (with the specimen inside) is placed in the water bath and heated from T_1 to T_2 by the water surrounding it in which:

$$V_a \gamma_a \Delta T + (V - V_a) \gamma_w \Delta T = \Delta V_i + V \gamma_f \Delta T$$

The formula we use to calculate the volumetric coefficient of thermal expansion is:

$$\gamma_a = \frac{\Delta V_i}{V_a \Delta T} - \left(\frac{V}{V_a} - 1 \right) (\gamma_w - \gamma_f) + \gamma_f$$

where

ΔV_i = observed total volumetric increase due to temperature change ΔT ,

A = inner cross area of tower,

Δh = rise of the water surface inside the tower,

ΔV_a = volumetric increase of aggregate V_a due to ΔT ,

ΔT = temperature increase from T_1 to T_2 ,

V = total inner volume of the flask,

V_w = volume of water in the flask,

V_f = volume of the flask,

V_a = volume of aggregate in the flask,

γ_a = coefficient of volumetric thermal expansion of aggregate,

γ_w = coefficient of volumetric thermal expansion of water, and

γ_f = coefficient of volumetric thermal expansion of flask.

CoTE is one-third of the volumetric coefficient of thermal expansion. As noted above, CoTE determined using the dilatometer method is determined at a saturated condition.

Prior to preparing the dilatometer, the specific gravity and absorption content of the aggregate are determined using standard ASTM or TxDOT testing procedures. The aggregates should be maintained in a saturated surface dry (SSD) condition until placement within the dilatometer. The weight of the dilatometer device W_1 is measured. The container is filled with distilled water. The temperature of the water should be equal to the room temperature. The float is then inserted into the tower. The lid on the flask must be tightly screwed to ensure against leaks. A selected screw on the side of the tower is unscrewed, allowing water to be added until the water surface rises to the lower access hole. After the screw is replaced, the weight of the dilatometer and water (W_2) is measured. The water temperature at the beginning of the test is also measured.



A vacuum is applied for 30 minutes at the top opening of the tower by means of a de-airing flask. Air bubbles can typically be seen coming out from the vertical glass tube during the de-airing process. The container and the de-airing flask are shaken periodically to facilitate removal of the air bubbles. The prepared dilatometer device is now moved to the water bath and equilibrated for about an hour at the room temperature T_0 . The lower screw on the side of the tower is unscrewed to allow any excess water to escape and to reset the water level. The core of LVDT with the guide rod is inserted, and the LVDT is attached.

The water bath temperature is lowered to about 4°C or to the desired starting temperature, and the water inside the flask is equilibrated at that temperature. It is recommended that the temperature and the LVDT signals be recorded by a computer data acquisition system. The dilatometer in the water bath is heated over a designated temperature range step by step. Every time after the temperature in the water bath is increased, an interval of at least one hour and 30 minutes is needed to allow the container and the water in it to become uniform in temperature.



Figure 3. Test Specimens.

Materials

The materials with known CoTE that were selected for evaluation included glass and steel rods and spheres of different lengths and diameters, respectively, and zinc spheres. The rocks considered for studying the effect of mineralogy on CoTE of aggregates were granite (which usually consists of a suite of silicate minerals), and limestone (calcium carbonate) and siliceous gravel (both of monomineralic composition). The rationale for selecting these rocks was their distinct differences in mineralogical composition.

What We Found . . .

In order to verify that the dilatometer-derived CoTE results correspond with the known CoTE values, a strain gauge was affixed to the surface of glass rod and steel rod specimens, and their CoTE values were then determined under controlled temperature conditions. The dilatometer test results were found to corroborate measurements from the gauged samples of the same materials.

Repeatability of dilatometer test results at three temperature ranges using glass and steel rods suggests that variations are within acceptable limits in all the tested temperature ranges. The data indicate the greatest amount of accuracy in the 5 to 55°C range.

Glass rods of 1/4 and 3/4 inch diameter and zinc spheres of 5/8 and 1 1/4 inch diameter were used to study the size effect. It was determined from the dilatometer results that variation in sample size does not affect CoTE as determined.

A source of error due to the differential expansion between the water and the container (with respect to the aggregate being tested) in the low-temperature range when calculating the experimental CoTE value was found to be insignificant. Initially, the thermal expansion of the material exceeds that of the

water, which causes the float to drop slightly rather than rise. This effect, however, disappears as the temperature begins to rise, and the change in float position, h , and change in temperature, T , curves gradually assume a nearly parallel relationship, indicating stability of the test apparatus (Figure 2).

Aggregate Testing

Both gauged and dilatometer specimens of gravel, granite, and limestone were tested. The repeatability and accuracy of the dilatometer for testing aggregates appear to be very good. It was evident from the difference in CoTE of these rocks that mineralogy of the aggregate (i.e., the type and amount of minerals) is a major factor influencing CoTE. Though the chemical composition of two aggregates may be similar, their CoTE can vary as a function of mineralogy.

The research included both natural rocks commonly used as concrete aggregates and other inorganic materials. The latter were mainly used for testing the applicability of the dilatometer for measuring CoTE. The dilatometer's level of repeatability and accuracy of results demonstrate its utility as an apparatus for determining the expansion characteristics of materials subjected to thermal changes.

The Researchers Recommend . . .

Further consideration be given to implementation of the dilatometer because of its proven accuracy and repeatability. This device represents the only practical means to directly measure the CoTE of aggregate samples.



For More Details . . .

Research is documented in Technical Memo 4926-1, "Summary of Work," September 1999, and Project 7-4926 Technical Memo, "Development of Thermal Coefficient of Expansion Tests Phase II."

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Implementation of the improved dilatometer to measure CoTE will be delayed until required specifications can be developed under research project 0-1700, "Improving Portland Cement Concrete Pavements." Once specifications are available, wide implementation of this device is expected.

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