EXPERIMENTAL MEASUREMENT OF CONCRETE THERMAL EXPANSION

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Abstract: Thermal coefficient of concrete was investigated for several influencing factors. The thermal coefficient is measured using AASHTO TP60-00 – i.e., the standard test method measured by the dilatometer and adopted recently in the U.S. DOT. To evaluate the influencing factors for thermal coefficient of concrete, four testing parameters were included in this study: those are six different aggregate types (coarse aggregates typically used in S. Korea), specimen shape (prism and cylinder), cycles of warming and cooling, and measurement types (dilatometer and strain gauges). According to experimental results, specimen shape is revealed as the main factor affecting the thermal coefficient of concrete. As indicated by other researches, the type of coarse aggregate used in the study also influenced thermal coefficient of concrete specimen. However, the prism concrete specimen produced almost same values of thermal coefficients under cycles of warming and cooling. Finally test results were compared to investigate the effect of different measurement types. The thermal coefficient value determined by the dilatometer device is similar to the value from PML 60.

Key Words: thermal expansion, coarse aggregate, recycled concrete, warming and cooling

1. INTRODUCTION

The coefficient of thermal expansion (CTE) of concrete is known as a key factor influencing early-age behavior of concrete pavements that require saw-cutting at the joints right before cracks are formed. To predict cracking response and thus prepare for its way to cope with it, a systematic way to do a stress-strain analysis in addition to the precise analysis on the heat of hydration is needed. It has been reported that the coefficient of thermal expansion of fresh concrete is several times higher than the hardened concrete (Miao et al., 1993; ACI Committee 517, 1988). Therefore, to precisely determine Portland cement concrete the CTE value for the concrete materials has been a big issue in concrete pavement engineers.

The CTE values between different layers in the Portland cement concrete (PCC) pavement should be compatible to adjacent layers; otherwise, thermal instability between two layers causes delamination such as splitting cracks or spalling. Thus, the CTE values both for the overlaying or patching materials and their underlying substrate concrete material are to be determined for the quality control in the laboratory. Besides concrete ages, there are many factors known to affect the coefficient of thermal expansion of concrete, that include, different types of coarse aggregates, relative humidity, admixtures, cycles of warming and cooling, etc.

Influencing factors on thermal coefficient of concrete are quantitatively investigated in this study. The thermal coefficient is measured using AASHTO TP60-00 - that is, the standard test method measured by the dilatometer and adopted recently in the U.S. DOT. The AASHTO thermal expansion apparatus measures the length change of the specimen due to a specified temperature range (10 to 50 °C), which is in a saturated condition, since it is known that the degree of saturation of concrete influences its measured coefficient of thermal expansion.

To evaluate the influencing factors for thermal coefficient of concrete, four testing parameters were included in the study: those are six different aggregate types (coarse aggregates including recycled aggregate typically used in S. Korea), specimen shape (prism and cylinder), cycles of warming and cooling, and measurement types (dilatometer and strain gauges).

2. INFLUENCING FACTORS

According to experimental results reported by numerous researchers, the coefficients of thermal expansion of concrete materials are affected by mixture gradients such as aggregate types, aggregate volume fractions, admixtures, and ages, relative humidity (Mindess and Young, 1981; Fu and Chung, 1999). The coefficient is also influenced by cycles of cooling and warming, temperature ranges, and specimen shapes (Mindess and Young, 1981; Helmuth, 1961). More detail research backgrounds on dimensional changes due to cycles of warming and cooling, specimen shape and relative humidity conditions are discussed in a subsequent way.

2.1 Dimensional Changes by Cycles of Warming and Cooling

Helmuth showed that strain versus temperature plot from water-saturated paste specimens during cooling and warming results is not only curved shapes but also hysteresis curves (Figure 1). It is reported that primary cause of the hysteresis appears to be essentially dependent on moisture distribution changes (Helmuth, 1961). It is also caused by the time-dependent nature of the dimensional change such as creep and shrinkage of concrete (Fu and Chung, 1999). For this reason the standard test method of AASHTO recommends conducting several cycles of warming and cooling. Then the average of the two CTE values obtained from the two test segments is reported as an apparent thermal coefficient provided the two values are within 0.3×10^{-6} /°C of each other. If the two values are not within the lowest of 0.3×10^{-6} /°C, one or more additional test segments are required until two successive test segments yield CTE values within the tolerance limit.

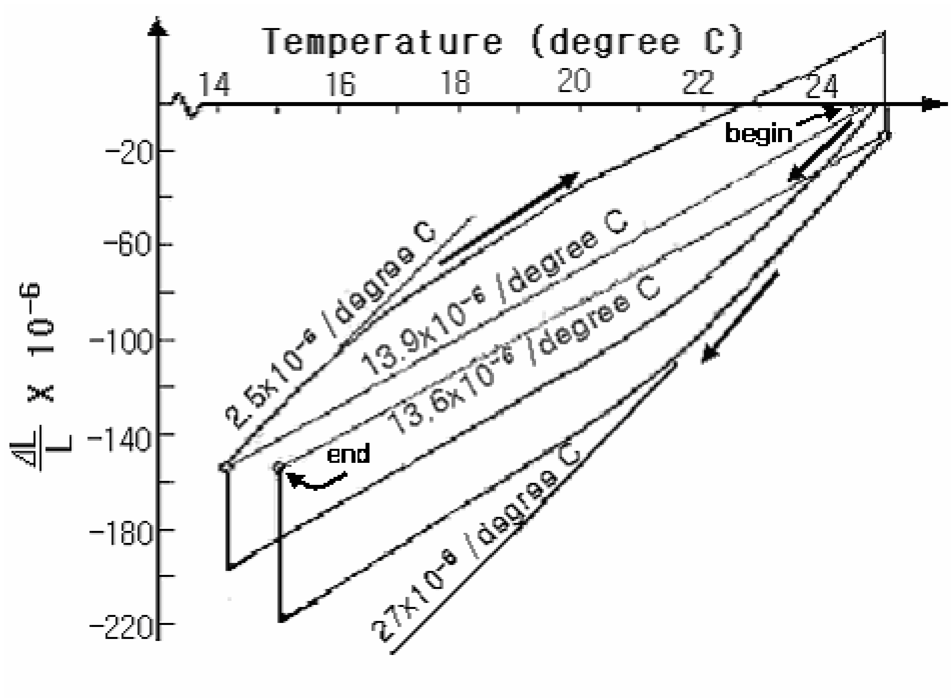

Figure 1. Effect of Warming and Cooling

2.2 Specimen Shape

Usually cylindrical specimens cored from the existing pavements or structures are preferred to assess properties and performance of PCC rather than the casted specimens. To measure the CTE values of 150 mm-diameter cylindrical specimen which is a typical cored or casted specimen size, however, it takes much longer if the hysteresis for the warming and cooling cycles are considered. In general, the dimensional changes are measured with temperature variation from the thermocouples or any other gauges probed at the middle position of the specimen. Thus, a rectangular prism specimen (150 x 150 x 50 mm) which is saw cut from a beam specimen will reduce overall test time, compared to the 150 x 300 mm cylindrical specimen since the time to reach equilibrium temperatures at every specimen locations is dependent on the specimen dimensions

2.3 Relative Humidity

There is an unusual moisture dependency, in which the coefficient increases considerably at intermediate relative humidities. This was explained that internal rearrangement of water takes place between capillary pores and gel pores without a change in the total water content of paste.(Emanuel and Helsey, 1997) In Figure 2 it can be seen that the CTE is a function of the moisture content of the specimen and the CTE is maximum at about 65 percent of relative humidity condition while the CTE value at the fully saturated condition is half of the maximum CTE value at 65 percent of relative humidity. Thus, it is logical to conduct the CTE values by considering the moisture variations. An environmental chamber which is controlled with constant relative humidity at varied temperature conditions, however, may not be available in many laboratories. Meanwhile Texas DOT adopts the AASHTO standard test method measuring at a water tank to specially control the quality of the pavement materials.

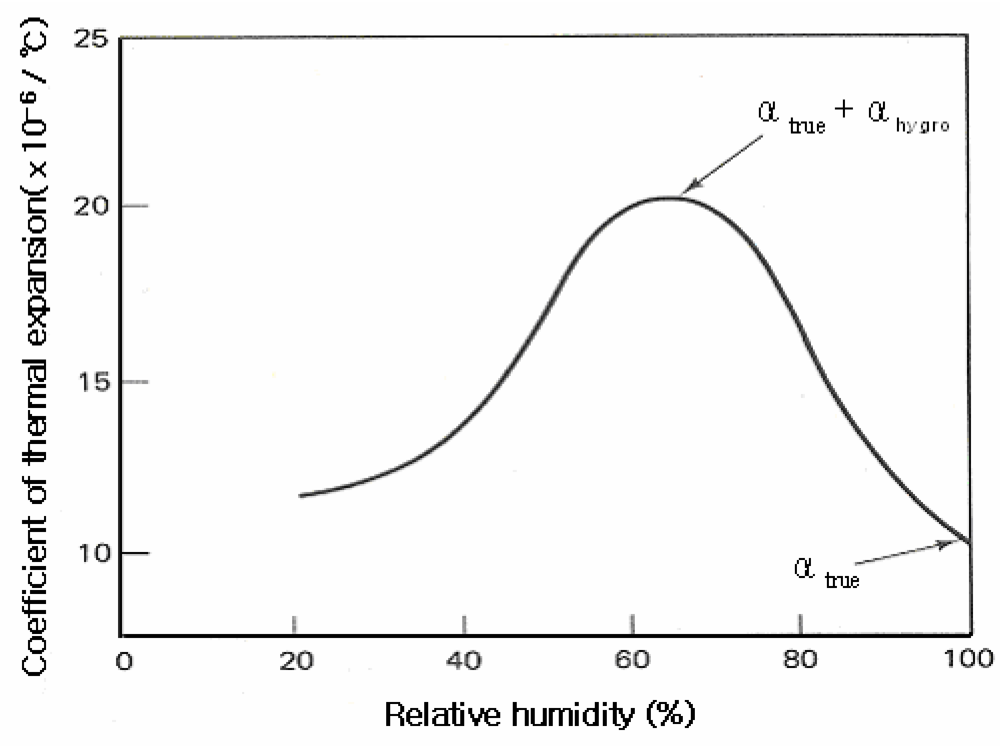

Figure 2. Variation of the CTE Values at Different Relative Humidity Conditions

3. EXPERIMENTAL PROGRAM

3.1 Measurement Device

There are various testing devices and the corresponding methods for the measurement of thermal coefficient. Such ways of measuring the CTE of concrete are divided into two distinct methods. First, the dilatometer method usually using by the LVDT has been widely accepted to determine thermal coefficient. Recently, engineers in U.S. DOT invented a decent measuring device which was adopted in the AASHTO TP 60 – serving as the standard test method for the coefficient of thermal expansion of concrete. The extensometer is mounted in a rigid invar frame and the specimens mounted on three pins set in the base plate of the frame are transmitted to the extensometer through an invar rod. Figure 3 shows a schematic diagram for the device, while Figure 4 shows a picture of the manufactured device for this study. In this study using the dilatometer-type device, the CTE measurements were taken from the cylindrical specimens as well as the prism specimens.

Also the CTE of concrete specimen is measured by strain gauges mounted on the surface of the specimen or strain gauges inserted inside the specimen. Each beam specimens (150 x 150 x 500 mm) was instrumented with the aid of two imbedded electrical wire strain gauges. These were of two types and imbedded in concrete: TML KM100B (transducer type) and PML 60. The maximum capacity of the KM 100B gauge is ±5,000 x 10^{-6} / °C, whereas that of PML 60 is ±20,000 x 10^{-6} / °C. Strain measurement at constant temperature by those electrical strain gauges does not cause any major problems, but if the surrounding temperature is changed, like the situation for this study, additional dimensional changes are added by the strain gauges because of dimensional changes of the gauge itself. The CTE of KM 100B itself was 10.9 x 10^{-6} / °C and that of PML 60 was 11.0 x 10^{-6} / °C . Prior to final installation, all the strain gauges were tested and the final CTE values of concrete will be calibrated as the following equation:

$$\alpha_c = \frac{\varepsilon_c + \Delta T \times \alpha_{ex}}{\Delta T} \tag{1}$$

where, α_C , α_{ex} : coefficient of concrete and extensometer itself, respectively
ε_C : strain measurements taken from the concrete specimen
ΔT : temperature changes (°C)

Imbedded strain gauges located inside the beam specimens are shown in Figure 5. Temperatures of the concrete specimen were automatically recorded using the I-button which was imbedded in the middle position of an additional specimen. The I-button contains a logger function inside the product and data can be downloaded through the USB port connected between the I-button and the PC. Meanwhile, dimensional changes were recorded from a data logger. Right before testing specimens were soaked inside the water bath (Figure 6) and the CTE measurements were taken at a saturated condition.

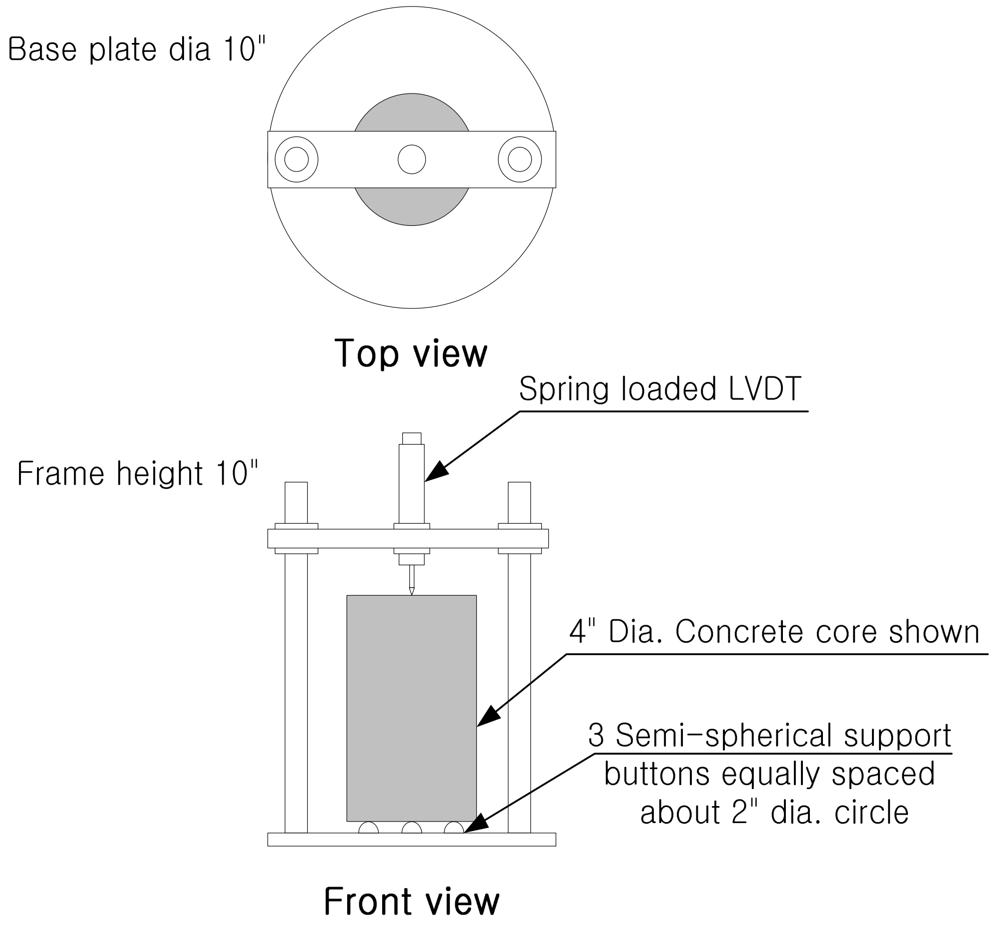

Figure 3. Schematic Diagram for the Device of the CTE Test (from AASHTO TP60-00)

Figure 4. Picture for the AASHTO-type Device of the CTE Test

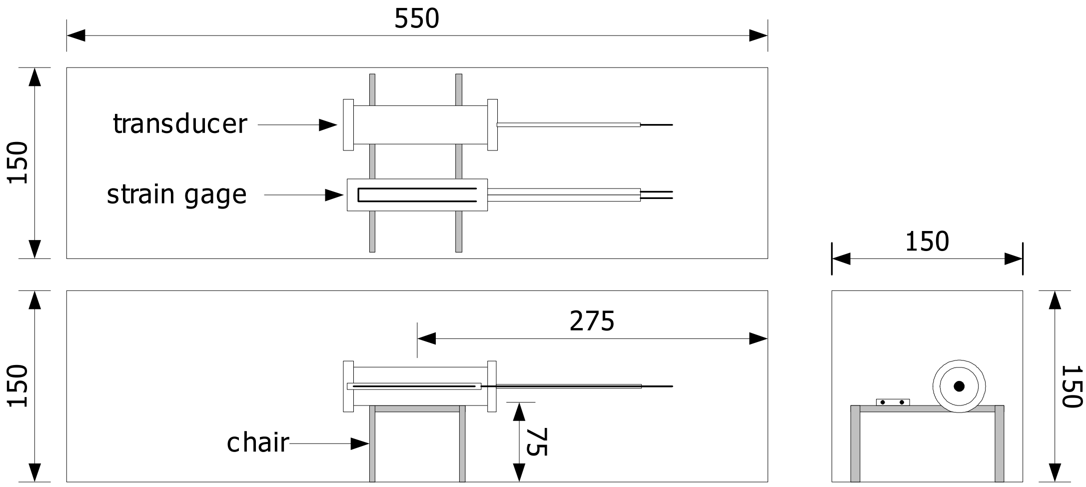

Figure 5. Strain Gauges as Placed Before Casting of Concrete(unit : mm)

Figure 6. Water Bath and Data Logger System

3.2 Materials and Specimen Preparation

Type I Portland cement manufactured from H Company in South Korea having the specific gravity of 3.15 and specific surface of 331.5 m^2/kg was used throughout this study.. River sand produced at Kumkang River was used as fine aggregate. Its specific gravity is 2.63 and finess modulus is 2.87 and water absorption was 1.52 %. Six different types of coarse aggregates were used: one from Test Road in S. Korea which is similar to the MinRoad, four typical sources for coarse aggregates in S. Korea (Granite, Andesite, Sandstone, Gneiss), one recycled coarse aggregates (type II classified in accordance with moisture absorption). The maximum size of the first 5 coarse aggregates was 32 mm whereas for the recycled aggregate, 25 mm. Their physical properties are tabulated in Table 1.

For each aggregate type, 5 to 6 cylindrical specimens and 4 beam specimens were made from two batches. All the specimens were demolded three days after casting and then cured in a moisture room for about 21 to 28 days. Beam specimens were cut by a diamond saw for the prism specimens 7 days after casting.

Table 1. Summary of Index Properties

Aggregate Type	Specific Gravity	Water Absorption(%)
Test Road	2.76	0.77
Granite	2.67	0.68
Andesite	2.65	2.68
Sandstone	2.63	0.91
Gneiss	2.70	0.46
Recycled Aggr.	2.50	3.99

3.3 Test Variables and Mix Proportions

The CTE measurements were performed with six different aggregate types, specimen shapes such as prisms (150 x 150 x 550 mm) and cylinders (150 x 300 mm), measurement types (LVDT and imbedded electrical extensometer), and cycles of warming and cooling (up to 2 cycles). Table 2 summarizes the test parameters. Table 3 summaries the mix proportions considered in this study, in which the first two letters in the second column designated different aggregate types.

Table 2. Test Parameters

Parameters	Variables for Test
Aggregate Type	Test Road, Granite, Andesite, Sandstone, Gneiss, Recycled Aggregate
Specimen Shape	Prism, Cylinders
Cycles of Warming and Cooling	Up to 2 Cycles
Measurement Type	Dilatometer, Strain Gauges (KM 100B, PML 60)

Table 3. Summary of Index Properties

Aggr. Type	Symols used	Water (kg)	Cement (kg)	Aggr (kg)	Sand (kg)	AE (%)	WR (%)	W/C (%)	S/a (%)
Test Road	RF-NS-AE	153	340	1196	683	0.01	0.3	45	38
Granite	GR-NS-AE	153	340	1188	683	0.01	0.3	45	38
Andesite	AN-NS-AE	153	340	1075	683	0.01	0.3	45	38
Sandstone	SN-NS-AE	153	340	1140	683	0.01	0.3	45	38
Gneiss	GN-NS-AE	153	340	1170	683	0.01	0.3	45	38
Recycled Aggregate	RA-NS-AE	170	378	1072	620	0.01	0.3	45	36

4. EXPERIMENTAL RESULTS

4.1 compressive Strength

Figure 7 summarizes the average compressive strength values, varying from 330 to 380 kgf/cm^2 for the cylindrical test specimen tested at 7 days and 28 days.

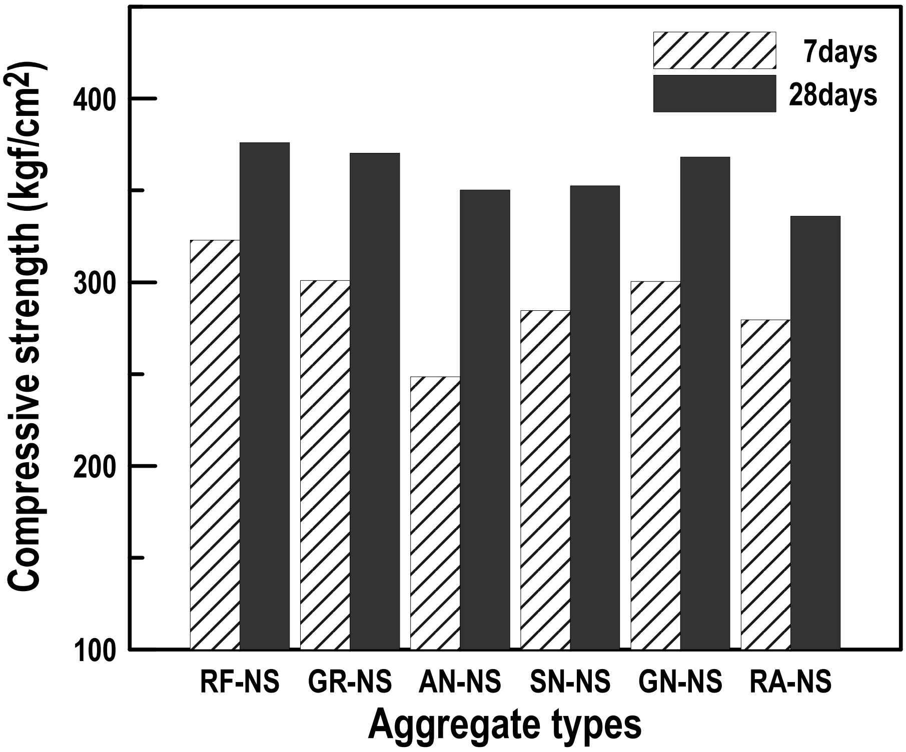

Figure 7. Compressive Strengths of Concrete Specimens Containing Different Coarse Aggregates

4.2 Dependence of CTE on Different Aggregate

To study the influencing mechanism of thermal coefficient on the different types of coarse aggregates, prism specimens were tested at 22 to 26 days after casting by using the dilatometer type device. As indicated in Table 4 and Figure 8, thermal coefficients of concrete specimens were dependent on different types of coarse aggregates, although the values from the RF-NS-AE, FR-NS-AE, GN-NS-AE specimens were similar to be ranged from 10.4 to 10.8 x 10^{-6} / °C. The lowest value was 9.2 x 10^{-6}/°C from AN-NS-AE and the highest value was 11.6 x10^{-6} / °C from RA-NS-AE.

Table 4. Aggregate Type Effect for Thermal Coefficient

Aggregate Type	Symbols used	Thermal Coefficient (x 10^{-6} /°C)
Test Road	RF-NS-AE	10.2
Granite	GR-NS-AE	10.7
Andesite	AN-NS-AE	9.2
Sandstone	SN-NS-AE	9.6
Gneiss	GN-NS-AE	10.7
Recycled Aggr.	RA-NS-AE	11.6

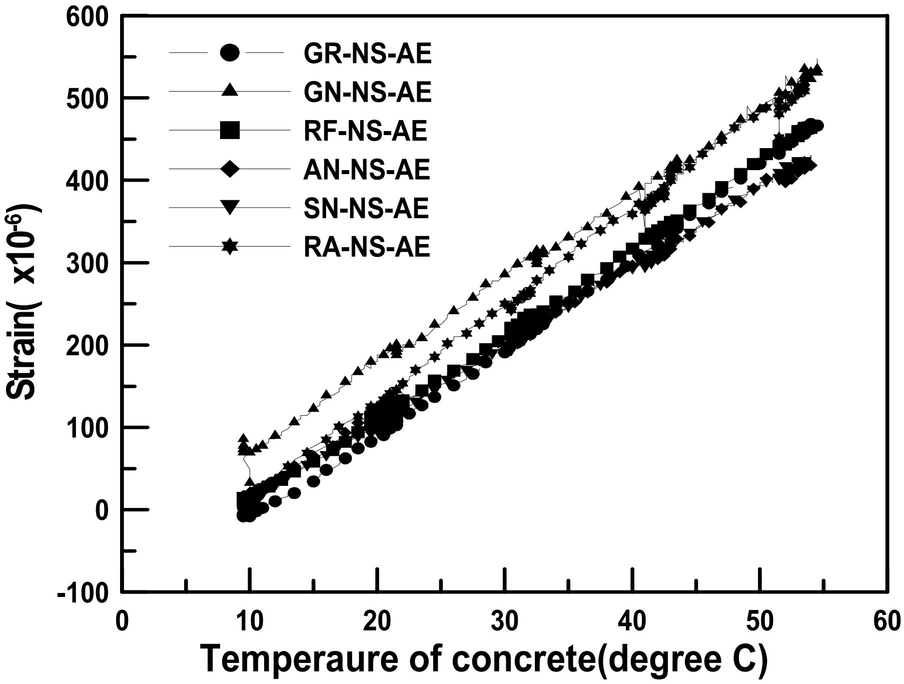

Figure 8. CTE Test Results from the Prism Specimens Containing Different Types of Coarse Aggregate (Measured by the Dilatometer Device)

4.3 Dependence of CTE on Cycles of Warming and Cooling

To determine the change in the thermal coefficient affected by the cycles of warming and cooling, tests were conducted from each prism specimens containing sandstone and recycled aggregates. This was done using the dilatometer device. At least two full cycles of warming and cooling were intended to simulate but the up-second cycle was omitted by a mistake. Table 5 summarizes test results. From Figure 9 it is seen that the specimen made with sandstone aggregate does produce almost same results under cycles of warming and cooling. Similar trend (Figure 10) was obtained from the specimen made with recycled aggregates although the CTE value of 0.4 x 10^{-6} / °C was reduced. This is partly attributed to the narrow width of the prism specimens used in this study.

4.4 Dependence of CTE on Specimen Shape

The effect of specimen shape on thermal coefficient was studied and its results are tabulated in Table 6. Figure 10 compares test results both from the prism and the cylinder made with sandstone as coarse aggregate. Figure 11 compares test results both from the prism and the cylinder made with recycled aggregate as coarse aggregate. It shows that the cylinder gives the CTE value of 1.8 and 2.7 x 10^{-6} / °C lower than that measured from the prism specimen containing sandstone and recycled aggregate, respectively.

Table 5. Aggregate Type Effect for Thermal Coefficient

Aggregate Type	Symbols used	Thermal Coefficient (x 10^{-6} /°C)			
		Up-1st	Down-1st	Up-2nd	Average
Sandstone	SN-NS-AE	9.6	9.4	9.5	9.5
Recycled Aggregate	GR-NS-AE	11.6	11.2	11.7	11.5

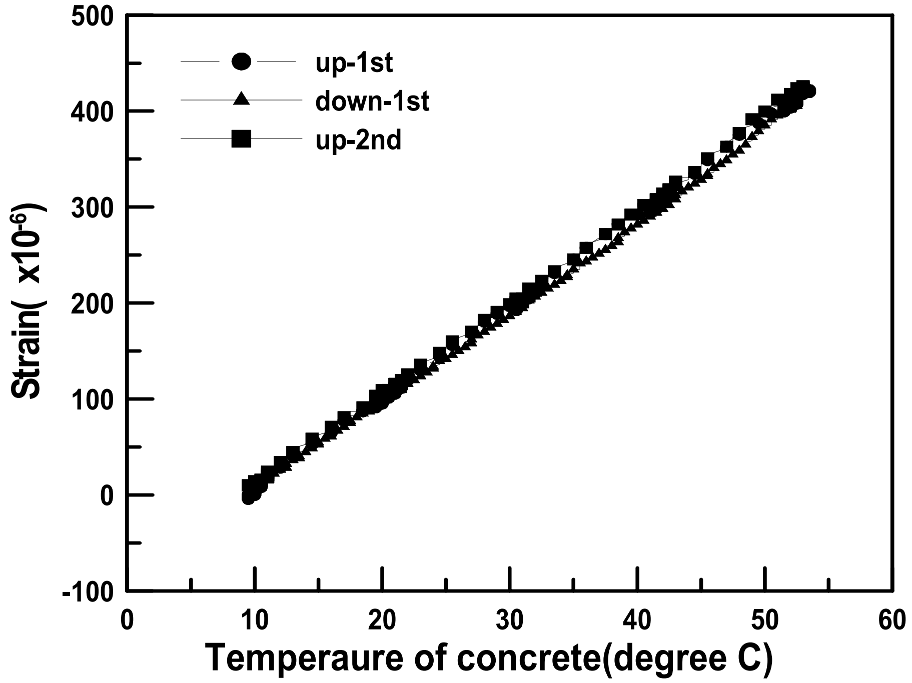

Figure 9. CTE Test Results with Cycles from the Prism Specimens Containing Sandstone (Measured by the Dilatometer Device)

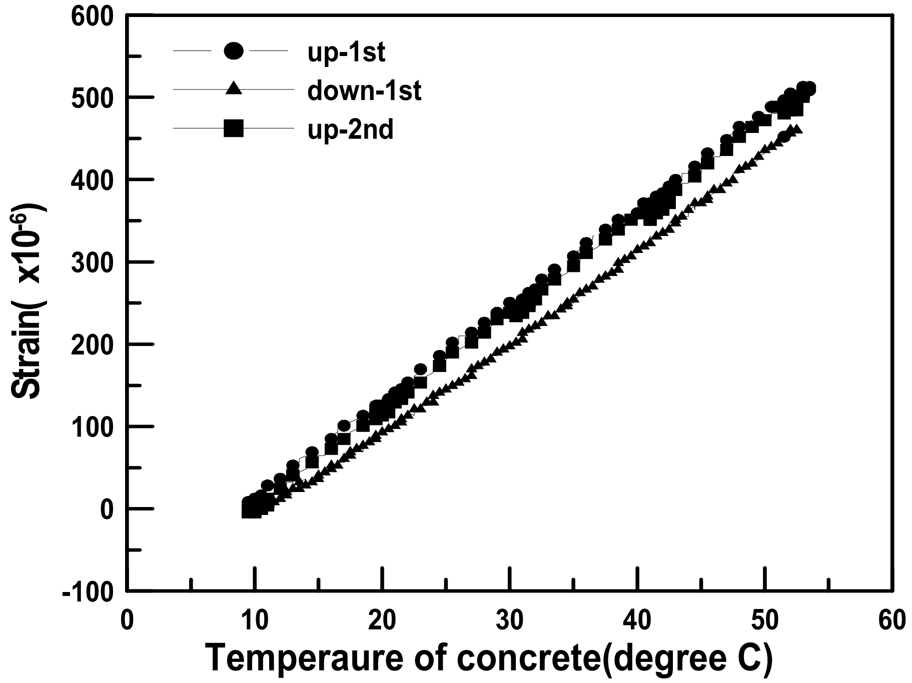

Figure 10. CTE Test Results with Cycles from the Prism Specimens Containing Recycled Aggregate (Measured by the Dilatometer Device)

Table 6. Specimen Shape Effect for Thermal Coefficient

Aggregate Type	Measurement Device Type	Thermal Coefficient (x 10^{-6} /°C)
Sandstone	Prism	9.6
	Cylinder	7.8
Recycled Aggregate	Prism	11.6
	Cylinder	8.9

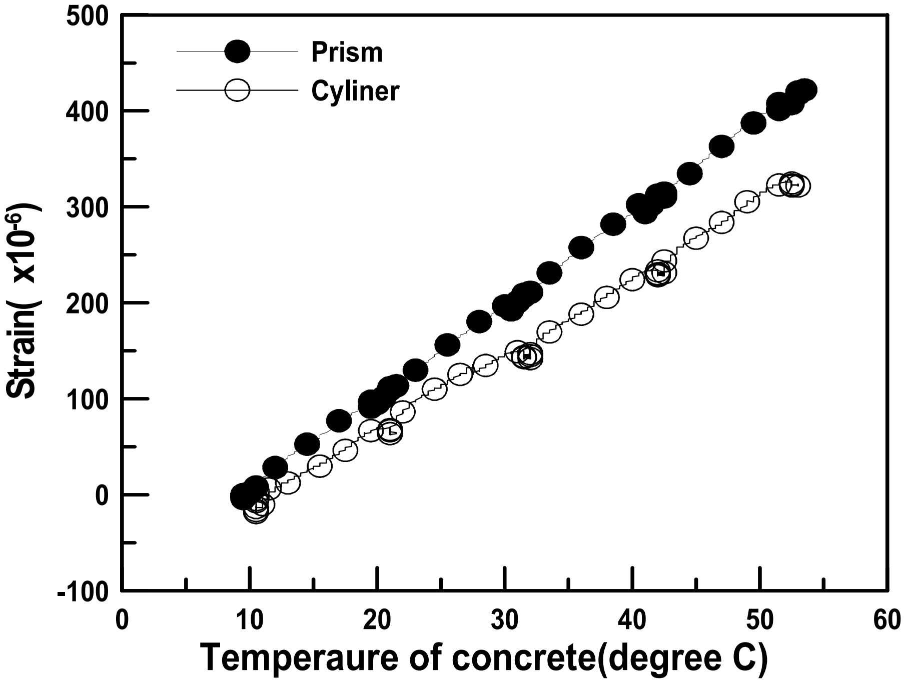

Figure 11. CTE Test Results Between the Prism and Cylinder Specimens Containing Sandstone (Measured by the Dilatometer Device)

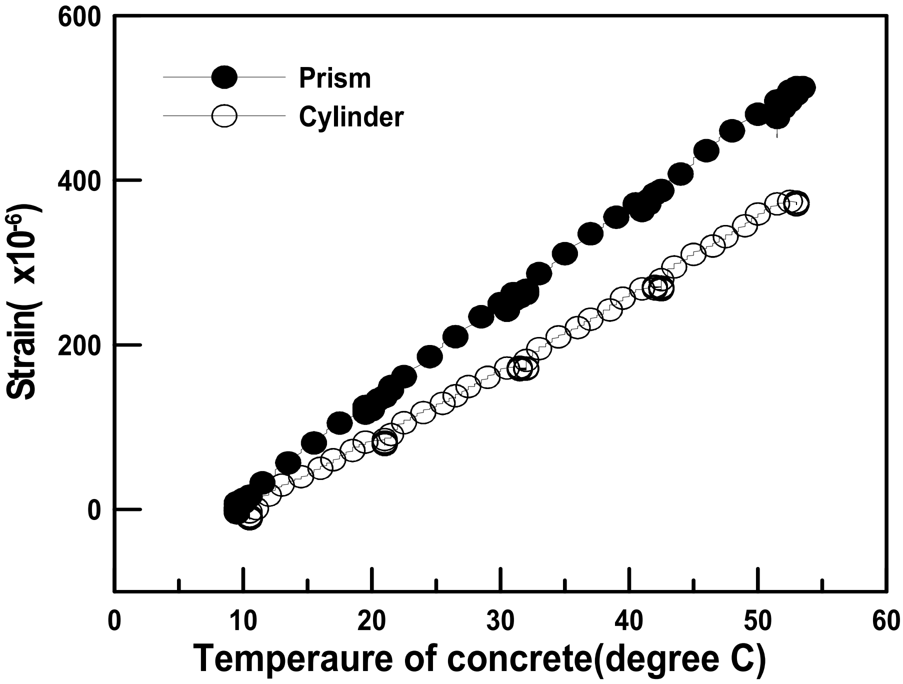

Figure 12. CTE Test Results Between the Prism and Cylinder Specimens Containing Recycled Aggregate (Measured by the Dilatometer Device)

4.5 Dependence of CTE on Measurement Type

Test results were compared to investigate the effect of different measurement type such as the dilatometer method and strain measurement device (KM 100B and PML 60). Test results summarized in Table 7 show that the CTE value determined by the dilatometer device is similar to the value from PML 60. However, the KM 100 B-type strain gauge yielded a CTE value of 2.7 x 10^{-6} / °C higher than the value from the dilatometer. Figures 12 show the CTE test results with the beam specimens containing gneiss measured by the KM 100B, and the PML 60, respectively.

Table 7. Measurement Device Type Effect for Thermal Coefficient

Measurement Device Type	Specimen type	Thermal Coefficient (x 10^{-6} /°C)
Dilatometer	Prism	10.6
KM 100B	Beam	13.9
PML 60	Beam	11.2

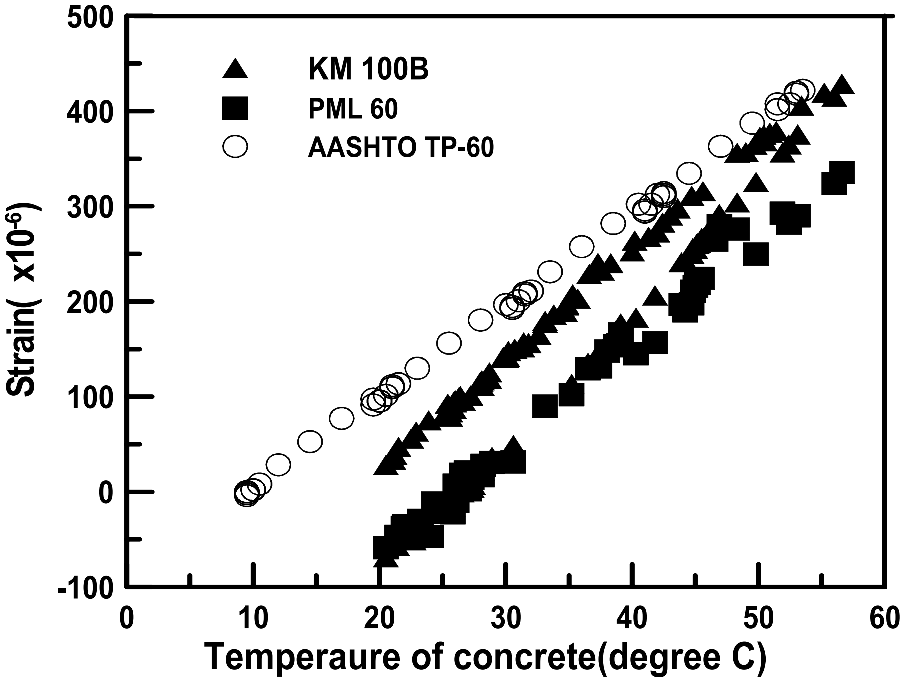

Figure 13. CTE Test Results with the Beam Specimens Containing Gneiss (Measured by KM 100B, PML-60 and Dilatometer)

Test results determined from the test method for measuring thermal coefficient of concrete by the dilatometer device will be an important input to the structural pavement design. Uniform temperature change or temperature gradient through the thickness of the concrete pavement will affect the openings at the joints or produce curling of the pavement slabs. Therefore, using the results of this test program, better estimate of slab movement and stress analysis due to temperature change can be obtained. The prediction of early-age concrete pavement behavior using FHWA HIPERPAV is a good example to use the thermal coefficient of concrete as a key input data in its structural analysis. Also, cores from the long term pavement performance sites can be used to provide important data to check their structural capacity.

5. CONCLUSIONS

The CTE measurements were performed with six different aggregate types, specimen shapes, measurement types, and cycles of warming and cooling and their test results are as follows:

(1) Thermal coefficients of concrete specimens were revealed dependent on different coarse aggregates.
(2) The prism concrete specimen produced almost same values of thermal coefficients under cycles of warming and cooling.
(3) Specimen shapes are revealed as mainly affecting factors on the thermal coefficient of concrete. It shows that the cylinder specimen gives the CTE value of 1.8 ~ 2.6 x 10^{-6} / °C lower than the prism specimen.
(4) Test results were compared to investigate the effect of different measurement type. The CTE value determined by the dilatometer device is similar to the value from PML 60.

REFERENCES

R. A. Helmuth, R. A. (1961) Dimensional changes of hardened Portland cement pastes caused by temperature changes, **Highway Research Board, Proc. Highway Research Record**, **Vol. 40**, 315-366

Emanuel, J. H. and Helsey (1977) Prediction of the thermal coefficient of expansion of concrete, **ACI, ACI Proceedings, Vol. 74, No. 4**, 149-155

AASHTO TP60-00 (2000) Standard test method for the coefficient of thermal expansion of hydraulic cement concrete, AASHTO

Yang, S. and Kim, N. (2002) Experimental measurement of concrete thermal expansion, **Korean Society of Pavement Engineers, Proc. KOSPE Conference, Vol. 4**, 161-164.

Fu, X. and Chung, D. D. (1999) Effect of Admixtures on thermal and thermomechanical behavior of cement paste, **ACI, ACI Materials, Vol. 96, No. 4**, 455-461

Mindess, S. and Young, J. F. (1981) **Concrete**, Prentice-Hall, N.J., USA

Miao, B., Aitcin, P. C., Cook, W. D., and Mitchell, D. (1993) Inflence of concrete strength on in situ properties of large columns, **ACI, ACI Materials, Vol. 90, No. 3**, 214-219

ACI Committee 517 (1988) Accelerated Curing of Concrete at Atmospheric Pressure, **ACI, State-of-the-Art, ACI Manual of Concrete Practice, Part 5**