INFLUENCE OF TYPES OF COARSE AGGREGATES
ON COEFFICIENT OF THERMAL EXPANSION OF
CONCRETE

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Influence of Types of Coarse Aggregates on Coefficient of Thermal Expansion of Concrete

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Abstract: The coefficient of thermal expansion (CTE) of a typical concrete-paving mixtures made with six different types of coarse aggregates, obtained from fifteen different sources in Wisconsin, was determined. These aggregates belonged to the basic class of glacial gravel, quartzite, granite, diabase, basalt, and dolomite. A total of fifteen different concrete mixtures were used in this study. Triplicate test specimens from each concrete mixture were used to determine the CTE of concrete at the age of 28 days, in accordance with the provisions of AASHTO TP60. In addition to the CTE test, concrete specimens were also tested for the compressive strength and splitting tensile strength. The two parameters, CTE and splitting tensile strength, are the basic input in the AASHTO’s new Mechanistic-Empirical pavement design method. The study revealed a noticeable variation in the values of the CTE of concrete with different types of aggregates. It was also found that concrete with quartzite aggregate had the highest value of the CTE followed by dolomite, glacial gravel, granite, and diabase/or basalt, respectively. Further, it was also found that the estimated value of the splitting tensile strength of concrete based upon its compressive strength, using the Mechanistic-Empirical design guide, for Level 2 design of the concrete pavements by the

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AASHTO method, was significantly lower (17 – 31%) than its actual experimentally
determined value.

**CE Database subject headings:** Coarse aggregate; Concrete; Coefficient of thermal
expansion; Splitting tensile strength; Mechanistic-empirical design.

**Introduction**

All materials expand and contract to a certain extent with the rise or fall of their temperature. The coefficient of thermal expansion (CTE) of a material is defined as the unit change in
length per degree of temperature change. The CTE is a measure of material’s expansion or contraction with temperature. Concrete, the most important composite construction material, is not an exception for this. At a simplified level, concrete is considered to have paste and aggregate phases. The two main constituents of concrete, cement paste and aggregates, have dissimilar coefficient of thermal expansion values. The coefficient of thermal expansion of concrete is dependent on material factors such as cement paste, aggregates, moisture conditions, its age, and environmental factors, such as temperature fluctuations and relative humidity (Emmanuel and Hulsey 1977; Mindess and Young 1981). The variation in CTE of paste due to variation of cement contents over normal range of cement is not as great as changing the type of aggregate (Mindess and Young 1981). Coarse aggregates normally constitute about 75 percent of the volume of concrete. Therefore, they have a major factor influencing the CTE of concrete. Jahangirmejad et al., 2009, reported that almost linear relationship exists between the percent volume of coarse aggregate in portland cement
concrete and its CTE. The CTE of concrete is important in numerous engineering applications including design of highway infrastructures such as bridges and pavements. It plays a key role in design, performance, and service life of concrete pavements because it affects critical slab stresses and joint and crack openings (NCHRP 1-37A, 2004). The CTE of aggregates influence the performance of concrete pavements mainly because of its effect on dimensional change due to the change in temperature condition. Several researchers (Mallela et al., 2005; Naik et al., 2006; Jahangirmejad et al., 2009; Won, 2005; Ndon and Bergeson, 1995) have investigated the CTE of concrete with various aggregates and reported a wide variation in the values of CTE among different aggregates depending on the type, origin, and geographic location. Studies (Naik et al., 2006; Jahangirmejad et al., 2009; and Won, 2005) have also revealed the variation in CTE values of concrete made with aggregates of the same type and from the same source. To minimize the effect of expansion or contraction of concrete on the highway infrastructures performance, the measured value of the CTE should be incorporated in design equations.

Measurements of the CTE of a wide range of concrete mixtures have shown its values in the range of 5.4 to 14.4 $10^{-6}/°C$ (3 to 8 $10^{-6}/°F$) in literature (NCHRP 1-37A, 2004) with a most commonly value of 11 $10^{-6}/°C$ (5.5 $10^{-6}/°F$) used in design. A higher coefficient of thermal expansion of concrete may adversely affect the durability of concrete due to thermal incompatibility of its components. Many pavement distresses such as early age or premature random cracking, faulting, blowups, corner breaks, joint spalling, and larger joint openings during adverse season are related to the thermal expansion properties of jointed plain concrete (Mallela, 2005; Huang, 1993). The present edition of the guideline for the design of pavement structures (AASHTO, 1993) is based on empirical equations derived from the AASHTO Road Test conducted from 1958 to 1968 and requires the coefficient of thermal expansion of concrete only to estimate the magnitude of joint movements and sealant
reservoir dimensions. The current practice is to use the value recommended by AASHTO, 1993. The AASHTO’s recommended value of CTE of concrete does not take into account variation in local material properties. Therefore, an inappropriate value of the CTE of a concrete mixture could adversely affect the pavement performance.

Due to the importance of the CTE, along with other factors affecting the design of concrete pavements, have led to the new Mechanistic – Empirical Pavement Design Guide (M-E PDG) developed under the National Cooperative Highway Research Program (NCHRP) Project 1-37A. The CTE and splitting tensile strength of concrete are key input parameters in this M-E design of concrete pavements. This has created necessity for state highway agencies (SHAs) to determine the CTE and splitting tensile strength for paving concrete mixtures containing local aggregates available in the state rather than relying on the default values of AASHTO guidelines. This M-E PDG also advocates estimating appropriate values of the CTE and splitting tensile strength, when material-specific data are not available. Based on accuracy in the CTE and splitting tensile strength, three levels, Level 1, Level 2, and Level 3, of input values are suggested in M-EPDG. This paper presents some of the findings of the research conducted to investigate the variation of splitting tensile strength and coefficient of thermal expansion (CTE) of concrete made with different types of aggregates obtained from different sources to support implementation of the AASHTO Mechanistic-Empirical Pavement Design Guide in Wisconsin.

Experimental Study

Materials
Six different types of primary rocks were used to obtain the coarse aggregates for this study. The coarse aggregates were obtained from 15 sources that included gravel from six sources, dolomite from five sources and quartzite, granite, diabase, and basalt each from one source, respectively. Table 1 presents the sources and the important physical properties of these coarse aggregates. ASTM Type I portland cement satisfying the requirements of ASTM Standard Specifications for portland cement, with physical properties as shown in Table 2, was used throughout the investigation. Since the Wisconsin Department of Transport (WisDOT) permits use of Grade A-FA (70% cement plus 30% Class C fly ash) concrete mixtures for pavement construction, ASTM Class C fly ash was used, with properties as given in Table 3. WisDOT recommends the use of blends of 60% WisDOT No. 1 (19 to 5 mm) and 40% WisDOT No. 2 (38 to 19 mm) coarse aggregates in the construction of concrete pavements. Table 4 shows the grading of the coarse aggregates used in producing concrete mixtures for this study. Natural sand meeting the grading of ASTM Standard Specification for Concrete Aggregates (C 33) was used as fine aggregate, Table 5. The water absorption, specific gravity on SSD basis, and bulk density of fine aggregate were 1.3%, 2.62, and 112 lb/ft³, respectively. Master Pave and Micro Air were used as water-reducing and air-entraining chemical admixture, respectively. They were supplied by BASF Construction Chemicals.

Mixture Proportions
Fifteen paving concrete mixtures of WisDOT Grade A-FA (using 70% cement and 30% Class C fly ash) were made by using different coarse aggregate types that included glacial gravel (Gvl) from six sources, dolomite (Dlm) from five sources and quartzite (Qtz), granite (Gnt), diabase (Dbs), and basalt (Bst) each from one source. The mixture proportions details as well as fresh concrete properties of the concrete paving mixtures are presented in Table 6. The water-to-cementitious material ratio (w/cm) of the mixtures was kept around 0.40 and the slump was kept between 25mm (one inch) to 105 mm (four inches).

**Test Specimens**

All the ingredients except the chemical admixtures were mixed in a dry state for about 30 seconds in a tilting drum type concrete mixer. Then three quarters of total water required was added in the mixer and the mixture was mixed for three minutes followed by three minute rest. The chemical admixtures, water reducing agent (WRA) and air-entraining agent (AEA), were thoroughly mixed in the remaining water and was added to the mixture. The mixing was further continued for about 2-3 minutes before evaluating the fresh concrete properties. The slump, air-content, and density were determined in accordance with the procedure of relevant ASTM standards as presented in Table 6. Concrete cylinders of 100 mm (4 in.) diameter and 200 mm (8 in.) length were prepared in accordance with the ASTM Standard Practice for Making and Curing Concrete Test Specimens in the laboratory (C 192) for the evaluation of the coefficient of thermal expansion, compressive strength, and splitting tensile strength of concrete. The specimens were demolded after 24 hours of casting. After demolding these specimens were immediately moved in a curing room with RH not less than 95% and temperature of 20 ± 2 °C. They were kept there until the time of testing.
Results and Discussions

**Fresh Property Tests**

Fresh properties tests for concrete mixtures were conducted in accordance with the ASTM standards presented in Table 6 and the results are given in Table 7. The target slump was 25 mm (1 in.) to 105 mm (4 in.). The percentage air content of the mixtures varied between 4.8% and 7.3%. These tests were conducted to ensure that concrete mixtures tested in the laboratory were similar to the concrete mixtures typically used in the field for the construction of the pavements by WisDOT. The water-to-cementitious ratio of the concrete mixtures was kept around 0.4 and the amount of WRA and AEA were varied to get a concrete mixture of the required slump and air content. The fresh density of concrete decreased with increase of the air content and varied between 2250 kg/m³ and 2440 kg/m³ depending on the air content.

**Coefficient of Thermal Expansion of Concrete**

**CTE of Concrete Made with Gravel**

The coefficient of thermal expansion of the concrete specimens made with gravel coarse aggregates obtained from six different sources was measured using AASHTO TP 60
procedure (Fig. 1). Table 8 presents the average 28-day CTE values (obtained on three test specimens) for the concrete mixtures. It can be observed from Table 8 that the CTE of concrete mixtures with gravel obtained from different sources varies from 9.1 to 10.7 microstrain/°C (5.4 to 5.9 microstrain/°F) with overall average of 10.2 microstrain/°C (5.6 microstrain/°F). This implies a 10% variation in the measured values of CTE of concrete due to different sources. The results indicate that the CTE of concrete made with gravel varies slightly due to variation of its source. The overall averaged value of CTE of concrete made with gravel aggregates will be used for the comparison of CTE values of concrete made with aggregate of other rock types (i.e., quartzite, granite, basalt, gravel, diabase, and dolomite).

### CTE of Concrete Made with Dolomites

Dolomite coarse aggregates obtained from five sources were used for this investigation. Table 9 presents the CTE values of the concrete mixtures. It can be seen from Table 9 that the CTE value of concrete mixtures varies from 10.4 to 10.8 microstrain/°C (5.8 to 6.0 microstrain/°F) with overall average of 10.6 microstrain/°C. This implies an insignificant variation in the measured values of CTE of concrete made with dolomite aggregates obtained from different sources. This may be due to the fact that all the sources of the aggregate have quite similar mineral composition. The overall average value of CTE of concrete made with dolomite aggregate was used for the compression of CTE value of concretes made with aggregate of other rock types (i.e., quartzite, granite, basalt, gravel, diabase, and dolomite).

### CTE of Concrete Made with Other Different Types of Coarse Aggregates
Table 10 shows the CTE of concrete mixtures made with aggregates of different types of rock. It is obvious from Table 10 that among the types of coarse aggregate used, the concrete made with quartzite (Qtz) had the highest CTE value, 12.2 microstrain/°C (6.8 microstrain/°F) followed by dolomite and gravel. The concrete mixtures made with diabase, basalt, and granite showed the lowest and nearly the same value of CTE, ranging from 9.3 to 9.5 microstrain/°C (5.2 to 5.3 microstrain/°F). These results indicate that up to 25% variation in CTE value of concrete is possible due to the variation in the types of aggregate. Therefore, it is important to use actual experimentally determined values in design of concrete pavements rather than normally suggested estimated-value.

**Splitting Tensile Strength of Concrete**

The other most important input parameter in M-EPDG is splitting tensile strength of concrete. The M-EPDG suggests use of experimentally determined value of splitting tensile strength as input at Level 1 design. It also advocates the estimation of splitting tensile strength of concrete from compressive strength through the use of correlations for input at the Level 2. Therefore, in addition to the splitting tensile strength of concrete, the compressive strength of concrete mixtures were also experimentally determined. Table 11 shows the experimental compressive and splitting tensile strength of the concrete at the age of 28 days. A comparison between estimated values of splitting tensile strength from compressive strength as per M-EPDG and experimentally obtained values are discussed in the following sections.
Estimation of Splitting Tensile Strength from Compressive Strength

The M-EPDG suggests estimation of splitting tensile strength of concrete from compressive strength through the use of correlations for the input at Level 2 design. It suggests first to convert compressive strength of concrete into Modulus of Rupture (MR) by using the following equation.

\[
MR = 9.5 \times (fc)^{0.5}
\]

Where, MR is modulus of rupture of the concrete and \( fc \) is the compressive strength of concrete at a given age, in psi. The MR so obtained is then multiplied by a factor of 0.67 to obtain the equivalent splitting tensile strength. In this study, in order to investigate the applicability of this method of estimation of spitting tensile strength, 28-day splitting tensile concrete with different types of aggregate was estimated and the values were compared with experimental values of the same at the same age (Fig. 2). From figure 2, it can be seen that the estimated values of the splitting tensile strength of the concrete is significantly lower (17 to 31% lower with respect to experimental values) than the corresponding experimental obtained values of the concrete. It is to be noted that the present study involved portland cement as well as ASTM Class C fly ash as cementitious material instead of portland cement only. This may be the reason for such variation in estimated values of splitting tensile strength in comparison of experimental values. The correlations between compressive strength of concrete with its modulus of rupture, modulus of elasticity, flexural strength, and spitting tensile strength are based on data generated only on portland cement concrete. Concrete containing portland cement and fly ash shows higher splitting tensile strength than
that with portland cement only. Therefore, for the present study, the suggested correlations in M-PEDG significantly underestimate the splitting tensile strength of concrete containing ASTM Class C fly ash and portland cement.

**Conclusions**

Based on this laboratory investigation the following major conclusions can be reached:

1. The types of coarse aggregate influenced the coefficient of thermal expansion (CTE) of concrete.

2. The CTE of concrete made with gravel aggregate obtained from different sources varied from 9.1 to 10.7 microstrain/°C (5.4 to 5.9 microstrain/°F).

3. The source of dolomite aggregates had insignificant effect on the CTE of concrete and the CTE varied between 10.4 and 10.8 microstrain/°C (5.8 to 6.0 microstrain/°F).

4. The concrete made with quartzite (Qtz) aggregates had the highest CTE 12.2 microstrain/°C (6.8 microstrain/°F).

5. Concrete made with aggregates of diabase, basalt, and granite rock types showed the lowest and nearly the same CTE with value of 9.3 to 9.5 microstrain/°C (5.2 to 5.3 microstrain/°F).

6. Experimentally determined value of CTE of concrete mixture avoids variation in CTE due to change in aggregate types.
7. Estimated value of the splitting tensile strength of concrete containing portland cement and ASTM Class C fly ash as cementitious materials from the experimental compressive strength values is significantly lower (17-31%) than the experimental value.

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