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Investigation of Compaction and Corresponding Thermal Measurement Techniques for Cementitiously Stabilized Soils

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Investigation of compaction and corresponding thermal measurement techniques

for cementitiously stabilized soils

By

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Cementitiously stabilized soils or soil-cement is a commonly used solution for highway subbase and base course construction, particularly in regions where higher quality soils and aggregates are limited. Even though the utilization of soil-cement as an engineered material has been around for over 70 years, there is still room for advancement with respect to characterizing the performance of these mixtures both in the laboratory and in the field.

The first objective of this thesis was to examine the Mississippi Department of Transportation soil-cement database to determine current soil-cement practices in Mississippi. The second objective of this thesis was to develop thermal measurement techniques to characterize compacted cementitiously stabilized soils. Over 800 compacted specimens were prepared and tested to investigate the feasibility and usefulness of performing thermal measurements on soil-cement mixtures.

DEDICATION

This thesis is dedicated to my family for their continual love, support, and encouragement throughout my academic career.

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LIST OF SYMBOLS AND ACRONYMS

AASHTO	American Association of State Highway and Transportation Officials
ACI	American Concrete Institute
A_s	Area beneath thermal profile curve (°C-hr)
ASTM	American Society for Testing and Materials
$A_{\Delta T}$	Area between thermal profile curve and reference curve (°C-hr)
BCD	Burns, Cooley, Dennis, Inc.
CaO	Calcium oxide
CF	Compactor Frame assembly
CI	Confidence interval
C_I	Cement index (%)
COV	Coefficient of variation (%)
C_w	Cement content by weight of dry soil mass (%)
DOT	Department of Transportation
E	Apparent activation energy (J/mol)
EPS	Expanded polystyrene foam
GGBFS	Ground Granulated Blast Furnace Slag
G_s	Specific gravity
G_{sb}	Bulk specific gravity
H_0	Null hypothesis
H_a	Alternative hypothesis

IC	Isothermal calorimetry
IQR	Inter quartile range (Q_3 - Q_1)
LL	Liquid limit (%)
M	Maturity index (°C-hr)
MDOT	Mississippi Department of Transportation
$M_{r12.5}$	Moisture content of material retained on 12.5 mm sieve (%)
MSU	Mississippi State University
MT-8	Mississippi test method 8
MT-9	Mississippi test method 9
MT-25	Mississippi test method 25
MT-26	Mississippi test method 26
N_b	Number of compactor hammer blows
N_p	Number of mixing passes
NP	Non plastic
NS	No significant difference as determined by *t*-test
OMC	Optimum Moisture Content (%)
OMC_{adj}	Optimum moisture content adjusted to include material retained on the 12.5 mm sieve (%)
$OMC_{p12.5}$	Optimum moisture content of material passing 12.5 mm sieve (%)
$P_{p12.5}$	Percent passing the 12.5 mm sieve (%)
$P_{r12.5}$	Percent retained on the 12.5 mm sieve (%)
PCA	Portland Cement Association
PFA	Pulverized fuel ash
PI	Plasticity index (%)
PL	Plastic limit (%)

PM	Plastic Mold split-mold assembly
PM-CF	Plastic Mold assembly used in conjunction with Compactor Frame
PM-P	Plastic Mold assembly used in conjunction with portable Plate
PRI	Prediction interval
$P_{\gamma d}$	Percentage of maximum dry density (%)
Q_1	25th percentile
Q_3	75th percentile
R	Universal gas constant (8.314 J/mol-K)
R^2	Coefficient of determination
RAP	Reclaimed Asphalt Pavement
R_{SI}	Thermal resistance (m^2*K/W)
S	Significant difference as determined by *t*-test
SAC	Semi-adiabatic calorimetry
SCB	Soil-cement bentonite
SL	Shrinkage limit (%)
SR	Shrinkage ratio
SR9	Mississippi State Route 9
SR475	Mississippi State Route 475
Stdev	Standard deviation
T	Temperature (°C)
T_0	Datum temperature (°C)
T_{BL}	Initial temperature of the thermal measurement block (°C)
T_i	Initial material temperature (°C)
T_{max}	Maximum temperature achieved by specimen (°C)

T_r	Temperature of reference specimen (°C)
T_s	Temperature of specimen (°C)
TTF	Temperature-Time Factor at σ_{max} test time (°C-hr)
UC	Unconfined compression
UNC	Unified Coarse Tread
UNF	Unified Fine Tread
USACE	United States Army Corps of Engineers
USCS	Unified Soil Classification System
V	Volume
VC	Volume change (%)
W	Width of mixing (m)
$W_{S\text{-}C}$	Weight of soil-cement mixture per lift of specimen (g)
XLPE	Cross linked polyethylene foam
df	Degrees of freedom
h/d	Height to diameter ratio of test specimen
n	Number of test replicates
n_o	Number of outliers removed from analysis
r	Correlation coefficient
t	Time
t_c	Time of cement spread
t_{comp}	Time of end final compaction with rubber tire roller
t_{crit}	Critical *t*-test statistic
t_d	Specimen compaction delay time (min)
t_e	Equivalent age at the reference temperature (day)

t_m	Time of first mixing pass
t_{max}	Time in which T_{max} occurs (hr)
t_{stat}	Calculated *t*-test statistic
t_{vib}	Time of end vibratory compaction
$t_{\sigma max}$	Time in which σ_{max} was measured (day)
w	Spacing of sample positions (m)
ΔT	T_s - T_r (°C)
Δt	Time interval
α	Level of significance
ε_{max}	Strain at failure (%)
γ_d	Maximum dry density (kg/m^3)
γ_{dadj}	Maximum dry density adjusted to include material retained on 12.5 mm sieve (kg/m^3)
γ_w	Unit weight of water (kg/m^3)
ω	Moisture content (%)
$\omega_{air\text{-}dried}$	Moisture content of air dried soil (%)
$\omega_{natural}$	Moisture content at time of sampling (%)
σ	Unconfined compressive strength (kPa)
σ_{max}	Unconfined compressive strength at failure (kPa)
$\sigma_{max\ adj}$	Adjusted unconfined compressive strength at failure (kPa)
9C	Class 9 group C material

CHAPTER 1

INTRODUCTION

1.1 Background

Soil-cement is defined by ACI (2009) and PCA (2001) as "a mixture of soil and measured amounts of portland cement (and/or other cementitious materials) and water, compacted to a high density to form a hardened material with specific engineering properties." Soil-cement mixtures were first studied as an engineering material for roadway base courses in the early 1930s by the South Carolina State Highway Department and the Portland Cement Association (Scullion et al. 2005). Today, portland cement stabilization is one of the most widely used and economical soil stabilization methods for highways (Griffin and Tingle 2009). This is particularly the case for regions containing natural soils and aggregates with marginal engineering properties.

ACI (2009) describes two general methods for mixing and constructing soil-cement pavement layers. The first method is in-place mixing which utilizes a single-shaft mixer. This method can adequately pulverize and mix practically all types of soil (granular to fine-grained), but this method may also require multiple mixing passes. The second method is central plant mixing which utilizes a rotary drum mixer, a continuous flow pug mill mixer, or a batch-type pug mill mixer. This method works best with granular borrow materials, but the mixed material must be transported (typically within

30 min) to the project site. Once on site, the material is placed using a motor grader, a spreader box, or a paver. Compaction and curing are the same for in-place and central plant mixing methods. Suitable compaction equipment includes sheeps-foot, vibratory, and rubber-tire rollers. Curing methods include continuous water-sprinkling and bituminous membranes.

Figures 1.1 and 1.2 illustrate construction practices for the two soil-cement base course projects observed for this thesis. These projects vary significantly with respect to size and amount of treated material, and these projects exemplify the range of acceptable soil-cement construction practices within the state of Mississippi.

Figure 1.1 Soil-Cement Base Course Construction on State Route 9 (April 2012)

Figure 1.2 Soil-Cement Base Course Construction on State Route 475 (June 2012)

Figure 1.1 illustrates construction of State Route 9 in north Mississippi which encompassed approximately 68,000 m^3 (88,900 yd^3) of mixed in-place soil-cement base material. First, the required amount of cement was spread onto the roadway using a mechanical cement-spreader attached to the back of the cement transport truck. The cement spread rate was monitored using spot and overall checks. The first mixing pass pulverized the soil and mixed the cement into the soil. If required, additional mixing water was added to the roadway to achieve optimum moisture content, and the second mixing pass incorporated the water into the layer. After mixing, the soil-cement layer was immediately compacted with sheeps-foot and vibratory steel-wheel rollers. Then, the layer was checked for proper density. The compacted surface was milled and shaped to the proper grade. A rubber-tire roller compacted the graded soil surface. Finally, the soil-cement layer was moistened and sealed with a bituminous membrane for curing.

Figure 1.2 illustrates construction of State Route 475 in central Mississippi which required approximately 12,200 m^3 (16,000 yd^3) of mixed in-place soil-cement base material. First, the required amount of cement was spread onto the roadway using a pipe cement-spreader attached to the back of the cement transport truck. Cement spread was monitored using overall checks. One or two mixing passes were performed to pulverize the soil and mix the cement into the soil. The mixture was checked for proper pulverization. Additional mixing water was added to the mixture to achieve optimum moisture content, and a final mixing pass was performed. After mixing, the layer was immediately compacted with sheeps-foot and vibratory sheeps-foot rollers. After compaction, the surface was graded and shaped. A rubber-tire roller compacted the graded surface. Then, the layer was checked for proper density. Finally, the soil-cement layer was periodically moistened for 24 hrs before being sealed with a bituminous membrane for curing.

Although soil-cement has been routinely used for 80 years, there is ample room for advancement with respect to soil-cement design and construction quality control. One possible way to improve soil-cement design and construction quality control is utilizing thermal measurements, which has shown merit for other cementitious materials (Cost and Gardiner 2009, Sullivan et al. 2012). This method involves monitoring cement heat generation during initial hours of hydration with minimum influence from ambient temperatures. These measurements could provide insight to the overall performance of a soil-cement mixture.

1.2 Objectives and Scope

This thesis is part of a larger effort (State Study 206) to develop a performance-based soil-cement specification for the Mississippi Department of Transportation (*MDOT*). The primary objectives of this thesis were to: 1) analyze *MDOT* soil-cement database to disclose the current practice of soil-cement in Mississippi, and 2) develop thermal measurement techniques to characterize soil-cement mixtures. To satisfy the primary objectives the following tasks were performed.

- Examine and analyze the *MDOT* soil-cement database for overall trends and possible correlations to design cement content.
- Develop protocols to measure thermal profiles and unconfined compressive strength on the same specimen.
- Analyze thermal measurement data to determine its effectiveness in characterizing soil-cement mixtures.
- Explore the possible implementation of thermal measurements as a means of construction quality control.

A literature review of soil-cement practices and thermal measurement applications was performed first (Chapter 2). Chapter 3 is an evaluation of the *MDOT* soil-cement database. Chapter 4 provides the experimental program describing equipment and protocols for preparing and testing specimens for thermal profiles and compressive strength. Chapter 5 provides analysis of laboratory thermal measurements, and Chapter 6 investigates field applications for thermal measurement devices. Chapter 7 provides conclusions and recommendations.

CHAPTER 2

LITERATURE REVIEW

2.1 Overview of Literature Review

A literature review was performed to locate information in the areas of current soil-cement mixture design procedures for stabilized base courses, soil-cement quality control, estimation of in-situ strength of constructed soil-cement layers, and thermal measurements. Overall, few studies were located that incorporated thermal measurement of soil-cement mixtures into analysis or quality control, which reinforces the need for the research performed in this thesis. This chapter presents relevant information pertaining to the thesis objectives.

2.2 Cement Stabilized Base Course Design

Current soil-cement design procedures are usually based on durability and/or unconfined compressive strength criteria. Soil-cement mixtures are designed to optimize cement content for satisfactory performance and economy. The following sections contain soil-cement design procedures, criteria, and protocols developed by the Portland Cement Association (*PCA*), United States Army Corps of Engineers (*USACE*), and state Departments of Transportation (*DOT*s).

2.2.1 *PCA* Design Procedure

PCA developed a design procedure based on strength and durability criteria (PCA 1992). Strength of soil-cement mixtures is determined by unconfined compression tests according to *ASTM D 1633*, and specimens are made according to *ASTM D 1632*. Specimens with height to diameter (*h*/*d*) ratio of 2.00 are recommended for a more accurate determination of compressive strength. In most cases, specimens with *h*/*d* ratio of 1.15 (101.6 mm diameter and 116.4 mm height) are tested because these specimens make use of common compaction equipment (standard proctor mold and hammer). With all variables constant, specimens with 1.15 *h*/*d* ratio are reported to achieve 10 percent greater unconfined compressive strength (σ) than 2.00 *h*/*d* ratio specimens.

Durability of soil-cement mixtures is evaluated using wet-dry tests (*ASTM D 559*) and freeze-thaw tests (*ASTM D 560*). Table 2.1 contains criteria developed by the *PCA* for adequate base course performance of soil-cement mixtures which is documented by Terrel et al. (1979) and Scullion et al. (2005). Cement contents with specimen weight loss less than those indicated in Table 2.1 after 12 cycles of wet-dry-brushing or freeze-thaw-brushing are considered adequate to produce a durable mixture (PCA 1992).

Table 2.1 *PCA* Soil-Cement Design Criteria from Terrel et al. (1979) and Scullion et al. (2005)

Soil Classification		**Max Weight Loss for 12 Wet-Dry or Freeze-Thaw Cycles (%)**	**Typical σ (kPa)**[1]	
AASHTO	***USCS***		**7-day**	**28-day**
A-1, A-2-4, A-2-5, A-3	GW, GC, GP, GM, SW, SC, SP, SM	14	2069 - 4137	2758 - 6895
A-4, A-5	ML, CL	10	1724 - 3447	2069 - 6205
A-6, A-7	MH, CH	7	1379 - 2758	1724 - 4137

1: Specimens were saturated in water prior to strength testing.

Additional Criteria noted by PCA (1992), Scullion et al. (2005), and Terrel et al. (1979):

- *Max volume change should not exceed 2% of original specimen volume.*
- *Max water content should be less than the quantity required to saturate the specimen.*
- *Compressive strength should always increase with age of specimen.*

PCA (1992) recommends that all laboratory cement contents be expressed as a percentage of dry soil mass. After determining the optimum cement content, the percentage cement by dry soil mass can be converted to a percentage by volume for field construction control. Equation 2.1 shows *PCA*'s calculation to convert cement content by dry soil mass to cement content by volume. The percentage by volume calculation is based on the volume of a 94 pound US bag of cement (PCA 1992).

$$Percent\ Cement\ by\ Volume = \frac{D - \frac{D}{C}}{94} \times 100 \qquad \text{Eq 2.1}$$

Where:

D = Oven-dry density of soil-cement (lb/ft^3)

$C = 1 + (C_w /100)$

C_w = Cement content by dry soil mass (%)

94 = Unit weight of US bag of cement (lb/ft^3)

2.2.2 *USACE* Design Procedure

USACE (1994) developed design procedures similar to *PCA* with slightly different criteria for durability and strength. *USACE* testing procedures are the same as *PCA* procedures. Table 2.2 shows *USACE* criteria for soil-cement base course materials.

Table 2.2 Soil-Cement Design Criteria from USACE (1994)

Type of Soil	**Max Weight Loss for 12 Wet-Dry or Freeze-Thaw Cycles (%)**	**Minimum σ at 7 days (kPa)**	
		Flexible Pavement	**Rigid Pavement**
Granular, PI < 10	11	5171	3447
Granular, PI > 10	8		
Silt	8		
Clays	6		

2.2.3 *DOT* Design Procedures

State departments of transportation (*DOT*s) have independently developed design procedures and criteria that are loosely based on the *PCA* and *USACE* procedures. Several variations of soil-cement design are implemented by state *DOT*s, but design criteria are predominantly based on unconfined compressive strength. To insure adequate durability, *DOT*s have developed correlations between strength and durability for the soil type being used in base course construction (Scullion et al. 2005). These correlations are used to specify a minimum compressive strength to meet durability requirements, thus eliminating separate durability testing. *DOT*s have adopted compressive strength criteria for soil-cement design largely because of the need for a more expedient testing regime. Wet-Dry and Freeze-Thaw testing usually requires 4 to 6 weeks to conduct whereas compressive strength testing only requires 1 to 4 weeks (Scullion et al. 2005). Table 2.3 contains compressive strength criteria, specimen size, and curing protocols for 13 state *DOT*s located in the southeastern United States of America.

Table 2.3 State *DOT*s Soil-Cement Design Criteria

State[1]	**Reference**	***h/d* ratio**[2]	**Req'd σ (kPa)**	**Curing Protocol**
AL	ALDOT (2012)	1.15	1720 to 4140	7-day moist cure, sealed, 5hr soak
AR	AHTD (2003)	1.15 or 1.00	2760	7-day moist cure, sealed, 5hr soak
GA	GDOT (2001)	1.15	2070	7-day moist cure, no soak
LA	LaDOT (2006)	1.15 or 1.00	1034 to 3450	7-day moist cure, no soak
MS	MDOT (2004)	1.15 or 1.00	2070	14-day moist cure, sealed, 5hr soak
NC	NCDOT (2002)	1.15	1380	7-day moist cure, 5hr soak
SC	SCDOT (2007)	1.00 or 0.76	NA	7-day moist cure, overnight soak
TX	TxDOT (2004)	1.33	1210 or 2070	7-day moist cure, no soak
VA[3]	VDOT (2007)	1.15	NA	7 & 28-day moist cure, 4hr soak

Note: Table information was obtained from corresponding state DOT standard specifications as of May 2012.
1: FL (FDOT 2010), KY (KYTC 2012), TN (TDOT 2006), and WV (WVDOT 2002) no longer utilize soil-cement as a base course pavement layer.
2: In some cases, specimen h/d ratio depends on material gradation.
3: Virginia requires durability testing to be performed on soil-cement mixture. Virginia also specifies use of ASTM D 806 to check cement content. All other states only check cement spread rates.

Use of supplementary cementitious materials such as ground granulated blast furnace slag (*GGBFS*) has become more popular with *DOT*s as a primary soil stabilizer. As of May 2012, all states, with exception of North Carolina and South Carolina, listed in Table 2.3 allow slag cement blends to be used as a stabilizer in soil-cement base courses. The potential benefits and performance of slag cement blends are well documented (Cost and Ahlrich 2005, George 2002, George 2006).

2.3 Soil-Cement Quality Control

The American Concrete Institute (*ACI*) identifies six soil-cement quality control factors: pulverization, cement content, moisture content, mixing uniformity, compaction, and curing. Checking and monitoring the quality of all six factors is vital to ensure proper construction practices according to appropriate plans and specifications to produce a well performing soil-cement layer (ACI 2009). Only quality control measures relating to in-place mixing are discussed in this literature review.

Pulverization is monitored by sieve analysis with the 4.75 mm sieve as the controlling sieve size. The degree of required pulverization varies, but most specifications require approximately 80 percent of the soil-cement mixture to pass the 4.75 mm sieve and 100 percent pass the 25.0 mm sieve. Pulverization is significantly affected by the amount of moisture present in the soil (ACI 2009, PCA 2001).

Cement is normally placed using bulk cement spreaders. Cement content is monitored with spot checks and overall checks. Spot checks involve: 1) placing a sheet of canvas or metal pan of known weight and area in front of the cement spreader; 2) carefully picking up and weighing the canvas or pan after cement is spread on top; and 3) if necessary, adjusting the cement spreader until the proper amount of cement is spread per unit area. Overall checks involve closely monitoring the area or distance in which a cement truckload of known tonnage is spread (ACI 2009, PCA 2001).

ASTM D 806 and *ASTM D 5982* are two specifications that can be followed to determine the cement content of soil-cement mixtures. *ASTM D 806* utilizes a chemical analysis (titration method) of *CaO* content in hardened soil-cement samples to determine cement content. This method requires soil-cement samples to have a significant degree of cement hydration or hardening and is not applicable to soils containing significant amounts of dissolved calcium oxide. *ASTM D 5982* uses a thermal measurement approach to estimate cement content of freshly mixed, uncompacted soil-cement. This method measures the peak temperature from an exothermic reaction between the calcium hydroxide in the soil-cement mixture and a sodium acetate-glacial acetic acid solution.

Optimum moisture content (*OMC*) determined in the lab is used as a guide for field control during construction. On site, moisture content is typically estimated by observation and feel. A mixture at *OMC* will usually dampen the hands when squeezed into a tight cast, and the cast can be broken into two pieces with little or no crumbling. Actual moisture contents can be checked by nuclear or conventional methods (ACI 2009, PCA 2001).

Mixing uniformity is evaluated by visual inspection throughout the entire mixing depth. Checking mix uniformity is performed by digging trenches or a series of holes at regular intervals for the full depth of treatment. Uniform color and texture signifies adequate mixing, whereas, streaked appearance suggests inadequate mixing of materials (ACI 2009, PCA 2001).

Proper compaction equipment is dictated by the soil type, and generally soil-cement should be compacted between 95 and 100 percent of maximum density as determined by moisture-density tests. Compacted densities are typically checked with a nuclear density gauge immediately after compaction operations are complete (ACI 2009).

Typical curing protocols specify a bituminous membrane to be applied to the finished grade at a rate between 0.82 and 1.63 L/m^2 (USACE 1994). Prior to applying the bituminous membrane, the finished soil-cement surface should remain moist and free of loose material. Most specifications require 3 to 7 days of undisturbed curing before traffic or subsequent paving layers can be placed on the soil-cement layer.

2.4 Traffic Opening and Early Age Properties

Teng and Fulton (1974) evaluated the performance of several soil-cement test sections located on Mississippi state route 395. Two of these sections were constructed to compare the effects of undisturbed curing and artificial trafficked curing of a soil-cement base course. Both sections were constructed with *AASHTO* A-2 soil (*MDOT* Class 9C) and were stabilized with Type I portland cement at a dosage of 6.5 percent by volume of raw soil with a target strength of 3540 kPa (no further clarification was given for cement content calculations using volume of raw soil). After 7 days of curing, cracks in the soil-cement layer were mapped, and subsequently the soil-cement layer was covered with asphalt pavement. After 2 years, each section was mapped again for cracks in the asphalt pavement. The pavement mapping was compared to the soil-cement mapping to determine how well each soil-cement curing method prevented reflective cracking. It was concluded both the undisturbed and artificially trafficked sections yielded numerous fine cracks, and for the most part, cracks did not reflect through the asphalt pavement. Based on these results, the traditional 7 day no-traffic curing period was recommended to be deleted from specification.

Findings of Teng and Fulton (1974) were later supported by George (2006). George (2006) evaluated the performance of several soil-cement test sections (9C material, target strength of 2070 kPa) on Mississippi State Route 302, and two of these sections investigated precracking or preloading of the soil-cement layer after 1 day cure. George (2006) concluded that precracking techniques produced numerous fine cracks which do not reflect through the pavement surface and recommended the implementation of precracking techniques. Benefits of precracking in soil-cement layers are well documented (Adaska and Luhr 2004, George 2002, George 2006, Sebesta 2005).

PCA (2001) and Halsted et al. (2006) suggest soil-cement layers can be opened to low-speed local and construction traffic provided the soil-cement mixture has sufficiently hardened to resist marring or permanent deformation and proper curing protocols are not impaired. Also, subsequent pavement layers can be placed soon after construction given the soil-cement layer has hardened sufficiently to resist marring or permanent deformation. George (2002) recommends that subsequent pavement layers be constructed no sooner than 3 days but no later than 7 days after construction of the soil-cement layer. Early placement of subsequent pavement layers may prevent moisture loss from the soil-cement layer, thus mitigating potential for shrinkage cracking. Early trafficking and early placement of subsequent pavement layers offer several benefits, but it is critical to evaluate the in-situ strength of the soil-cement layer to ensure the layer will not sustain permanent damage.

2.5 Measurement of In-Situ Strength

According to Griffin and Tingle (2009), there is no standard method for determining the strength capacity of cement stabilized soils after construction other than field cores. Two potential non-destructive approaches for monitoring the extent of cement hydration in soil-cement mixtures were identified. The first approach is field measurements using devices such as the dynamic cone penetrometer, Clegg Hammer, soil stiffness gauge, Proceq Type PT test hammer, and portable falling-weight deflectometer. These devices are referred to as Strength Estimating Devices in this thesis. The second approach is the maturity concept for cementitious materials.

2.5.1 Strength Estimating Devices

Guthrie et al. (2005), Abu-Farsakh et al. (2004), and Okamoto et al. (1991) presented favorable results supporting the use of the dynamic cone penetrometer, Clegg Hammer, soil stiffness gauge, Proceq Type PT test hammer, and portable falling-weight deflectometer as indicators of strength gain in cement treated bases. Griffin and Tingle (2009) conducted a similar study and compared the instrument readings with compressive strengths and modulus values from traditional laboratory tests. The study reported a poor to moderate relationship between instrument measurements, actual strength, and modulus measurements. Griffin and Tingle (2009) concluded that these instruments are better served to monitor strength gain rather than predict actual strength.

2.5.2 Maturity Method

The maturity method is an analysis approach used to account for the combined effect of time and temperature on the development of hydration and strength of cementitious materials (Carino 2001). Saul (1951) proposed the following principle which is known as the maturity rule: "Concrete of the same mix at the same maturity (reckoned in temperature-time) has approximately the same strength whatever combination of temperature and time go to make up that maturity." There are two predominant maturity functions presented in literature which are derived from the work of Nurse (1949), Saul (1951), and Hansen and Pederson (1977). *ASTM C 1074* refers to these functions as temperature-time factor and equivalent age, respectively.

Nurse (1949) and Saul (1951) examined the strength development of concrete at different elevated temperature curing methods and proposed that the product of time and temperature could be utilized for the purpose of characterizing strength development. This idea led to the development of Equation 2.2 which is commonly known as the Nurse-Saul maturity function (Carino 2001, Tikalsky 2003).

$$M = \sum_{0}^{t} (T - T_0)\Delta t \qquad \text{Eq 2.2}$$

Where:

M = Maturity index (ºC-hours or ºC-days)

T = Average temperature during Δt (ºC)

T_0 = Datum temperature (ºC)

t = Elapsed time (hours or days)

Δt = Time interval (hours or days)

Equation 2.2 is based on the assumption of a linear relationship between the initial rate of strength gain and temperature. This approximation has been stated by some to be invalid when curing temperatures vary over a wide range. Chanvillard and D'Aloia (1997) noted that the Nurse-Saul equation tends to underestimate the influence of high temperatures on compressive strength development at very early ages and overestimate at later ages. Despite controversy, Equation 2.2 is still a widely used means to characterize maturity of cementitious materials.

A similar maturity function was proposed by Hansen and Pederson (1977) and is based on the Arrhenius equation shown in Equation 2.3. The Arrhenius equation characterizes the effect of temperature on the rate of a chemical reaction. Equation 2.3 incorporates the Arrhenius equation which allows for a non-linear relationship between the initial rate of strength gain and temperature. The nonlinear maturity function is believed to better represent the effect of temperature on strength development over a wide range of temperatures. However, this maturity function is unreliable to predict the effects of early-age temperature on later-age strength according to several researchers (Carino and Lew 2001, Schindler 2004, Chitambira et al. 2007).

$$t_e = \sum_0^t \left[e^{\frac{-E}{R}\left(\frac{1}{T}-\frac{1}{T_0}\right)} \right] \times \Delta t \qquad \text{Eq 2.3}$$

Where:

t_e = Equivalent age at the reference temperature (hours or days)

E = Apparent activation energy (J/mol)

R = Universal gas constant (8.314 J/mol-K)

Δt = Time interval (hours or days)

T = Average absolute temperature during interval Δ*t* (Kelvin)

T_0 = Absolute reference temperature usually 296 K (Kelvin)

The key parameter to Equation 2.3 is the apparent activation energy (*E*) of the mixture. The apparent activation energy defines the temperature sensitivity of the hydration process and the rate of strength development of a particular cementitious mixture. A higher value indicates a greater sensitivity to changes in temperature while a lower value indicates a lower sensitivity. The activation energy is determined by first evaluating the hydration extent as a function of time. Unconfined Compressive (*UC*) strength is a commonly measured parameter for cementitious materials and is a function of the degree of hydration; therefore, *UC* strength can be used to evaluate the hydration process (Chitambira 2005). Chitambira (2007) presents a simple graphical method for determining the apparent activation energy. This approach is similar to methods described in *ASTM C 1074*. Table 2.4 shows a range of apparent activation energies for a variety of cementitious materials.

Table 2.4 Apparent Activation Energy from Literature

Cement Type	**Mixture Type**	**Type of Testing**[1]	***E* (J/mol)**	**Reference**
Type I[2]	Concrete	*SAC*	41,977 to 46,269	Schindler (2004)
Type II	Concrete	*SAC*	41,788	Schindler (2004)
Type III	Concrete	*SAC*	49,955	Schindler (2004)
Type IV	Concrete	*SAC*	39,978	Schindler (2004)
Type V	Concrete	*SAC*	37,461	Schindler (2004)
Type I, *PFA*[3]	Soil, Sand	*SAC*	63,220 to 70,990	Chitambira (2007)
Type I, Lime, *SCB*[4]	Soil, Sand	*SAC*	63,220 to 70,990	Chitambira (2007)
Type I	Cement Paste	*IC*	39,000	Ma et al. (1994)

1: SAC = Semi-Adiabatic Calorimetry; IC = Isothermal Calorimetry.
2: Sampled from three sources.
3: PFA = pulverized fuel ash.
4: SCB = Soil-Cement Bentonite.

The maturity approach is commonly used in the concrete industry to predict in place concrete strengths. Mohsen et al. (2004) documents the widespread use of the maturity concept in concrete highway construction. Other works document the successful application of maturity concepts to chemically stabilized soils (Anday 1963, Circeo 1962, and Chitambira 2005, 2006 and 2007).

Anday (1963) used the maturity concept to compare field cured and laboratory cured specimens of lime stabilized cohesive soils. Lab specimens were cured under accelerated conditions in an oven at 49 °C. Specimens cured under these conditions for two days were found to have the same strength as field specimens at about 3,000 ºC-days using a datum temperature of 0 °C. The actual curing temperature for each lab cured specimen was taken to be the temperature of the oven (49 °C).

Circeo et al. (1962) compiled over 500 sets of data for portland cement treated soils with varying curing times up to five years and was able to develop a relationship between curing time and *UC* strength. The relationship was observed to be both semi-logarithmic and logarithmic in nature. The study concluded that the relationship was affected by cement content, curing temperature, specimen density, moisture content, chemical additives, soil type, specimen size, and curing protocols.

Studies conducted by Chitambira et al. (2005, 2006, 2007) have shown that the maturity method using the apparent activation energy derived from *UC*-temperature results can be used to model the hydration of cement stabilized soils. These works demonstrate the applicability of modeling cement hydration using the maturity concept and the Arrhenius equation approach.

2.6 Thermal Measurements Testing

Thermal measurements testing is sometimes referred to as Semi-Adiabatic Calorimetry (*SAC*) or thermal profile testing. Thermal measurements testing is defined by Cost and Gardiner (2009) as the "process of measuring and recording the changing temperatures of a hydrating cementitious sample, with relatively little influence from ambient temperature changes, as an indication of the hydration heat energy evolved from the sample." The thermal profile of a specimen refers to the graph of changing temperatures over time during the initial hours of hydration. Thermal profile characteristics (e.g. magnitude and timing of peaks, shape, etc.) can be useful in analysis as indicators of mixture performance when compared to other similar mixtures of known performance (Cost and Gardiner 2009). It is important to note that thermal measurement testing cannot provide quantified measurements or corrected approximations of actual hydration heat like in isothermal or adiabatic calorimetry but can serve as a simple and expedient tool for comparison of relative performance of a particular mixture (Morabito 1998).

Thermal measurement devices are relatively simplistic in nature. Devices usually consist of the following components: insulation provided by a thermos flask or some form of polystyrene or equivalent material; instrumentation in the form of thermistors or thermocouples; and data logging device to record temperature measurements over time. The amount of insulation and the instrumentation type for a device largely depend on the objectives and goals of a particular study (Cost and Gardiner 2009, Morabito 1998). According to Morabito (1998), most thermos flask devices can only accommodate specimens of 2.5 kg or less. Alternatively, devices utilizing polystyrene material as insulation can be built to accommodate cylindrical or cube specimens of any size. The cement and concrete industries utilize thermal measurements to evaluate setting characteristics, compatibility of different cementitious materials, sulfate balance, and early strength development of concrete, mortar, and paste mixtures. In a limited capacity, this technology has been applied to stabilized soils (Sullivan et al. 2012).

Sullivan et al. (2012) conducted thermal measurement testing on cementitiously stabilized clays at high moisture contents. The study showed that thermal measurement equipment is capable of detecting and recording thermal profiles of cement stabilize soils at low cement dosages (as low as 3% by mass was tested). Also, the magnitudes, shape, and timing of thermal peaks were directly influenced by specimen size, amount of insulation, and mix proportions (namely cement and water). The study also developed specimen preparation protocols where the thermal profile and *UC* strength were measured on the same specimen. Sullivan et al. (2012) concluded that thermal measurement testing shows merit as a potential quality control measure in the laboratory and field.

Peethamparan et al. (2008) performed thermal profile and *UC* tests on kaolinite clays stabilized with cement kiln dust. Separate specimens were prepared for thermal profile testing and *UC* testing. Temperature profiles and *UC* strength data clearly demonstrate performance differences in the four cement kiln dusts tested. From a design perspective, thermal measurement and *UC* strength results gave an indication of the effectiveness of the cementitious material as a soil stabilizer.

Scavuzzo (1991) utilized a thermal measurement approach to determine the cement content of freshly mixed soil-cement mixtures by measuring the heat of neutralization. In the study, uncompacted freshly mixed soil-cement was mixed with a sodium acetate-glacial acetic acid buffer solution and the peak temperature rise of the resulting exothermic reaction was recorded using thermal measurement equipment. The amount of heat generated was proportional to the quantity of cement in the sample. The relationship between the heat generated and cement content was linear. A calibration curve was developed in the laboratory which correlated the measured peak temperature and cement content for a particular mixture. The proposed test method would allow for the cement content to be checked in the field in approximately 15 minutes and would be ideal for quality control and quality assurance. For field applications, Scavuzzo (1991) concluded that the cement content of a soil-cement mixture can be predicted within ±1% of actual cement content.

CHAPTER 3

MDOT SOIL-CEMENT DATABASE AND PRACTICE REVIEW

3.1 General Overview of Database and Practice Review

In Mississippi, use of cement stabilized soil for pavement base course layers is widespread. This chapter focuses on the current laboratory test methods used to design soil-cement base courses in the state of Mississippi. This chapter also includes a detailed analysis of the *MDOT* soil-cement database, which includes all soil-cement mixture designs performed from 2005 through 2010 that were made available by the *MDOT* Materials Division (all data is provided in Appendix A).

3.2 Materials Criteria

All of the material used in soil-cement base course construction must meet the criteria outlined in section 700 of MDOT (2004). The soil must classify as Class 9 Group C (*9C*) material or better (Table 3.1). The soil is allowed to have a maximum Liquid Limit (*LL*) of 30 and a maximum Plasticity Index (*PI*) of 10. In most cases, the soil is obtained from a local borrow pit near the construction site, and the size and scale of the borrow pit can range from a commercially owned and operated borrow pit to a hillside on residential property.

Soils are typically stabilized with Type I or Type II portland cement, but occasionally, an alternative cementitious blend with Ground Granulated Blast Furnace Slag (*GGBFS*) or Class F fly ash replacement is permitted. Type I cement is most frequently used, while Type II and/or alternative blends are usually required when the soil has an elevated soluble sulfate content. Soils with negligible sulfate content (0.00 to 0.09%) are usually stabilized with Type I cement. Soils with moderate sulfate content (0.10 to 0.19%) require either Type II cement or Type I cement with 50% *GGBFS* or 50% Class F fly ash replacement. Soils with severe sulfate content (>0.20%) require Type II cement with 50% *GGBFS* replacement or 25% Class F fly ash replacement.

Table 3.1 Soil Gradation Requirements of Class 9 Group C (*9C*)

Sieve Size (μm)	Sieve Designation Number	Percent Passing (%)
425	40	20 to 100
250	60	15 to 85
75	200	6 to 40

Note: 9C material must have 30 to 100 percent passing the 2 mm sieve (No. 10). Criteria given in Table 3.1 are applied to 9C material passing the 2 mm sieve (e.g. 20 to 100% of the material passing the 2 mm sieve must pass the 425 μm sieve).

3.3 Mississippi Test Methods for Soil-Cement Design

All soil-cement mixture designs are performed by *MDOT*'s central laboratory in Jackson, MS. A soil sample from the borrow pit source is sent to the central laboratory for material approval and to determine mixture proportions for design. Material approval is based on soil properties including hydroscopic moisture content, full gradation, Atterberg Limits, and soluble sulfate content. Test methods used to determine soil properties include *AASHTO T 87*, *T 265*, *T 27*, *T 11*, *T 88*, *T 85*, *T 89*, *T 90*, *T 92*, and Mississippi Test Method 58. Material approval is dependent upon the material meeting the criteria given in Section 3.2. After the material is approved, the design cement content for the soil-cement mixture is determined using Mississippi Test Methods 8, 9, 25 and 26. The following sections discuss each of these methods.

3.3.1 Mississippi Test Method 8

In general, Mississippi Test Method 8 (*MT-8*) is a modification of *AASHTO T 99* with a few notable modifications. This test method is applicable to embankment soils, design soils, and untreated subgrade and base materials. Before testing, the soil is air dried and processed according to *AASHTO T 87*. Typically, soil processing is performed by light tamping with hand tools and/or use of a soil mortar and pestle. *MT-8* is divided into Case 1 (≈90% of material passes the 4.75 mm sieve) and Case 2 (≈10% of material is retained on the 4.75 mm sieve). Case 1 corresponds to Method A described in *T 99* and Case 2 loosely corresponds to Method B described in *T 99*.

MT-8 Case 1 protocols do not deviate from *T 99* Method A protocols. Approximately 3 kg of processed soil passing the 4.75 mm sieve is mixed with water to about 4 percentage points below the expected optimum moisture content. Normally, all mixing is performed by hand, but *MT-8* notes that a suitable mechanical mixing apparatus is desired. Then, the soil is compacted in a 101.6 mm diameter (V = 943e^{-6} m^3) proctor mold in three equal layers to give a total compacted depth to fill the mold but not to exceed 127 mm. Each layer is compacted with 25 equally distributed blows from a 2.5 kg hammer dropping from a height of 305 mm above the top of the soil. Both manual and mechanical compaction hammers are acceptable, but a mechanical compaction hammer with a segmented head is desired and used routinely for laboratory compaction.

After compaction, the soil specimen is trimmed even with the top of the mold, weighed, extruded, and sampled for moisture content determination. The remaining portion of the molded specimen is thoroughly broken up by hand and combined with the remaining prepared sample. Additional water is added to the sample to increase the moisture content 1 to 2 percentage points, and the process is repeated until a decrease or no change in the wet mass of the compacted specimen is observed between consecutive trials.

Equation 3.1 and Equation 3.2 are used to calculate the moisture content and dry density for each trial. The optimum moisture content (*OMC*) and maximum dry density (γ_d) of the soil sample is determined by plotting moisture content versus dry density and drawing a curve through the points. The coordinates corresponding to the apex of the curve are *OMC* and γ_d.

$$\omega = \frac{A - B}{B - C} \times 100 \qquad \text{Eq 3.1}$$

Where:

ω = Moisture content of specimen (%)

A = Mass of container and wet soil (g)

B = Mass of container and dry soil (g)

C = Mass of container (g)

$$W = \frac{(D - E) \times F}{\omega + 100} \times 100 \qquad \text{Eq 3.2}$$

Where:

W = Dry density (kg/m^3)

D = Mass of compacted specimen and mold (kg)

E = Mass of mold (kg)

F = Mold factor; 1059.43 for 101.6 mm mold; 470.74 for 152.4 mm mold ($1/m^3$)

ω = Moisture content of specimen (%)

MT-8 Case 2 protocols are similar to *T 99* Method B protocols with a few significant differences. *MT-8* Case 2 requires approximately 9 kg of material passing the 12.5 mm sieve whereas *T 99* requires 7 kg of material passing the 4.75 mm sieve. Overall, Case 2 procedures are the same as Case 1 with the exception of compaction mold size, number of lifts and number of blows. *MT-8* Case 2 specifies specimens to be compacted in a 152.4 mm diameter by 116.3 mm tall ($V = 2124e^{-6}$ m^3) mold in 4 equal lifts with 56 blows per lift (*T 99* Method B specifies 3 lifts with 56 blows per lift). Moisture contents and dry densities are determined in the same manner as Case 1 using Equations 3.1 and 3.2. The procedure for selecting *OMC* and γ_d is the same as Case 1. After selecting the *OMC* and γ_d, Equations 3.3 and 3.4 are used to adjust the *OMC* and γ_d to account for the plus 12.5 mm material.

$$OMC_{adj} = \frac{M_{r12.5}}{100} \times \left(P_{r12.5} + \frac{OMC_{p12.5}}{100} \times P_{p12.5} \right) \qquad \text{Eq 3.3}$$

Where:

OMC_{adj} = Adjusted optimum moisture content (%)

$M_{r12.5}$ = Moisture content of material retained on 12.5 mm sieve (%)

$P_{r12.5}$ = Percent retained on 12.5 mm sieve (%)

$OMC_{p12.5}$ = Optimum moisture content of material passing 12.5 mm sieve (%)

$P_{p12.5}$ = Percent passing 12.5 mm sieve (%)

$$\gamma_{dadj} = \frac{1}{\left(\frac{1}{\gamma_d} \times P_{p12.5}\right) + \left(\frac{1}{G_{sb} \times \gamma_w} \times P_{r12.5}\right)} \times 100 \quad \text{Eq 3.4}$$

Where:

$\gamma_{d_{adj}}$= Adjusted maximum dry density (kg/m^3)

γ_d = Maximum dry density of material passing 12.5 mm sieve (kg/m^3)

γ_w = Unit weight of water (kg/m^3)

G_{sb} = Bulk specific gravity of plus 12.5 mm material

3.3.2 Mississippi Test Method 9

Mississippi Test Method 9 (*MT-9*) is a modification of *AASHTO T 134*. This test method is applicable to all soil mixtures to be stabilized with cementitious materials. MT-9 Method A is used for design procedures while Method B is utilized during construction. *MT-9* Method A is further broken into Case 1 and 2, which have the same criteria and distinction as defined in *MT-8*. The protocols of *MT-9* are the same as *MT-8* with the exception of the compaction mold size for Case 2 and cement addition. *MT-9* Case 2 specifies a 152.4 mm diameter by 152.4 mm tall (V = 2832e^{-6} m^3) mold, which is different from the mold specified in *MT-8*. Cement is added and mixed with the dry processed soil prior to water addition and mixing. Mixing operations are the same as *MT-8*. After mixing the cement, soil, and water, the procedures and calculations to determine the *OMC* and γ_d are identical to *MT-8*. Unlike *MT-8*, the top surface of each lift is scarified to eliminate compaction planes between lifts.

Mississippi Test Method 25 (*MT-25*), which is described in 3.3.3, states that the cement content used to perform *MT-9* should be estimated using the untreated γ_d determined by *MT-8* and the soil *PI*; although, *MT-25* does not state how these values are to be used to estimate the cement content. To the knowledge of the author, common practice relies on material handling experience to estimate the cement content to be used in *MT-9*. Typically, the estimated cement content will be between 4 and 8 percent according to *MDOT*'s current cement content definitions.

Cement content is currently expressed as a percentage referencing volume which is similar to PCA (1992) cement content calculations for field control factors during construction (see Section 2.2.1). The cement content calculation is based on the volume of a 94 pound U.S. bag of cement rather than the volume of the soil mixture; this is not necessarily intuitive and may be misleading to some.

Equations 3.5 through 3.8 are example calculations from *MT-9* which show how to calculate the amount of cement needed to perform a treated proctor test given a 4500 gram sample of dry soil, an untreated maximum dry density of 120.6 lb/ft^3 and an estimated cement content of 4 percent by *MDOT*'s current definition. Example values were taken from Mix ID 61 located in Table A.3.

$$\frac{4\%}{100} \times 94\frac{lb}{ft^3} = 3.76\frac{lb}{ft^3} \qquad \text{Eq 3.5}$$

$$120\frac{lb}{ft^3} + 3.76\frac{lb}{ft^3} = 124.36\frac{lb}{ft^3} = \text{assumed density of soil-cement mixture} \qquad \text{Eq 3.6}$$

$$\frac{3.76\frac{lb}{ft^3}}{120.6\frac{lb}{ft^3}} \times 100 = 3.12\% \ = \text{percent cement by dry soil mass} \qquad \text{Eq 3.7}$$

$$\frac{3.12\%}{100} \times 4500 \text{ grams} = 140.4 \text{ grams of cement} \qquad \text{Eq 3.8}$$

If the maximum dry density obtained from *MT-9* varies from the assumed density of soil-cement mixture (Eq 3.6) by more than 1 lb/ft^3, the test should be repeated using the maximum dry density obtained, and Equations 3.9 through 3.12 are used to re-calculate the amount of cement. For this example, the first test yielded a standard maximum dry density of 122.7 lb/ft^3 and all other factors remain the same.

$$\frac{4\%}{100} \times 94 \frac{lb}{ft^3} = 3.76 \frac{lb}{ft^3} \qquad \text{Eq 3.9}$$

$$122.7 \frac{lb}{ft^3} - 3.76 \frac{lb}{ft^3} = 118.94 \frac{lb}{ft^3} \qquad \text{Eq 3.10}$$

$$\frac{3.76 \frac{lb}{ft^3}}{118.94 \frac{lb}{ft^3}} \times 100 = 3.16\% = \text{percent cement by dry soil mass} \qquad \text{Eq 3.11}$$

$$\frac{3.16\%}{100} \times 4500 \text{ grams} = 142.2 \text{ grams of cement} \qquad \text{Eq 3.12}$$

According to the example, 4 percent cement by volume is equal to 3.16 percent by weight of dry soil mass, and 142.2 grams of cement is required to dose 4500 grams of dry soil. Note the amount of cement calculated in Equation 3.12 does not match the amount of cement recorded in Table A.3; this discrepancy is explained in Section 3.4.3. As the example calculations show, the cement content is not a true mixture volume calculation. A cement content by compacted soil volume should be less than the same value reported by mass (portland cement specific gravity is higher than the other materials), not more as seen in the previous example. Therefore, the commonly expressed cement content by volume is referred to as a cement index (C_I) for the remainder of this thesis.

3.3.3 Mississippi Test Method 25

Mississippi Test Method 25 (*MT-25*) specifies the design cement content selection for soil-cement mixtures. The design cement content selection is based solely on compressive strength. The design cement content is the minimum cement content that will produce a 14 day compressive strength of 2070 kPa (300 psi) or greater. *MT-25* provides the recommended design cement index and the number of curing days (7 or 14) required to achieve a compressive strength of 2070 kPa.

Six specimens are prepared according to *MT-9* Method A. Two specimens are prepared at 1 percentage point below the estimated design cement index, two are prepared at the estimated design cement index, and two are prepared at 1 percentage point above the estimated design cement index. Following compaction according to *MT-9*, specimens are trimmed even with top of the mold, extruded carefully, and placed under a damp cloth for 4 hours. Common practice is to leave specimens under a damp cloth overnight. Then, specimens are placed into plastic bags and set in a moisture room for curing. For each tested cement index level, one specimen is tested for compressive strength at 7 days, and the other specimen is tested for compressive strength at 14 days. At the end of the 7 and 14 day curing periods, specimens are immersed in water for 5 hours and tested according to Mississippi Test Method 26. The soaking period is routinely incorporated into the last 5 hours of the 7 and 14 day cure times.

3.3.4 Mississippi Test Method 26

Mississippi Test Method 26 (*MT-26*) is the procedure for determining the unconfined compressive strength of 101.6 mm diameter soil-cement cylinders prepared according to Mississippi Test Method 11 ("Preparation of Field Specimens of Soil Cement") or *MT-25*. *MT-26* is also applicable to compressive strength testing of soil-cement field cores. After the appropriate curing time, specimens are immersed in water for 5 hours (48 hours for field cores). Usually, the 5 hour soaking time is included in the total cure time as noted in Section 3.3.3. *MT-26* allows specimens to be capped before testing to satisfy smoothness criteria, but specimen capping is rarely needed. A compression load frame equipped with a spherically-seated head loads the specimen at a constant rate of 1.27 mm/min (0.05 in/min) until failure. The max load at failure is recorded to the nearest 40 N (10 lbs), and the compressive strength is calculated by dividing the max load at failure by the original specimen cross-sectional area.

3.4 MDOT Soil-Cement Database

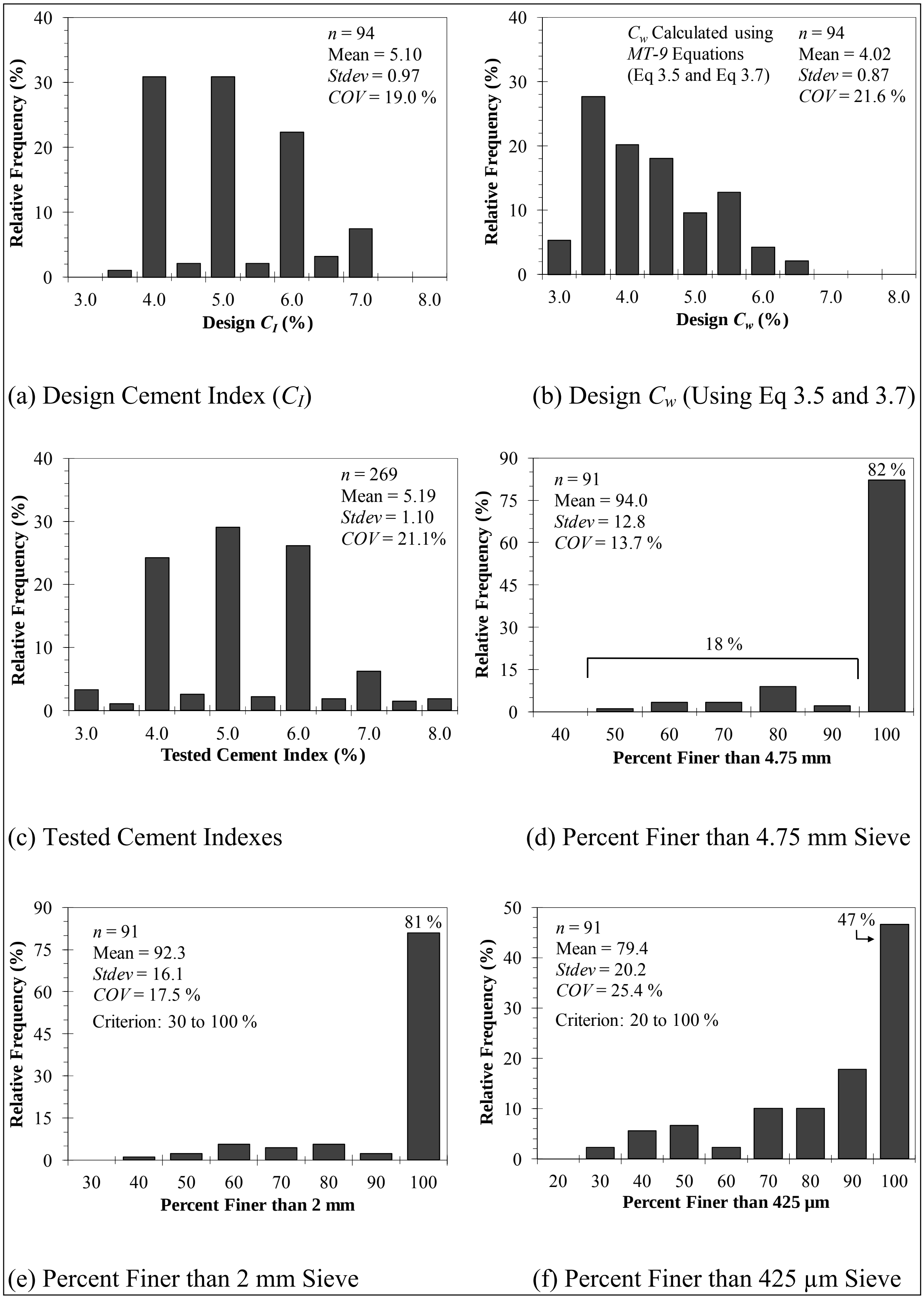
MDOT maintains statewide records of soil-cement mixture designs used for highway construction. The database was obtained and analyzed to investigate current *MDOT* soil-cement design practices. A total of 176 soil-cement mix designs were acquired which includes all documented cementitiously stabilized subgrade and base course designs performed over the six year period from January 2005 to December 2010.

The *MT-25* compressive strength results for the design cement index were used to distinguish between subgrade and base course designs. If the design cement index produced a compressive strength less than 2070 kPa (300 psi), the mix was considered to be a subgrade design; otherwise, it was considered to be a base course design. Twelve mix designs were missing *MT-25* results; therefore, the type of design was identified and sorted using additional descriptions and notes given in the database. Of the 176 mix designs, 55 were found to be subgrade designs, and 121 were base course designs.

The database was further sorted to only include mix designs with soils meeting the Class 9 Group C material criteria defined in Section 3.2. A preliminary investigation was conducted and presented at the 2011 Mississippi Transportation Institute Conference titled "State of Practice in Soil Cement" which used 98 mix designs in analysis, but ultimately the total number of mix designs analyzed was reduced to 94 after closer examination of the database. For the current work, 94 mix designs met the criteria for *9C* cement stabilized base courses and were used in analysis. The 94 mix designs include the three designs conducted for the current study. Approximately 2 percent of the database could not be located. Appendix A contains the *MDOT* soil-cement database obtained for analysis.

3.4.1 Database Trends

First, the soil-cement database was analyzed to observe general trends among the design cement contents and soil properties. Figures 3.1, 3.2 and 3.3 contain relative frequency histograms showing the distributions of the recommended design cement indexes, tested cement indexes, and soil properties. Each histogram notes the total number of data points (*n*), mean, standard deviation (*Stdev*), and coefficient of variation (*COV*) for the data shown.



(a) Design Cement Index (C_I)

(b) Design C_w (Using Eq 3.5 and 3.7)

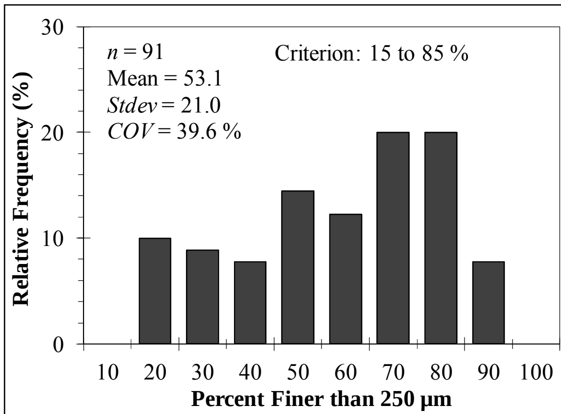
(c) Tested Cement Indexes

(d) Percent Finer than 4.75 mm Sieve

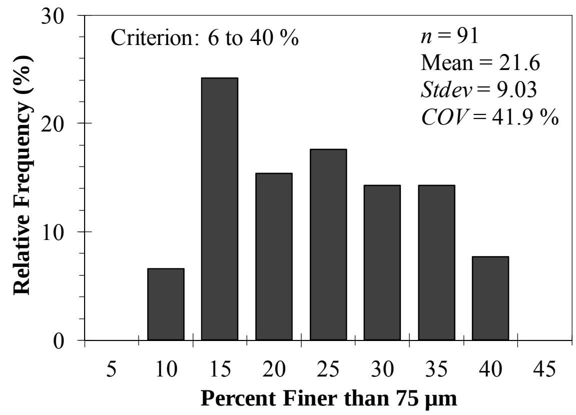
(e) Percent Finer than 2 mm Sieve

(f) Percent Finer than 425 µm Sieve

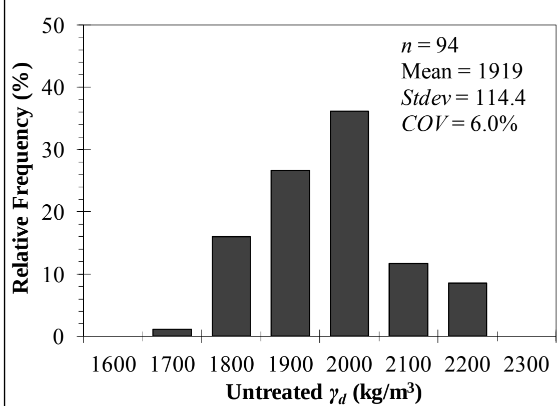
Figure 3.1 *MDOT* Soil-Cement Database Histograms (1 of 3)



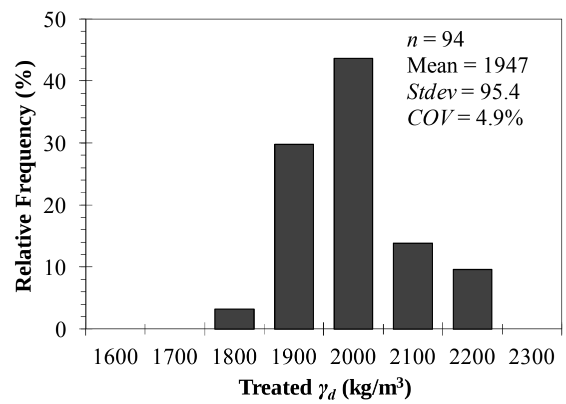
(a) Percent Finer than 250 μm Sieve



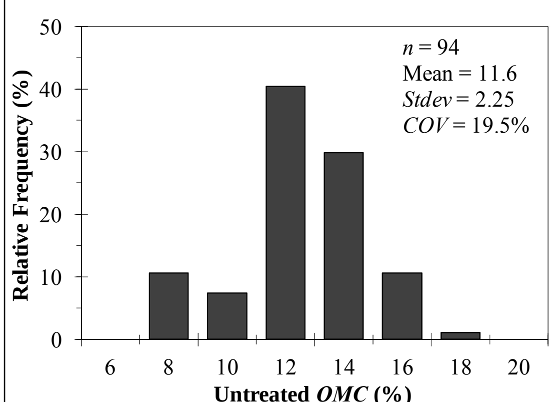
(b) Percent Finer than 75 μm Sieve



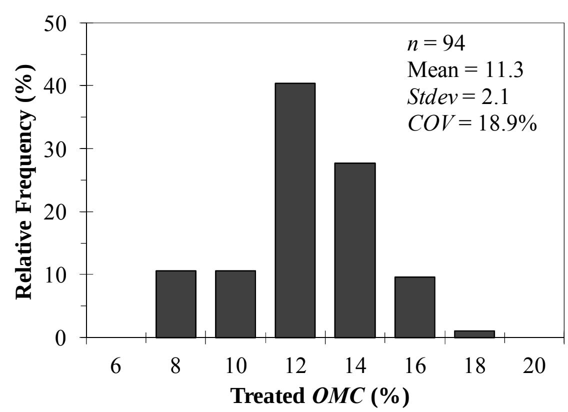
(c) Untreated Maximum γ_d



(d) Treated Maximum γ_d



(e) Untreated *OMC*



(f) Treated *OMC*

Figure 3.2 *MDOT* Soil-Cement Database Histograms (2 of 3)

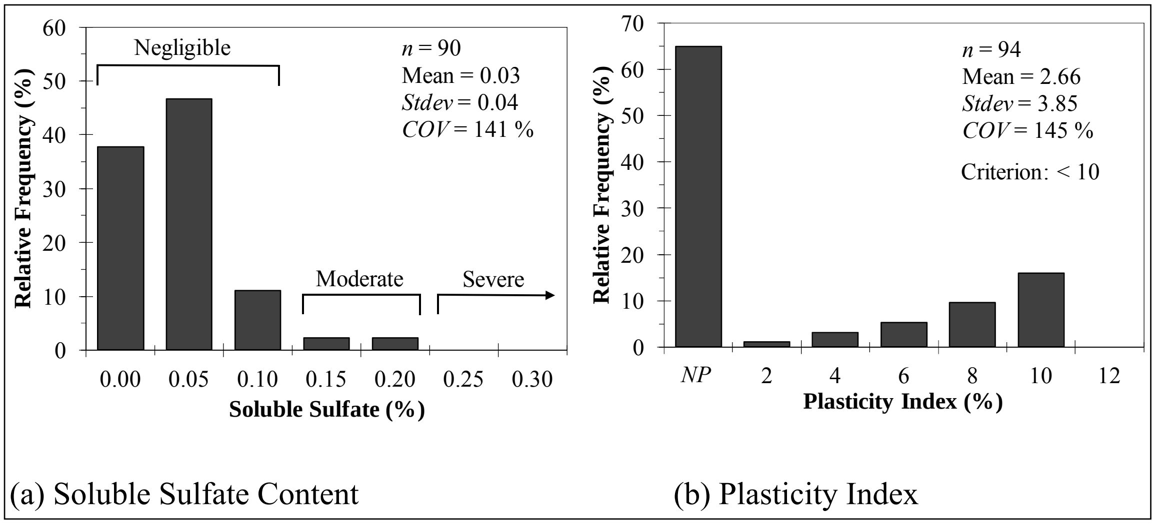


Figure 3.3 *MDOT* Soil-Cement Database Histograms (3 of 3)

Figure 3.1a shows the recommended design cement index (C_I) was 4, 5, or 6 percent in most cases. The minimum and maximum design cement indexes were 3.5 and 7 percent, respectively, with an average design cement index of about 5 percent. Figure 3.1b shows the same design cement indexes expressed as a percentage of dry soil mass (C_w). The cement content by dry soil mass is always less than the cement index. The average design cement content by dry soil mass was about 4 percent, and the minimum and maximum cement contents were 2.7 and 6.3 percent, respectively. Figure 3.1c shows all of the cement indexes tested in *MT-25*. Again, the most common indexes tested were 4, 5, or 6 percent. The minimum and maximum cement indexes tested were 3 and 8 percent, respectively, with an approximate average of 5 percent.

Figures 3.1d, 3.1e, 3.1f, 3.2a, and 3.2b contain relative histograms showing the distributions of percent passing each sieve size. Figure 3.1d shows that approximately 82 percent of the mix designs have 90 to 100 percent passing the 4.75 mm sieve. This indicates that about 82 percent of the mix designs should be performed according to Case

1 protocols in *MT-8* and *MT-9*, and approximately 18 percent of the mix designs should be performed according to Case 2 protocols. Figure 3.1e shows that approximately 81 percent of the mix designs have 90 to 100 percent passing the 2 mm sieve, and Figure 3.1f shows that approximately 47 percent of the mix designs have 90 to 100 percent passing the 425 µm sieve. Figures 3.2a and 3.2b show a fairly equal distribution among the histogram bins for the percent finer than 250 µm and 75 µm, respectively.

Figures 3.2c, 3.2d, 3.2e, and 3.2f contain relative histograms of untreated and treated values for maximum dry density (γ_d) and optimum moisture content (*OMC*) obtained from *MT-8* and *MT-9*. Figure 3.2c shows the distribution of untreated standard maximum dry densities with a mean of 1919 kg/m^3 and standard deviation of 114.4 kg/m^3. Figure 3.2d shows the distribution of treated standard maximum dry densities with a mean of 1947 kg/m^3 and standard deviation of 95.4 kg/m^3. Figure 3.2e shows the distribution of untreated optimum moisture contents with a mean of 11.6%. Figure 3.2f shows the distribution of treated optimum moisture contents with a mean of 11.3%. Overall, a slight increase in standard maximum dry density and a slight decrease in optimum moisture content were observed with the addition of cement.

Figure 3.3a shows a relative histogram of the soluble sulfate contents. Approximately 5 percent of the mix designs had a moderate soluble sulfate content, 95 percent of the mix designs had a negligible soluble sulfate content, and no soil-cement designs had severe soluble sulfate content levels. Figure 3.3b contains a relative histogram for soil plasticity index (*PI*). Approximately 65 percent of the mix designs were non-plastic (*NP*).

3.4.2 Soil Property Correlations to Design Cement Content

The soil-cement database was analyzed to detect any correlations between measured soil properties and the design cement content. Each soil property was plotted on the x-axis with the corresponding design cement content for the mixture on the y-axis. Soil properties were plotted against both the design cement index and the equivalent design cement content expressed as a percentage of dry soil mass (C_w). Results from this analysis yielded very poor to no correlations between any soil property and the design cement content. Linear, exponential, logarithmic, and power trendlines were considered to develop a correlation between the data, but ultimately, a linear function was deemed appropriate to describe the relationships. Table 3.2 summarizes the results. The strongest observed correlation was the percent passing the 75 µm sieve (R^2 = 0.24).

Table 3.2 Summary of Soil Property Correlations to Design Cement Content

Abscissa (x)	**Ordinate (y)**	***n***	**Correlation**	R^2
Percent Finer 75 µm	Design C_I	91	y = -0.05x + 6.26	0.23
Percent Finer 250 µm	Design C_I	91	y = -0.01x + 5.69	0.05
Percent Finer 420 µm	Design C_I	91	y = -0.01x + 5.93	0.05
Percent Finer 2 mm	Design C_I	91	y = -0.02x + 6.51	0.06
Percent Finer 4.75 mm	Design C_I	91	y = -0.02x + 6.95	0.07
Dust Ratio[1]	Design C_I	92	y = -0.03x + 5.85	0.07
Plasticity Index	Design C_I	94	y = -0.02x + 5.14	0.00
Soluble Sulfate	Design C_I	90	y = -0.17 + 5.14	0.00
Raw Max γ_d	Design C_I	94	y = -0.03x + 8.81	0.05
Percent Finer 75 µm	Design C_w	91	y = -0.05x + 5.06	0.24
Percent Finer 250 µm	Design C_w	91	y = 0.00x + 4.18	0.00
Percent Finer 420 µm	Design C_w	91	y = 0.00x + 4.00	0.00
Percent Finer 2 mm	Design C_w	90	y = 0.00x + 4.11	0.00
Percent Finer 4.75 mm	Design C_w	91	y = 0.00x + 4.17	0.00
Dust Ratio[1]	Design C_w	92	y = -0.03 + 4.97	0.16
Plasticity Index	Design C_w	94	y = -0.05x + 4.15	0.04
Soluble Sulfate	Design C_w	90	y = 0.55x + 4.04	0.00
Raw Max γ_d	Design C_w	94	y = -0.06x + 11.37	0.23

1: One data point was believed to be erroneous and was omitted from analysis.

3.4.3 Batching Calculations

As of January 2011, *MDOT* uses a computer program to calculate soil-cement mixture proportions to perform *MT-9* and *MT-25*. Closer examination of the computer program revealed a discrepancy between the program calculation equations and the *MT-9* example calculation equations for amount of cement (discussed in Section 3.3.2). Equations 3.13 through 3.16 show the actual program equations used to calculate the amount of cement for *MT-9* and *MT-25*, and equations 3.17 and 3.18 show the calculations for the amount of soil and water. For comparison, the same given values from Section 3.3.2 were used (C_I = 4%, untreated γ_d = 120.6 lb/ft^3, hydroscopic moisture = 0.5%, *OMC* for soil-cement mixture = 10.3%).

$$\frac{4\%}{100}\times 94\frac{lb}{ft^3}=3.76\frac{lb}{ft^3} \qquad \text{Eq 3.13}$$

$$120.6\frac{lb}{ft^3}-3.76\frac{lb}{ft^3}=116.84\frac{lb}{ft^3} \qquad \text{Eq 3.14}$$

$$\frac{3.76\frac{lb}{ft^3}}{116.84\frac{lb}{ft^3}}\times 100=3.22\%=\text{percent by dry soil mass} \qquad \text{Eq 3.15}$$

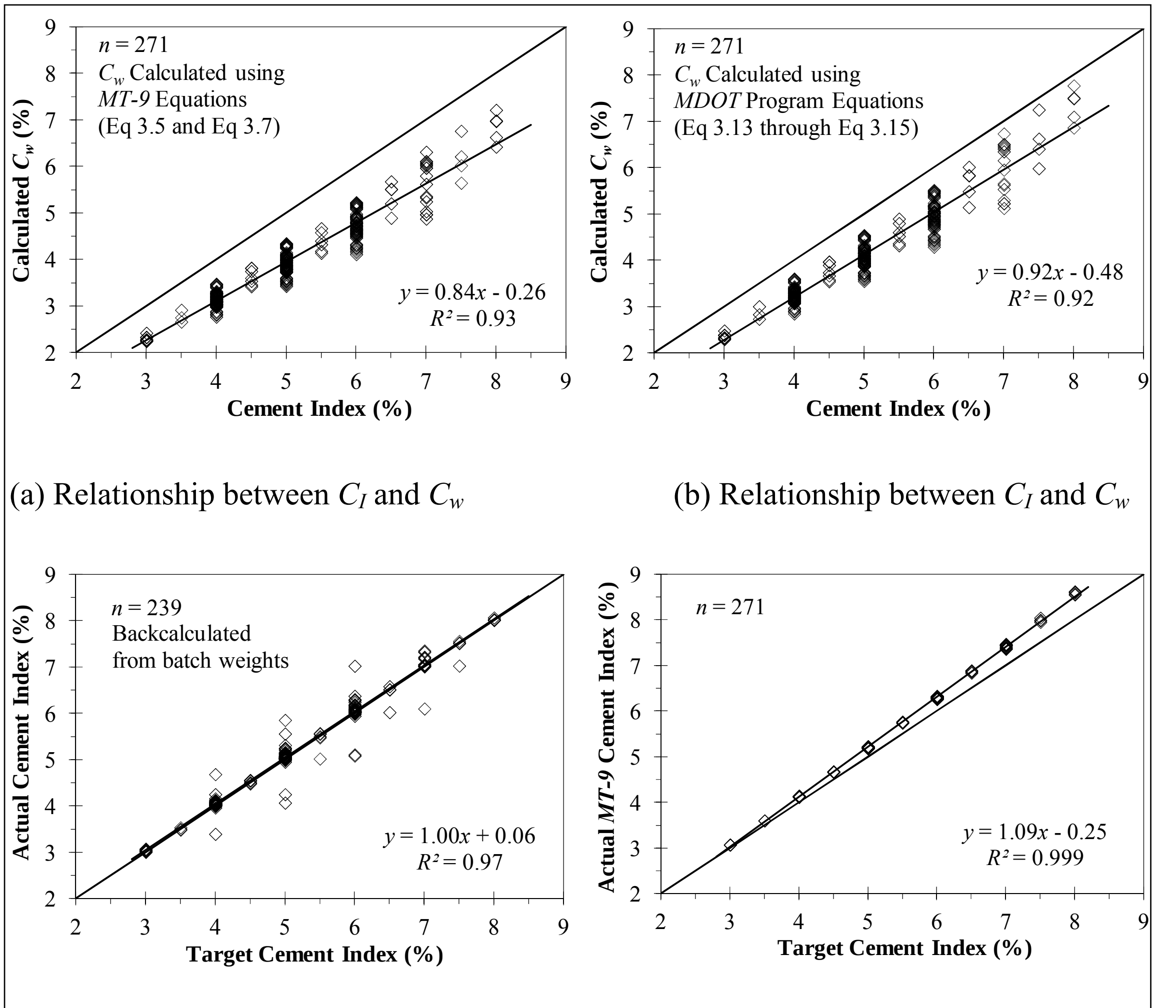
$$\frac{3.22\%}{100}\times 4500\text{ grams}=144.9\text{ grams} \qquad \text{Eq 3.16}$$

$$4500\times\frac{(0.5+100)}{100}=4522.5\text{ grams}=(\text{amount of batched soil}) \qquad \text{Eq 3.17}$$

$$(4500+144.9)\times\frac{(10.3\%-0.5\%)}{100}=455.2\text{ grams}=(\text{amount of water}) \qquad \text{Eq 3.18}$$

According to the *MDOT* program calculations, the soil-cement mixture should consist of 144.9 grams of cement, 4522.5 grams of air-dried soil with 0.5 % hydroscopic moisture, and 455.2 grams of water. The discrepancy is contained within Equation 3.15. In order to be consistent with *MT-9* equations, the treated maximum dry density should be used instead of the untreated maximum dry density. To the knowledge of the author, the calculation equations defined in *MT-9* (discussed in Section 3.3.2) are not used, and Equations 3.13 through 3.18 were used herein to calculate mixture quantities for all mixtures found in the soil-cement database. The program calculations produce an increase in cement content within the soil-cement mixture, but the increase is not dramatic. Additionally, common practice is to batch 4500 grams of soil even though the calculations adjust the amount of batched soil to account for the moisture in the soil (4522.5 grams for the example above). Omitting the adjustment for moisture in the batched soil increases the cement content as well as decreases the moisture content.

Figure 3.4a shows the relationship between cement index and cement content by dry soil mass (C_w). The data plotted includes all of the *MT-25* tested cement indexes from the database. The cement content by dry soil mass was calculated using equations defined in *MT-9* (Equations 3.5 and 3.7). In every case, the cement content by dry soil mass was considerably less than the cement index. Figure 3.4b shows the same relationship as Figure 3.4a, but the program calculations (Equations 3.13 through 3.15) were used to calculate C_w.



(a) Relationship between C_I and C_w (b) Relationship between C_I and C_w

(c) Effect of Batching Discrepancies (d) Index Correction by Calculation

Figure 3.4 Database Cement Contents and Calculations

The soil-cement database provides *MT-25* batch weights for the cement, soil, and water for each mix design. This data was utilized to evaluate the discrepancies associated with the program calculations and batching practices related to *MT-25*. From the batch weights, the actual cement content by dry soil mass (C_w) was calculated for each specimen tested. To demonstrate the effect of batching discrepancies, the cement index was back-calculated using the program calculations (Equations 3.13 through 3.15) and the actual cement contents by dry soil mass were calculated from the database batch weights. Figure 3.4c shows how the actual back-calculated cement indexes deviate from the targeted cement indexes. It is clear that in some cases the batching discrepancies have a noticeable effect on the cement content of tested specimens, though overall the two approaches have a trendline slope of 1 and have a near zero intercept.

Figure 3.4d shows the discrepancy solely associated with the program calculations. First, the target cement indexes were converted to cement content by dry soil mass using the batching program calculations (Equations 3.13 through 3.15). Then, the actual *MT-9* cement index tested was back-calculated using *MT-9* defined equations (Equations 3.5 and 3.7) and the program calculated cement content by dry soil mass. The back-calculated *MT-9* cement indexes were then plotted against the target cement indexes to derive a correction equation (R^2 near 1). The correction equation was confirmed by back-calculating the program cement index and the *MT-9* cement index from the batch weights given in the database; this equation only differed from Figure 3.4d due to rounding differences. The formula that should be used to adjust the program calculations to *MT-25* is given in Equation 3.19.

$$y = 1.09x - 0.25 \qquad \text{Eq 3.19}$$

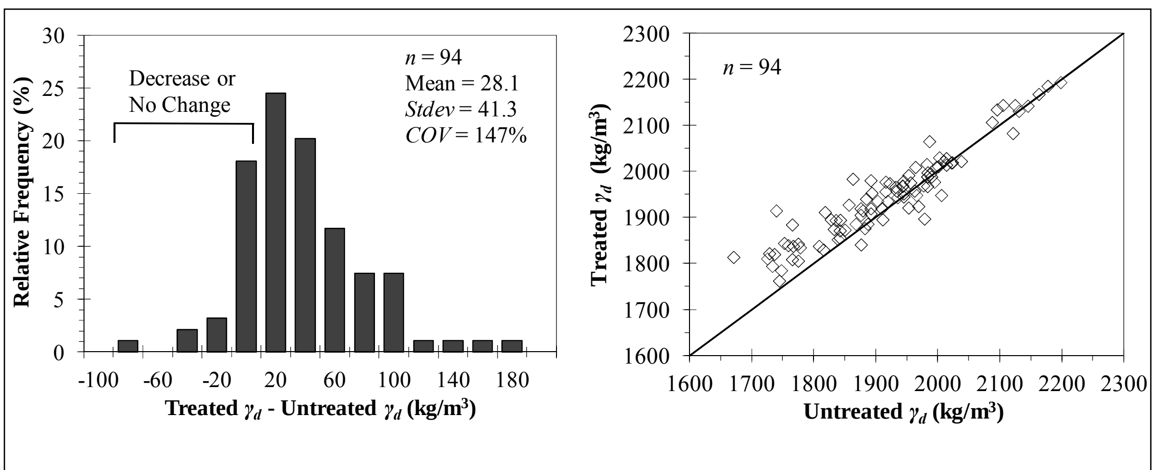
Where:

y = Actual cement index tested

x = Target cement index

3.4.4 Treated Proctor Density

Overall, the database demonstrated a slight increase in maximum dry density with cement addition. Upon closer examination, a considerable portion of the mix designs showed a drop in maximum dry density with cement addition. Figure 3.5a shows a relative histogram of the difference between treated and untreated maximum dry densities, and Figure 3.5b shows an equality plot of the same data. Twenty-four percent of the database mix designs experienced a decrease or no change in the maximum dry density (γ_d) when cement was added to the mixture. This behavior could be caused by an accelerated cement hydration rate and/or prolonged time between cement addition and compaction. An accelerated hydration rate could be caused by the type of soil, cement source, or their interaction. ACI (2009) attributes this behavior to the flocculating action of the cementitious materials. In addition, three or four mix designs show a dramatic increase in γ_d with cement addition; these data points are believed to be testing error.



(a) Distribution of Treated γ_d - Untreated γ_d (b) Treated γ_d vs. Untreated γ_d

Figure 3.5 Maximum Dry Density Decrease with Cement Addition

3.5 Summary of Database and Practice Review Findings

A concise list has been compiled to summarize aspects of the soil-cement mixture design procedures, test methods, and database results. The list also includes recommendations for enhancement based on information and data presented.

- Mississippi Test Methods 8 and 9 are not in agreement with respect to mold sizes used for material having greater than 10 percent retained on the 4.75 mm sieve. *MT-8* specifies a 152.4 mm diameter mold having a volume of $2124e^{-6}$ m^3, and *MT-9* specifies a 152.4 mm diameter mold having a volume of $2832e^{-6}$ m^3. A review of the database also showed that the mold size specified in *MT-9* was not used once during the design process, and the mold specified in *MT-8* is always used if Case 2 protocols were required.

- The sample calculations contained in Mississippi Test Method 9 that are used to determine the appropriate amount of cement for specimens made in *MT-9* and *MT-25* need to be updated.

- Review of Mississippi Test Methods and the soil-cement database revealed the cement index (cement by volume) calculations could be confusing and possibly misunderstood by some end users. Recommended design cement contents range from 3 to 7 percent under the current terminology, but this range is actually 2.7 to 6.3 percent by dry soil mass. It is strongly recommended that cement contents by weight (C_w) be used for laboratory operations and testing. If a cement index is desired for field control, then the design cement content by weight can easily be converted to a cement index at the conclusion of laboratory testing. Field control, however, can also be performed using mass proportions. The *PCA* calculation (PCA 1992) is recommended for converting cement content by weight to an equivalent cement index in the field, if this approach is desired.

- Mississippi Test Method 25 provides guidance for estimating the design cement content for soils using the untreated maximum dry density and plasticity index, but the guidance is not clearly defined. The database revealed that there is no correlation between the estimated cement content or the design cement content and the untreated maximum dry density and plasticity index. Nevertheless, the estimated cement content was equal to the ultimate design cement content for 96 percent of the database mix designs.

- Mississippi Test Methods and the database constantly switch back and forth between English and Metric units. A consistent system of units would be more beneficial for data analysis.

- Analysis of the soil-cement database revealed no correlation between soil properties and design cement content or compressive strength.

- Analysis of batch weights used for *MT-25* testing disclosed some batching discrepancies. The discrepancy lies with accounting for moisture within the batched soil. In most cases, this discrepancy is relatively small since the soils tested contain little moisture, but mixture proportions should be closely controlled and monitored in a laboratory environment since it is feasible to do so.

- Twenty-four percent of the database mix designs exhibited a drop in maximum dry density (γ_d) with the addition of cement. This behavior is believed to be associated with the compaction time and re-use of material in *MT-9*. It is recommended that a time-frame relative to cement and water combination be set in which compaction must be completed for *MT-9* and *MT-25*. Additional tests with known longer time frames might be a useful addition to *MT-9* for quality control purposes.

- The *MDOT* soil-cement database proved to be extremely insightful to the practice of soil-cement mixture design for the state of Mississippi. Continual archiving of soil-cement mix designs in a manner conducive to quick retrieval and analysis would be of great benefit for future monitoring, research, and practice enhancements.

CHAPTER 4

EXPERIMENTAL PROGRAM

4.1 Experimental Program Overview

This thesis focuses on measuring thermal profiles and eventual compressive strength of hydrating soil-cement for field quality control operations. A total of 828 soil-cement specimens were tested, which were identified according to Equation 4.1. Each specimen was given a label designating the type of testing performed, series number, soil identification, cement index, and specimen number. For example, TP-1-PA5-2 is a thermal profile specimen from Series 1 using pit soil *A*, a cement index of 5%, and is the second replicate.

1-2-3-4 Eq 4.1

1. The first position indicates the type of testing performed. Testing types include thermal profile (TP) or field work (FW).

2. The second position indicates the series number. A series number (1 to 49) was given to a group of tests performed for a given purpose.

3. The third position indicates the combination of soil type and cement index. Labels for soil type are given below and the cement index (C_I) is designated with a number.

PA:	*Pit A*	PE:	*Pit E*
PB:	*Pit B*	HA:	*HWY49-A*
PC:	*Pit C*	HB:	*HWY49-B*
PD:	*Pit D*		

4. The forth position is a sequential numbering of specimens within each series.

4.2 Testing Equipment and Accessories

Custom laboratory and field equipment (with accessories) was needed to conduct thermal profile testing. Specialty items included modified plastic specimen molds, compaction apparatuses, and thermal measurement devices. The following sections describe the design and fabrication of the specialty testing equipment alongside descriptions of key equipment used that is more conventional. The design and concepts for some of the testing equipment were largely derived from Sullivan et al. (2012).

4.2.1 Plastic Specimen Molds

Specimen molds were constructed from standard 76.2 by 152.4 mm plastic molds which meet the requirements of *ASTM C 470* for single-use concrete molds. The plastic molds were modified and utilized as a single-use specimen mold (Figure 4.1). The modified molds cost approximately $1.25 each and allow thermal profile and strength measurement on the same specimen. This project used each mold once prior to disposal for consistency, but a retrospective evaluation suggests the molds could be re-used.

Molds were modified by sanding the bottoms to remove the plastic ridge around the edge to provide a flush surface for compaction. Sanding was performed with a belt-sander and by hand. After sanding, a drill-press was used to drill a 35 mm diameter hole through the center of the mold bottoms. The 35 mm hole allows for the specimens to be manually extruded without damage for strength testing. An aluminum plate (76.2 mm diameter and 1.6 mm thick) was inserted into the bottom of the mold to cover the hole and provide a rigid surface for manual extrusion. The aluminum plate thickness changed the aspect ratio from 2:1 to 1.98:1, which was considered insignificant. The plastic cutouts from the drilling process were used to fill the gap between the metal plate and the exterior bottom of the mold to provide a solid compaction surface. The drilling process made a small hole in the plastic cut-out which was filled with Bondo® Body Filler. Tape was used to hold the plastic cut-out in place and help seal the bottom of the mold.

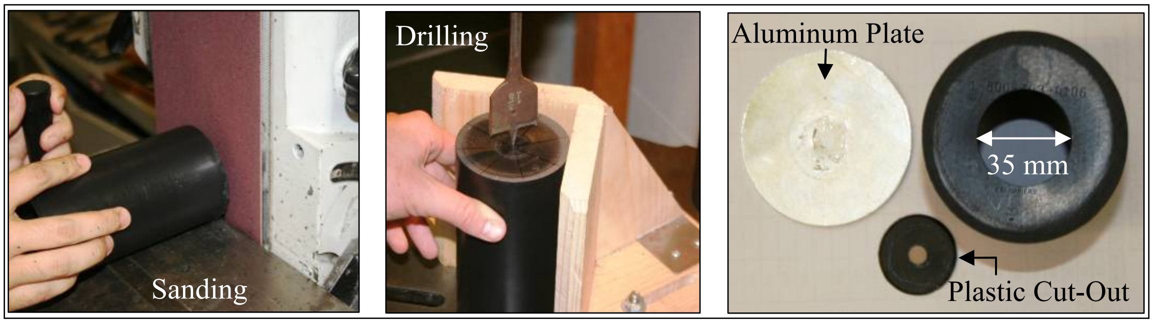


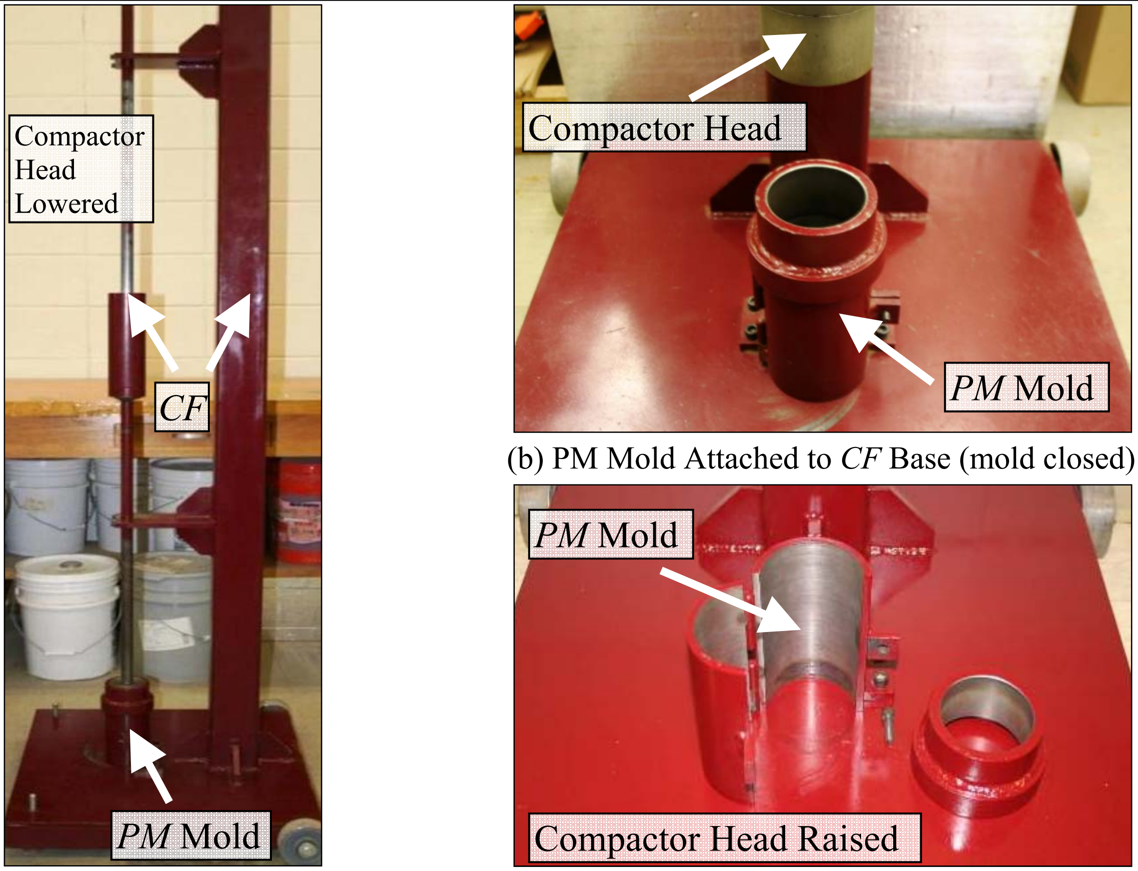
Figure 4.1 76.2 by 152.4 mm Plastic Mold Modifications

4.2.2 Laboratory and Field Compactors

Equipment to compact soil-cement specimens inside a plastic mold was not found commercially. As a result, a steel mold was designed and fabricated that allowed 76.2 mm diameter by 150.8 mm tall specimens (1.98:1 *h/d* aspect ratio) to be compacted inside the plastic molds modified as described in Section 4.2.1. Figure 4.2 provides photos of the split mold and collar, and detailed drawings are provided in Appendix C. The concept of the split mold is similar to the molding apparatus described in *ASTM C 1435*. The split mold inner diameter is the same as the plastic mold outer diameter, while the collar and plastic mold have the same inner diameter to facilitate alignment and to prevent the plastic mold from being struck during compaction. The collar also helps contain the soil during compaction. The split mold is referred to hereafter as *PM* for plastic molded specimen.

Figure 4.2 Split Mold and Collar (Referred to as *PM*)

The *PM* split mold was used in two manners. The first was as the lower assembly of a compaction frame (*CF*) designed and fabricated during this research (Figure 4.3). Specimens compacted in the *PM* mold by the compaction frame were referred to as *PM-CF*, with details provided in the following paragraph and drawings provided in Appendix C. The second use of the *PM* mold was alongside a modified proctor hammer when bolted to a 28.9 by 24.1 by 1.3 cm steel plate (Figure 4.4). Specimens compacted in the *PM* mold by a modified proctor hammer were referred to as *PM-P*. The *PM-P* compaction approach can easily be performed in the laboratory or the field. The total cost for the *PM-CF* split mold and compaction assembly was approximately $3,000 (materials and fabrication), while the total cost of the *PM-P* split mold and base plate minus the proctor hammer was approximately $900 (materials and fabrication).

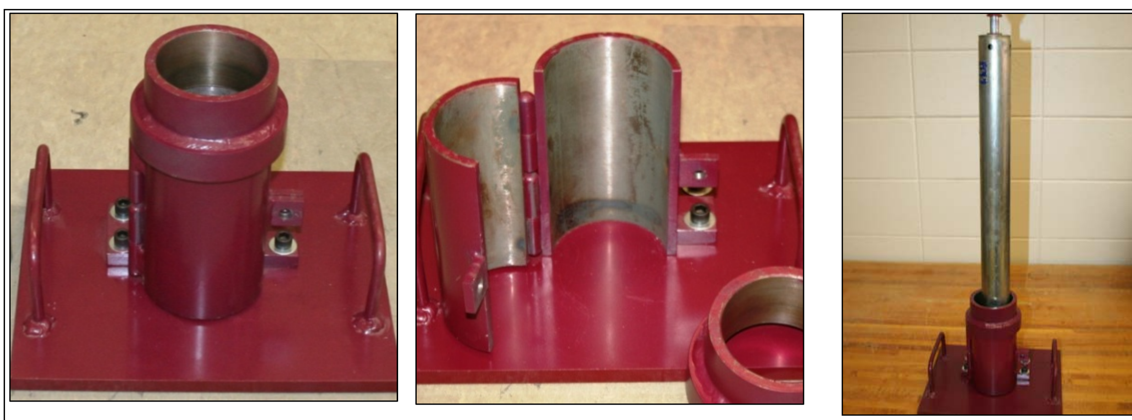


(a) Compaction Frame (*CF*)

(b) PM Mold Attached to *CF* Base (mold closed)

(c) *PM* Mold Attached to *CF* Base (mold open)

Figure 4.3 Compaction Frame and *PM* Mold (*PM-CF* Approach)



(a) *PM-P* (closed) (b) *PM-P* (open) (c) *PM-P* w/ Mod. Hammer

Figure 4.4 *PM* Mold with Modified Proctor Hammer (*PM-P* Approach)

The *CF* was designed to compact a known amount of material to a prescribed height, thus achieving a target specimen density. The *CF* fabricated for this study is very similar to the dropping-weight compacting machine described in *ASTM D 1632*. The compaction head is connected to a guide rod and is placed on top of the soil to be compacted. Compaction is performed by dropping a 6.8 kg weight from a height of 30.5 cm and hitting a striker plate which transfers the compaction energy to the soil. The striker plate has a robust weld to withstand repeated striking from the 6.8 kg weight. Compaction heights for each layer were etched into the compaction head for consistency.

4.2.3 Thermal Measurement Equipment

Two thermal measurement devices were built from Expanded Polystyrene (*EPS*) blocks (R_{SI} = 0.775) and are referred to as Blocks A and B or *EPS* devices. One thermal measurement device was built from 48 kg/m^3 density chemically Cross Linked Polyethylene (*XLPE*) foam blocks ($R_{SI} \approx 0.564$) and is referred to as Block C or *XLPE* device. The exact R_{SI} value for the tested *XLPE* block was unavailable, but an equivalent chemically cross linked polyethylene foam product from another producer was found to have an R_{SI} value of 0.564. Unless additional information is made available, the R_{SI} value of the tested *XLPE* device (Block C) is considered be approximately 0.564. The *EPS* and *XLPE* devices are the same except for amount of insulation and sensor type. A higher R_{SI} value indicates greater insulation. Device designs were based on Sullivan et al. (2012). One device is capable of testing eight specimens. A Channel ID was given to each device slot and denotes the Block type (e.g. A, B, or C) and slot position (e.g. 1 through 8). A list of the materials needed to construct one *EPS* device is given below:

1. One 15 by 38 by 66 cm *EPS* block (32 kg/m^3 density)
2. Two 5 by 38 by 66 cm *EPS* blocks (32 kg/m^3 density)
3. Six 0.64 by 20.32 cm carriage bolts
4. Twelve 1.11 cm diameter flat washers
5. Six 0.64 cm wing nuts
6. One 8-channel data logger (Pico Technology model *TC-08*)
7. Eight K-type thermocouples with fiberglass insulation and 1 m leads
8. Eight 0.79 by 4.13 cm fender washers
9. Aluminum foil tape and clear packing tape

Item 1 is the main block of the device which holds and insulates the specimens. One *EPS* block from Item 2 is the bottom of the device and accommodates the thermocouple instrumentation. The second *EPS* block from Item 2 is the lid for the device. Items 3 through 5 are the hardware needed to fasten the *EPS* blocks together. Items 6 through 8 are the instrumentation components. Tapes needed to finish the device construction are Item 9. The following paragraphs describe the *EPS* device fabrication, and Figure 4.5 contains drawings and photos of the *EPS* device.

Eight 76.2 mm diameter holes and six 64 mm diameter holes were drilled through the main *EPS* block (Item 1). The six 64 mm diameter holes extend through the bottom *EPS* block (Item 2). The 76.2 mm holes house the specimens while the 64 mm holes are for the carriage bolts and other hardware (Items 3 through 5) that fasten the blocks together. Figure 4.5a is a schematic of the device which shows hole locations for the main and bottom blocks. Holes were drilled using a 76.2 mm (3 in) diameter hole-saw bit and a 64 mm (0.25 in) diameter drill bit. A drill press was used to perform cuts to ensure the precise vertical and horizontal alignment of each hole. Interior walls of the 76.2 mm diameter holes were lightly sanded until the plastic molds (described in 4.2.1) fit tightly inside without becoming lodged. The edges and exposed sides of the *EPS* blocks were wrapped with aluminum foil tape for added durability (Figure 4.5b).

(a) Thermal Measurement Device Schematic (b) Main Block

(c) Bottom Block (d) Device Lid

(e) Thermocouple Instrumentation (f) Thermocouple Sensor

(g) Disassembled Device and Data Logger (h) Assembled Device and Lid

Figure 4.5 Schematic and Photos of Thermal Measurement Equipment (*EPS* shown)

By design, approximately 10 mm of the specimens extended beyond the top of the main block for easy specimen removal after testing. A lid was constructed to cover and insulate the exposed specimen tops during testing (Figure 4.5d). Circular recesses were cut into the bottom of the lid to provide a tight fit around the specimen tops and the fastening hardware. The indentions allowed for a flush seal between the main block and lid. Edges, exposed sides, and cut indentions were wrapped in aluminum foil tape.

The thermal measurement device was fastened together using carriage bolts, washers, and wing nuts (Items 3 through 5). The carriage bolts were inserted from the bottom of the bottom block through the 64 mm drilled holes, and were fastened with wing nuts. The head of each bolt was counter sunk so the device can rest on a flat surface. Washers were used to prevent the bolt head and wing nut from ripping through the *EPS* blocks. Wing nuts were hand tightened. Figures 4.5g and 4.5h show the completed device. One thermal measurement device costs approximately $700 (materials and data logger), and takes about 8 hours to fabricate. Cost estimate does not include the computer or data logging software (ThermoCal software was used for the current work).

4.2.4 Environmental Chamber

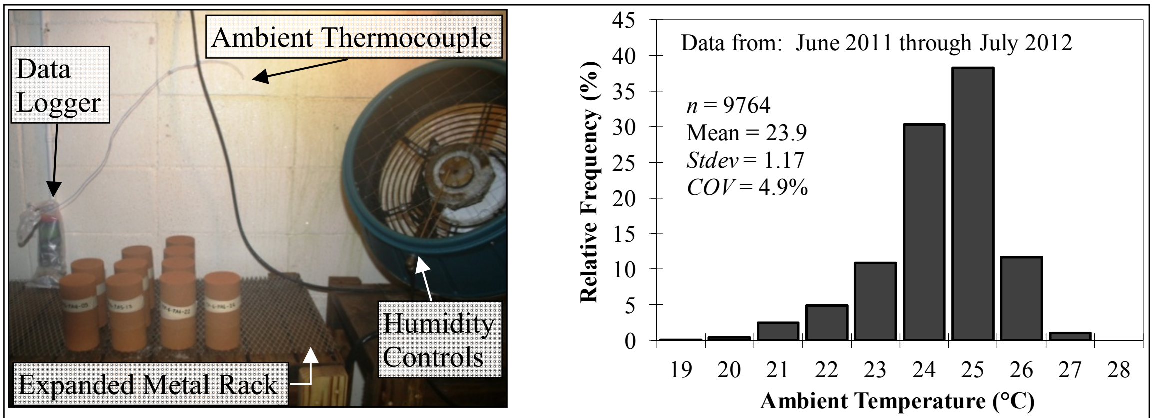
The environmental chamber used for the current work is commercially available and designed to cure concrete cylinders according to *ASTM C 31*. All laboratory thermal profile measurements were conducted inside the environmental chamber. The chamber is capable of cooling and heating a water bath to temperatures of 7 to 43 °C with a precision of ±1 °C. Testing protocols utilized the curing chamber to regulate the ambient air temperatures inside the chamber by heating and cooling the water bath. A metal rack was placed just above the water surface to accommodate thermal measurement equipment, and a small submersible pump was used to circulate the bath water and help minimize temperature variations in the chamber. Thermocouple wires were directed out the front of the chamber through the lid seal. Figure 4.6 is a photo of the curing chamber with two devices inside. One environmental chamber was used to precondition materials, and a second chamber was used to house the thermal measurement devices.

The temperature of the water within the curing chamber does not directly correlate to the ambient temperature above the water. The discrepancy occurs because the environmental chamber is not perfectly insulated, and air temperatures inside the chamber are influenced by the air temperatures outside the chamber. Curing chamber adjustments were made by placing a thermocouple inside the curing chamber and adjusting the controls to achieve the desired air temperature.

Figure 4.6 Environmental Curing Chamber with Devices

4.2.5 Moisture Curing Room

Specimens were cured in a moisture curing room as needed. Specimens were not placed in plastic bags; rather, they were exposed to the humidity of the moisture curing room. Moisture room shelves were covered with sheets of flattened stainless steel expanded metal (12.7 mm #18 style) that was mounted on wooden dowels to prevent soil-cement specimens from resting in standing water. The moisture room maintained humidity between 99.5 and 100%. A *SPER Scientific Model 800024* data logger was used to monitor the ambient air temperature of the moisture room every 60 minutes. Figure 4.7 shows a photo of the moisture curing room and a relative frequency histogram of the curing room ambient temperatures observed throughout testing.



(a) Moisture Curing Room (b) Ambient Temperature Distribution

Figure 4.7 Moisture Curing Room and Ambient Temperature Distribution

4.3 Materials Tested

Seven soils and five cementitious materials were tested. Five soils were sampled from borrow pits (referred to as pit soils). Three pit soils were tested more extensively in a lab setting, while the other two were from a field study and were tested less extensively. The sixth and seventh soils tested were in-place recycled asphalt materials (*HWY49-A* and *HWY49-B*). Four portland cement sources and one slag-cement blend were tested.

4.3.1 Pit Soils

Five borrow pit soils were tested (Figure 4.8). The majority of lab efforts focus on three pit soils which were taken from highway construction sites utilizing soil-cement as base course. Pit soils *A*, *B*, and *C* were sampled from the first available *MDOT* base course project site located in central, north, and south Mississippi. Samples were obtained from: 1) US Interstate 20 interchange project near Meridian, MS (*Pit A*); 2) US Hwy 45 interchange project near Saltillo, MS (*Pit B*); and 3) expansion of US Hwy 84 in Jefferson-Davis County, MS (*Pit C*). Approximately 2000 kg of material was obtained from each project. Pit soils *D* and *E* were sampled from: 4) State Route 9 project near Tupelo, MS (*Pit D*) and 5) State Route 475 relocation in Rankin County, MS (*Pit E*). Approximately 300 kg of material was obtained from both projects. *Pit D* and *Pit E* were sampled from the roadway prior to construction; whereas, *Pit A*, *B*, and *C* were sampled from the project borrow pit. Figure 4.9 provides photos of pit soil acquisition.

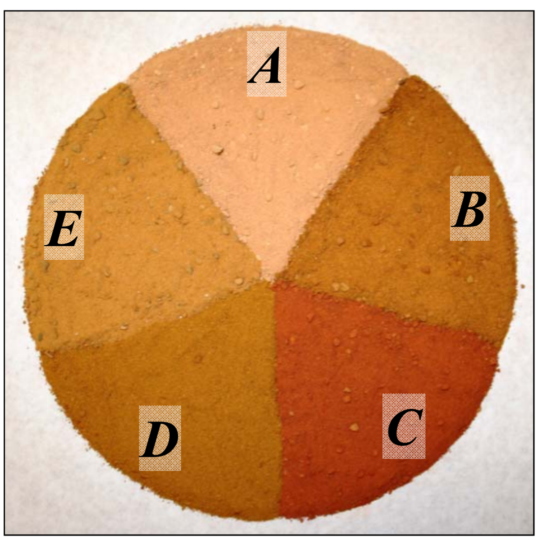


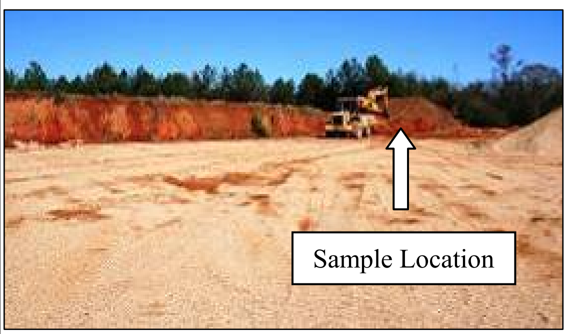
Figure 4.8 Pit Soils Tested (Post Processing)

(a) Borrow *Pit A*

(b) *Pit A* Sample Location

(c) Borrow *Pit B*

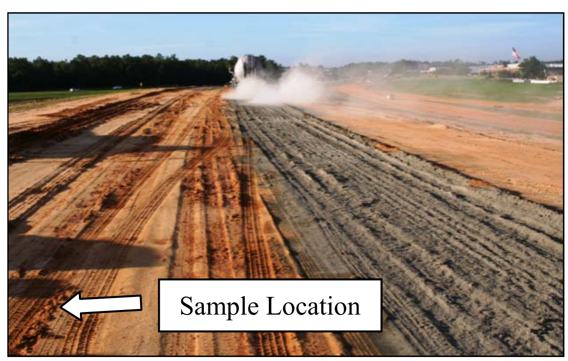
(d) *Pit B* Sample Location



(e) Borrow *Pit C*

(f) *Pit C* Sample Location

(g) *Pit D* sampled from roadway



(h) *Pit E* sampled from roadway

Figure 4.9 Photos of Pit Soil Acquisition

After processing (see Section 4.4), pit soil samples were tested for fundamental properties (Table 4.1). A sample of pit soils *A*, *B*, and *C* was sent to *MDOT* Central Laboratory to perform a soil-cement mix design. Data reported include results determined by *MDOT* Central Laboratory, Mississippi State University (*MSU*), and Burns, Cooley, Dennis, Inc (*BCD*). Table 4.1 also contains data from the soil-cement mix designs used for the corresponding projects from which each pit soil was sampled. Since pit soils *D* and *E* were part of a field study, only the project soil property results are reported.

Table 4.1 Fundamental Properties of Pit Soils

	Pit A		***Pit B***		***Pit C***		***Pit D***	***Pit E***
Soil Property	**Res.**[a]	**Proj.**[b]	**Res.**[a]	**Proj.**[b]	**Res.**[a]	**Proj.**[b]	***BCD***[c]	**Proj.**[b]
$\omega_{natural}$ (%)	≈ 9.4	--	≈ 13.4	--	≈ 11.0	--	≈ 11.1	≈ 18.6
$\omega_{air\text{-}dried}$ (%)	0.6 - 0.8	0.5	1.3 - 1.7	0.3	0.7 - 0.9	1.1	0.8	1.1
Plasticity Index	*NP*	*NP*	*NP*	*NP*	*NP*	9	*NP*	*NP*
% Pass 2 mm	99 - 100	100	100	100	98 - 100	100	100	100
% Pass 425 µm	77 - 83	66	95 - 96	97	89 - 93	95	98	100
% Pass 250 µm	57 - 64	41	61 - 65	62	53 - 59	67	71	80
% Pass 150 µm	24 - 27	--	25 - 29	--	30	--	--	--
% Pass 105 µm	21 - 22	--	22 - 26	--	27 - 28	--	--	--
% Pass 75 µm	19 - 21	14	21 - 25	11	26 - 29	40	19	16
G_s	2.65	2.66	2.65	2.66	2.65	2.67	--	2.65
Soluble SO_4 (%)	0.00	0.03	0.00	0.01	0.00	0.00	--	0.00
USCS	SM	SM	SM	SM	SM	SM	SM	SM
AASHTO Class.	A-2-4	A-2-4	A-2-4	A-2-4	A-2-4	A-4	A-2-4	A-2-4
MDOT Class.	*9C*	*9C*	*9C*	*9C*	*9C*	*9C*	*9C*	*9C*

Note: Three natural moisture contents, forty air-dried moisture contents, and 9 or 10 gradations were conducted for Pits A, B, and C for Res. samples.
a: Results from pit soil samples tested for the current research study.
b: Results from mix design performed by MDOT for the corresponding project.
c: Results from a mix design (MT-25) performed by BCD laboratory for the project (Station No. 219+00).

As shown in Table 4.1, soil properties for pit soils *A*, *B*, and *C* are similar to the results for each corresponding project. All of the soil samples were non-plastic (*NP*) with the exception of the project mix design for *Pit C* (*PI* = 9). *Pit A* and *B* have a slightly finer gradation than the project results, and *Pit C* has a noticeably coarser gradation than the corresponding project results.

Standard proctor tests were conducted in accordance with Mississippi Test Methods 8 and 9 (referred to as Protocol 1). Protocol 1 procedures for *MT-8* and *MT-9* are discussed in Sections 3.3.1 and 3.3.2. Results from standard raw and cement proctors for all pit soils are provided in Table 4.2. These proctor values were used as the target densities for all tested specimens. The project proctor values in Table 4.2 were only reported for comparison to proctor values determined for the sampled pit soils. Project proctor values were not used to determine target proctor densities for the current work with the exception of *Pit D* and *E*. Raw proctors (*MT-8*) were performed multiple times, and Table 4.2 gives the average values and denotes the number of replicates.

A decrease in maximum dry density (γ_d) with cement addition was observed for *Pit B*. This behavior is discussed in greater detail in Section 3.4.4. For this reason, a second protocol for cement proctors (*MT-9*) was implemented, and is referred to a Protocol 2. In Protocol 2, each proctor point was batched, mixed, and compacted separately. No material was reused, and each point was compacted within 7 minutes of cement addition. All cement proctors for *Pit B* were performed using Protocol 2.

Two single proctor point checks were conducted on one random cement content for *Pit A* and *Pit C* to evaluate the appropriateness of utilizing Protocol 1 procedures. All check points for *Pit A* and *Pit C* indicated Protocol 1 procedures were adequate for these soils. Additionally, a single proctor point check was performed on one random cement content from each pit soil to determine if proctor values changed when a different cement source was used (*GV* cement source). These check points indicated the γ_d and *OMC* did not drastically differ with the different cement source; therefore, the same proctor values were used for specimens prepared using the *GV* cement source.

Table 4.2 Pit Soil Standard Raw and Cement Proctor Results

Pit	C_I (%)	Type	Cement Type[1]	Protocol	γ_d (kg/m^3)	*OMC* (%)	*n*
A	0[2]	Res.	None	1	1860	11.6	2
	0	Proj.	None	1	1863	11.9	1
	2	Res.	*TH*	1	1906	11.6	1
	4	Res.	*TH*	1	1878	11.8	1
	5	Res.	*TH*	1	1919	11.8	1
	5[3]	Res.	*GV*	2	1909	11.7	1
	5	Proj.	Type I	1	1983	10.6	1
	6	Res.	*TH*	1	1910	11.8	1
	7	Res.	*TH*	1	1922	12.0	1
	8	Res.	*TH*	1	1942	11.2	1
	10	Res.	*TH*	1	1949	11.0	1
	4	Res.	*TH, GGBFS*	1	1891	11.5	1
	5	Res.	*TH, GGBFS*	1	1895	11.7	1
	6	Res.	*TH, GGBFS*	1	1938	11.2	1
	7	Res.	*TH, GGBFS*	1	1942	11.2	1
	8	Res.	*TH, GGBFS*	1	1950	10.9	1
B	0	Res.	None	1	1834	13.8	3
	0	Proj.	None	1	1725	15.5	1
	4	Res.	*TH*	2	1813	14.5	1
	5	Res.	*TH*	2	1812	14.0	1
	5[3]	Res.	*GV*	2	1814	13.8	1
	6	Res.	*TH*	2	1813	14.2	1
	6.5	Proj.	Type I	1	1810	15.2	1
C	0	Res.	None	1	1946	11.0	4
	0	Proj.	None	1	1963	11.3	1
	3	Res.	*TH*	1	1959	10.9	1
	4	Res.	*TH*	1	1935	11.4	1
	4[3]	Res.	*GV*	2	1937	11.5	1
	4	Proj.	Type I	1	1958	11.7	1
	5	Res.	*TH*	1	1975	11.0	1
D[4]	0	Proj.	None	1	1772	14.5	1
	7	Proj.	*NC*	1	1796	14.7	1
E	0	Proj.	None	1	1756	15.1	1
	7	Proj.	TH_{SR475}	1	1737	13.6	1

1: Refer to Tables 4.5 and 4.6 for Cement Type terminology.
2: One test was suspect and was not included to determine the average value.
3: Test result represents a single proctor check point, while all other results represent a full proctor curve.
4: Project target densities were based on daily one point proctor checks and not mix design values. Target density of 1796 kg/m^3 was used for this thesis.

Table 4.3 contains compressive strength results from *MT-25*. See Section 3.3.3 for procedures. A sample of pit soils *A*, *B*, and *C* was sent to *MDOT* Central Laboratory to conduct *MT-25*. For *Pit B* and *Pit C*, the test results were reasonable as compared to results from the corresponding projects. Therefore, 5 percent and 4 percent cement index was considered the design cement content for *Pit B* and *Pit C*, respectively. For *Pit A*, the results from *MDOT* Central Laboratory indicated a failure to reach strength criterion at 4, 5, and 6 percent cement indexes. Additional *MT-25* tests were conducted by *MSU* at 4, 5, 6, 7, and 8 percent cement indexes. These additional results indicated that the design cement index for *Pit A* was 5 percent which agreed with the results from the corresponding project. Also, *MT-25* was conducted on *Pit A* using a slag-cement blend (*TH* 25%, *GGBFS* 75%). Results indicated the design cement content for the slag-cement blend was 4 percent. Design cement indexes for *Pit D* and *E* were taken to be the same as the project mix design.

Table 4.3 Mississippi Test Method 25 Results

Pit	Cement Type	C_I (%)	7-Day σ_{max} (kPa)	14-Day σ_{max} (kPa)	Source[1]
A	Type I	5	1269	1517	*MDOT*
	TH	5[3]	2451[2]	2828[2]	*MSU*
	Type I	5	2710	2689	Proj.
	TH, GGBFS	4[3]	1560[2]	2477[2]	*MSU*
B	Type I	5[3]	2117	2448	*MDOT*
	Type I	6.5	2523	--	Proj.
C	Type I	4[3]	2372	3027	*MDOT*
	Type I	4	2613	3178	Proj.
D[4]	Type I	5	2275	2620	*BCD*
E	Type I	7[3]	2110	2648	Proj.

Note: Compressive strength criterion is 2070 kPa at or before 14-days.
1: MDOT = Results from MDOT Central Lab on Res. soils; MSU = Results from MSU Lab on Res. soils; Proj. = Results from MDOT Central Lab for the corresponding project mix design; BCD = Results from BCD lab for the corresponding project.
2: Average of two specimens.
3: Selected design cement index for the current study.
4: Cement Index of ≈ 7% was used on the SR9 project; therefore, 7% was also used to prepare laboratory specimens.

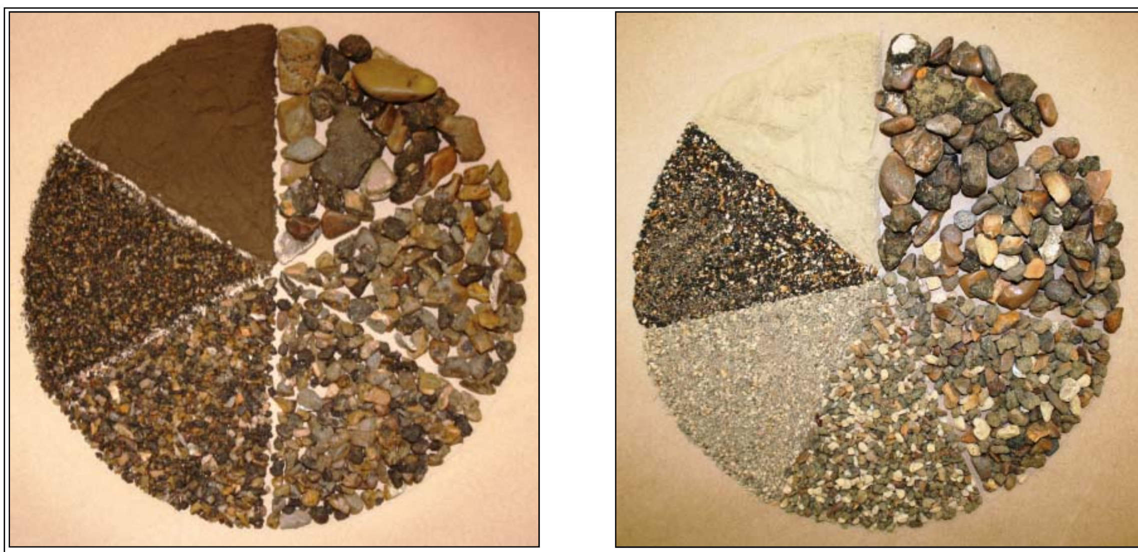
4.3.2 In-Place Recycled Materials

Two samples of in-place recycled material were taken from the full-depth reconstruction of US Hwy 49 in Madison County, MS (Table 4.4). The first sample (*HWY49-A*) consisted of reclaimed asphalt pavement (*RAP*). The second sample (*HWY49-B*) consisted of *RAP* and subgrade material. More details of these materials can be found in State Study 250. Figure 4.10 shows photos of the in-place recycled materials.

Table 4.4 Fundamental Properties of In-Place Recycled Materials

Property	***HWY49-A***	***HWY49-B***[1]
% Pass 9.50 mm	85	79
% Pass 4.75 mm	55	60
% Pass 2.38 mm	38	49
% Pass 75 µm	2	15
Untreated γ_d (kg/m^3)	1974	2054
Untreated *OMC* (%)	6.2	6.3
Design Cement Index (%)	5.5	6.0
Treated γ_d (kg/m^3)	1995	2045
Treated *OMC* (%)	5.9	6.3

1: Results shown are for the average gradation as defined in future works.



(a) *HWY49-A* (b) *HWY49-B*

Figure 4.10 In-Place Recycled Materials Tested (Post Processing)

4.3.3 Cementitious Materials

Five cementitious blends were used in this research: four *ASTM C 150* Type I portland cements and one Ground Granulated Blast Furnace Slag (*GGBFS*) blend (Tables 4.5 and 4.6). The majority of testing was performed with *TH* cement. The *GGBFS* met requirements for Grade 100 according to *ASTM C 989* and *AASHTO M-302*.

Table 4.5 Portland Cement Properties

Source[1]	***TH***	***GV***	***NC***[2]	$\boldsymbol{TH_{SR475}}$
SiO_2 (%)	19.9	20.0	--	19.9
Al_2O_3 (%)	4.7	4.5	--	4.8
Fe_2O_3 (%)	3.4	3.1	--	3.6
CaO (%)	64.5	64.2	--	64.0
MgO (%)	1.2	2.3	--	1.0
SO_3 (%)	3.7	3.2	--	3.5
C_3S (%)	60	62	--	61
C_2S (%)	11	9	--	11
C_3A (%)	7	6	--	7
C_4AF (%)	10	9	--	11
Limestone (%)	2.5	3.3	--	0.8
LOI (%)	2.2	2.7	--	1.4
Blaine (m^2/kg)	379	383	--	395
Initial Vicat (min.)	101	90	--	100
Air (%)	7	7	--	8
1-day strength (MPa)[3]	16	16	--	--
3-day strength (MPa)[3]	26	30	--	23
7-day strength (MPa)[3]	33	36	--	31
HoH, 7-day (kJ/kg)	353	344	--	328

1: TH = Holcim Cement Theodore, AL; GV = Holcim Cement Saint Genevieve, MO;
NC = National Cement (SR9 field cement); TH_{SR475} *= Holcim Cement Theodore, AL (SR475 field cement).*
2: Cement data for NC cement source was unavailable.
3: 1, 3 and 7 day compressive strengths according to ASTM C 109.

Table 4.6 Ground Granulated Blast Furnace Slag (*GGBFS*) Properties

Property	**Result**
Sulfide-S (%)	0.6
Sulfate Ion-SO_3 (%)	0.3
Blaine Fineness (m^2/kg)	582
Plus 45 um (No. 325) (%)	1
Air Content (%)	5
Activity Index (%), 7-day	88
Activity Index (%), 28-day	126
7-day strength (MPa)	25
28-day strength (MPa)	43

Note: GGBFS Source was Holcim Birmingham, AL.

4.4 Pit Soil Processing

Pit soils *A*, *B*, and *C* were sampled from a borrow pit using a backhoe or front-end loader that mixed the soil prior to loading into the trailer (Figure 4.9). Soil from *Pit A* was sampled below optimum moisture content while *Pit B* and *Pit C* were sampled near optimum moisture content. Pit soils *D* and *E* were sampled directly from the roadway just prior to soil-cement construction operations. Both soils *D* and *E* were sampled near optimum moisture content.

A detailed procedure was used to process all pit soils (Figure 4.11) to preserve the original raw material gradation. Each pit soil was sampled (and subsequently processed) entirely at one time. The following paragraphs describe each soil processing step.

Material was first spread onto tarps and allowed to air dry under fans until the soil reached a consistent moisture content (Figure 4.11a). While drying, the soil was stirred and thoroughly mixed. Stirring and mixing of the soil was implemented to speed up the drying process as well as provide uniformity throughout the entire sample. After drying, the soil was divided into several sections (Figure 4.11b). All of the material in each section was passed through a 4.75 mm sieve (Figure 4.11c). Material passing the 4.75 mm sieve was placed into a barrel, and material not passing the 4.75 mm sieve was placed into buckets for further processing (Figure 4.11d). Sections were processed one at a time to ensure that all of the material in each section remained in the same barrel with the exception of the plus 4.75 mm material.

(a) Air Drying of Soil

(b) Dividing Soil into Sections

(c) Portable Bin and 4.75 mm Sieve

(d) All Plus 4.75 mm Material

(e) Tamping of Plus 4.75 mm Material

(f) Soil after Processing

(g) Remixing Barrel of Soil

(h) Placing Soil into Buckets

Figure 4.11 Photos of Soil Processing (*Pit C* shown)

The plus 4.75 mm material consisted mostly of fine particles (i.e. silt and clay) which tended to cluster together in clumps. These large silt/clay clumps had a tendency to segregate during acquisition and initial handling of the raw material. Therefore, the research team decided to process the silt/clay clumps separately and equally distribute the fine material to each barrel at a later stage of processing. Each soil yielded approximately 14 buckets of silt/clay clumps that did not initially pass through the 4.75 mm sieve. The material was placed on a tarp and was lightly tamped until the material would pass through a 4.75 mm sieve (Figure 4.11e). The fine material was then redistributed equally to each barrel based on weight. The contents of each barrel were dumped, thoroughly remixed, and sealed in barrels for storage (Figure 4.11f). As the fully processed material was being placed into barrels, a sample was taken from the top, middle, and bottom of each barrel. This sample was taken to perform water content and gradation tests to ensure consistency among and between barrels. Seven barrels were available per pit soil *A*, *B*, and *C*.

Long term storage and subsequent batching from barrels poses the potential for segregation, particularly for soils with multiple particle sizes. For precaution, each barrel was emptied onto a tarp and remixed before batching test specimens (Figure 4.11g). To minimize the potential for segregation (especially during batching) the remixed soil was placed into 18.9 liter plastic buckets for temporary storage (Figure 4.11h). A barrel of soil typically yielded ten 18.9 liter buckets of material. Each bucket was labeled with the Pit ID (e.g. *A*, *B*, *C*, *D*, *E*), barrel number of origin, and a bucket number.

4.5 Batching, Mixing, and Material Conditioning

Batching operations were conducted in the same manner as *MDOT* common practice discussed in Chapter 3. Equations 3.13 through 3.18 (Section 3.4.3) were used to calculate the amount of soil, water, and cement required for each mixture. Batch water adjustments were required in order to achieve the appropriate optimum moisture content as measured by *MT-9*. Excess batch water is needed because some batch water is lost on mixing tools, to evaporation, and to cement hydration. An experiment was conducted to determine the amount of additional batch water needed to achieve the optimum moisture content as measured in *MT-9*. Test results show an additional 0.7 percent batch water was required to achieve the appropriate moisture content for all soils.

Mixing operations were conducted in a manner slightly different than common practice. Traditionally, soil-cement mixtures are mixed by hand, but many specifications state that a suitable mechanical mixing device is acceptable and often preferred. For this study, mixing was performed using a stationary mechanical bucket mixer for consistency (Figure 4.12a). A mixing paddle was used to mix the materials and a hand trowel was used to aid in mixing (Figure 4.12b). Mixing was performed in two stages. The first stage involved mixing of the soil and water, and the second stage entailed mixing the cement with the soil/water mixture (Figure 4.12c and 4.12d). In both stages, mixing was performed for two minutes which was determined to be an adequate amount of mixing time to ensure uniformity.

(a) Bucket Mixer (b) Mixing Tools (c) Mixing Soil and Water

(d) Mixing Cement (e) Preconditioning Materials

Figure 4.12 Mixing Equipment, Mixing Operations, and Material Conditioning

Preconditioning of materials was performed for all laboratory thermal profile specimens before cement addition (Figure 4.12e). The soil and water were mixed prior to conditioning. Initial material temperatures (T_i) of 10, 21 and 32 °C were investigated with the majority of testing occurring at 21 °C. For 10 °C tests, the materials were placed outside during cooler months to condition overnight. Outside temperatures were recorded and weather conditions were closely monitored to ensure materials did not freeze. Specimens conditioned to 21 °C were conditioned overnight in one of the environmental chambers. For 32 °C tests, materials were placed in a small room where the ambient temperature was regulated with multiple space heaters. The ambient temperatures were recorded and closely monitored during conditioning and testing. After conditioning, the soil/water mixture was remixed for 30 seconds and initial material temperature was recorded prior to cement addition and mixing. In almost every case, the thermal measurement device temperature (T_{BL}) was 21 °C during laboratory testing. The T_{BL} was varied in one case to investigate the effect of T_{BL} on thermal measurements.

4.6 Laboratory Specimen Preparation

Figure 4.13 illustrates specimen preparation with the laboratory compactor (*PM-CF*). All laboratory specimens were compacted within 20 minutes of cement addition. Data discussed in Section 3.4.4 and an additional investigation not presented herein suggest soil-cement specimens can be influenced by compaction delay, and 20 minutes appears to be a reasonable threshold for the pit soils tested in this study. All laboratory specimens were compacted between 98 and 101 percent of target γ_d and moisture contents were within 0.5 percent of target *OMC*. During specimen preparation, the number of blows (N_b) required to compact each specimen was recorded.

Prior to specimen preparation, the thermal measurement devices and software were configured. For this study, ThermoCal data logging software was utilized to record thermal profiles, but other logging software packages are also available. The ThermoCal software is very user friendly. Before each experiment, the thermal measurement equipment was calibrated. This was performed by allowing the equipment to equalize in a closed environmental chamber for at least 12 hours and running the sensor calibration routine in the ThermoCal software. The calibration reference temperature was taken as the average temperature reading from all sensors. This calibration procedure removed the slight temperature variation (±1 °C) among the thermocouple sensors.

(a) Measuring Each Lift (b) Compactor Hammer (c) Compactor Head at Height

(d) Scarifying Surface (e) Finish Compaction (f) Striking off Surface

(g) Inserting into Device (h) Starting Data Collection (software screenshot)

Figure 4.13 Laboratory Specimen Preparation with *PM-CF* Approach

After materials were batched, conditioned, and mixed with cement (Section 4.5), a moisture content sample was taken to verify mixture proportions. A single plastic mold was securely clamped into the compactor lower assembly and the collar was placed on top. Then each specimen was compacted in three equal lifts. Material for each lift was pre-batched using Equation 4.2. Equation 4.3 is a simplified form of Equation 4.2 where a single constant accounts for the mold volume, unit conversion, number of lifts, and 1 percent material increase.

$$W_{S-C} = \left(\frac{V \times \gamma_d \times 453.5924 \times \left(\frac{100 + OMC}{100} \right)}{3} \right) \times 1.01 \qquad \text{Eq 4.2}$$

$$W_{S-C} = 3.75 \times \gamma_d \times \left(\frac{100 + OMC}{100} \right) \qquad \text{Eq 4.3}$$

Where:

$W_{S\text{-}C}$ = Weight of soil-cement material per lift (g)

V = Volume of the plastic mold (ft^3)

γ_d = Maximum dry density of soil-cement mixture (lb/ft^3)

453.5924 = Unit conversion from pounds to grams

OMC = Optimum moisture content of soil-cement mixture (%)

3 = Division for the three separate lifts

1.01 = Increase amount of material to account for material left on compacting hammer

3.75 = Constant value for mold volume, units, lift division, and material increase

Material for each lift was placed into the mold (Figure 4.13a) and compacted to a prescribed height to replicate proctor density (Figure 4.13b and 4.13c). Before compaction of the second and third layers, the surface of the previous layer was scarified to produce a uniform specimen (Figure 4.13d). For this research, a scarifying tool was made to provide consistent scarification throughout the study. After compaction (Figure 4.13e), the top of the specimens was struck off level with the top of the plastic mold (Figure 4.13f), and the specimens were sealed and inserted into the thermal measurement device (Figure 4.13g). Data collection on any particular channel was started as soon as a specimen was inserted into the corresponding slot in the device (Figure 4.13h). The Channel ID notes the block and channel number for each specimen. Time zero for each specimen was taken to be the time when thermal data was first collected.

4.7 Field Application

Field work was conducted on State Route 9 near Tupelo, MS (*Pit D*) and State Route 475 in Rankin County, MS (*Pit E*). The primary goal of the field work was to investigate the feasibility and potential of utilizing thermal profile measurement techniques as a means of construction quality control. Three trials were conducted on each project with each trial conducted at a different location. In total, field testing including 78 specimens prepared with onsite materials (control mixed and field mixed), 36 field cores were cut, and 6 probes were used to measure in-situ temperature profiles at each trial location. All field specimens were prepared using the *PM-P* approach (Figure 4.4).

Each field trial included 8 thermal profile specimens utilizing one thermal measurement device. One specimen was an inert reference which consisted of the project soil compacted near optimum moisture content with no cement. Two control specimens were prepared at the design moisture and cement content. The control specimens consisted of premeasured soil, water, and cement which were mixed using the mechanical laboratory bucket mixer using Section 4.5 protocols. Five thermal profile specimens were prepared using field mixed materials. After final mixing operations were complete, samples were taken from the roadway before compaction operations began. Figure 4.14a shows the positions from which samples were taken. At each position, the full depth of freshly mixed soil-cement was sampled (Figure 4.14b) and mixed for 10 seconds with the mechanical bucket mixer. Two specimens were prepared using material sampled from Position 1; one specimen was prepared using material sampled from Position 2; and two specimens were prepared using material sampled from Position 3. Additionally, 6 specimens were compacted with material from Positions 4, 5, and left over material from other positions. These additional specimens were placed on the side of the roadway and were tested for compressive strength to assess early traffic opening assessment potential.

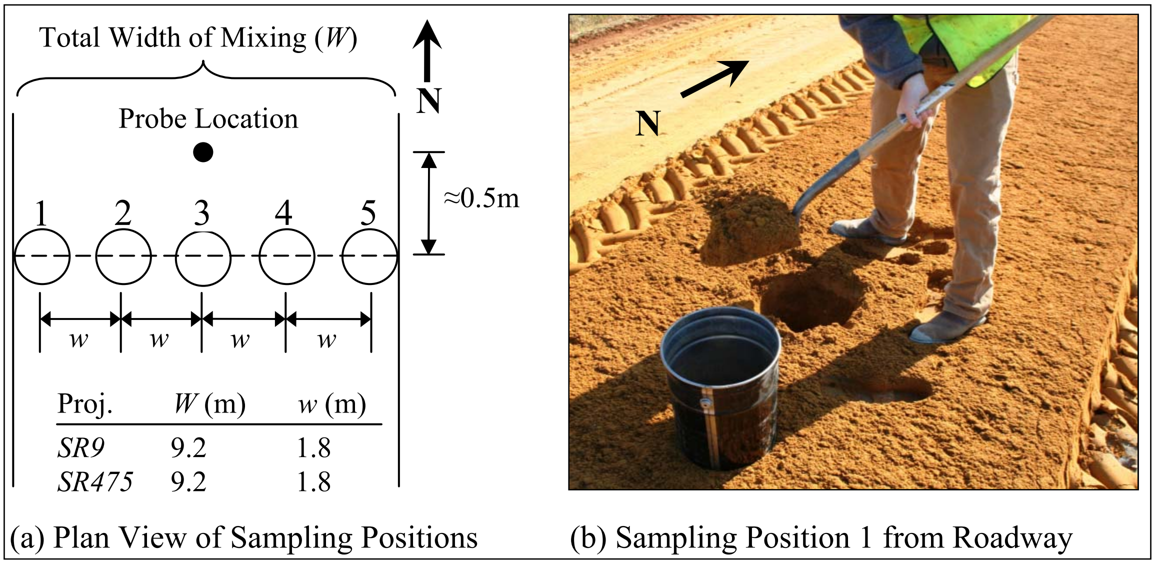


Figure 4.14 Field Sampling Positions and Sampling Field Mixed Soil-Cement

4.7.1 Field Specimen Preparation

In general, field thermal profile specimens were prepared in the same manner as laboratory specimens. Field specimens were compacted as quickly as possible after completion of field mixing operations, and timing between mixing and compaction was recorded for each specimen. Specimens were compacted in three pre-weighed lifts with the field compactor and modified proctor hammer. Equation 4.4 was used to calculate the appropriate amount of material for each lift. Equation 4.4 is the same as Equation 4.3, but the amount of material for each layer was increased to account for a larger amount of material left on the compaction hammer.

$$W_{S-C} = 3.8 \times \gamma_d \times \left(\frac{100 + OMC}{100} \right) \qquad \text{Eq 4.4}$$

Where:

$W_{S\text{-}C}$ = Weight of soil-cement material per lift (g)

3.8 = Constant value for mold volume, units, lift division, and material increase

γ_d = Maximum dry density of soil-cement mixture (lb/ft^3)

OMC = Optimum moisture content of soil-cement mixture (%)

Each lift was compacted with 5 blows with a 4.54 kg hammer dropping from a height of 45.7 cm (modified proctor hammer). This method of compaction produced specimens with densities between 92 and 100 percent of target max dry density (γ_d). Between lifts, the surface was scarified in the same manner as laboratory specimens. After compaction, the procedures were exactly the same as laboratory thermal profile specimens. The thermal measurement devices were kept in the back of an air-conditioned van during specimen preparation and transit. After preparation was complete, the devices were transported to the laboratory. Thermal profiles were measured for 24 hours, and thereafter the thermal profile specimens were cured inside the sealed plastic molds for the remaining cure time. After curing, specimens were extracted from the plastic molds and tested using the same protocols as laboratory specimens.

4.7.2 Specimen Density Correction

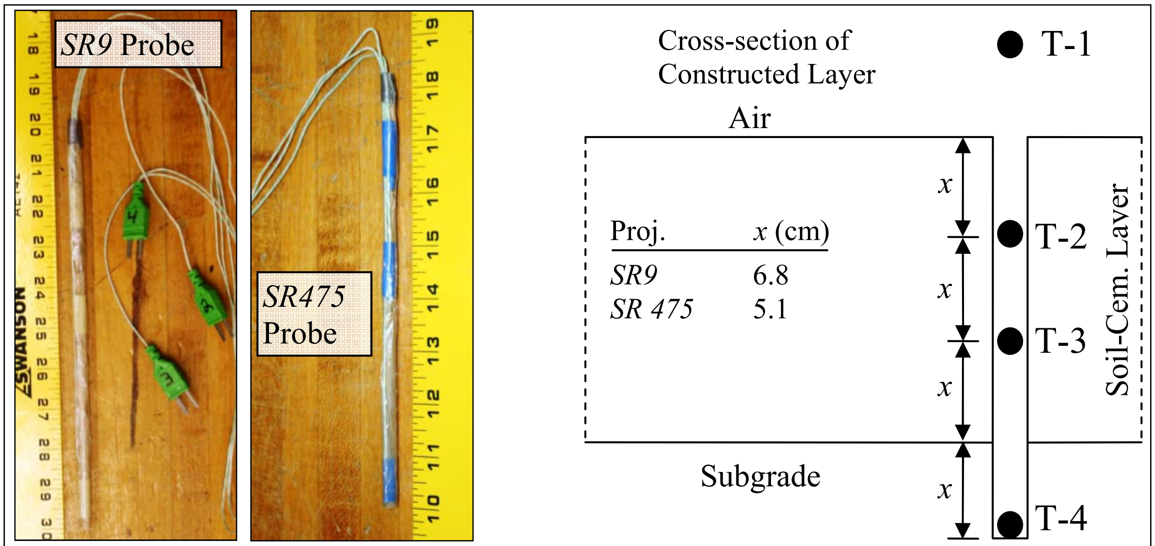
A few series of tests were conducted to evaluate the effect of specimen density on the compressive strength and thermal profiles of field prepared specimens. *Pit D* and *E* were batched, conditioned to 21 °C, and treated with the corresponding project cement and *TH* cement in accordance with Section 4.6. Specimens were compacted using the *PM-P* approach to densities varying from 90 to 105 percent of target γ_d by varying the number of hammer blows. Specimen thermal profiles were measured for 24 hours, and thereafter specimens were cured inside plastic molds. After 7 days, specimens were measured and tested according to Sections 4.8 and 4.9.

4.7.3 Specimen Time Delay Correction

A few series of tests were conducted to examine the effect of the time delay between cement addition and specimen preparation on the compressive strength and thermal profiles of field prepared specimens. *Pit D* and *E* were batched, conditioned, and treated with the corresponding project cement in accordance with Section 4.6. Specimens were compacted using the *PM-P* approach with 5 blows per layer. Specimen thermal profiles were measured for 24 hours; thereafter, specimens were cured inside the plastic molds. After 7 days of curing, specimens were measured and tested according to Sections 4.8 and 4.9.

4.7.4 In-Situ Temperature Measurement

Probes were used to measure the in-situ temperature of constructed soil-cement pavement layers. The probes were made from wooden dowel rods and thermocouples (Figure 4.15a). After final compaction and finishing operations, a 6.4 mm diameter hole was drilled into the constructed soil-cement layer. The thermocouple probe was inserted, and the top of the probe was sealed with Plaster of Paris. The internal probe was positioned on the centerline of the roadway approximately 0.5 m from sample Position 3 (Figure 4.15a). Temperature was recorded at three depths within the constructed pavement layer (Figure 4.15b points T-2, T-3, and T-4), and ambient air temperature was recorded above probe location (Figure 4.15b point T-1).

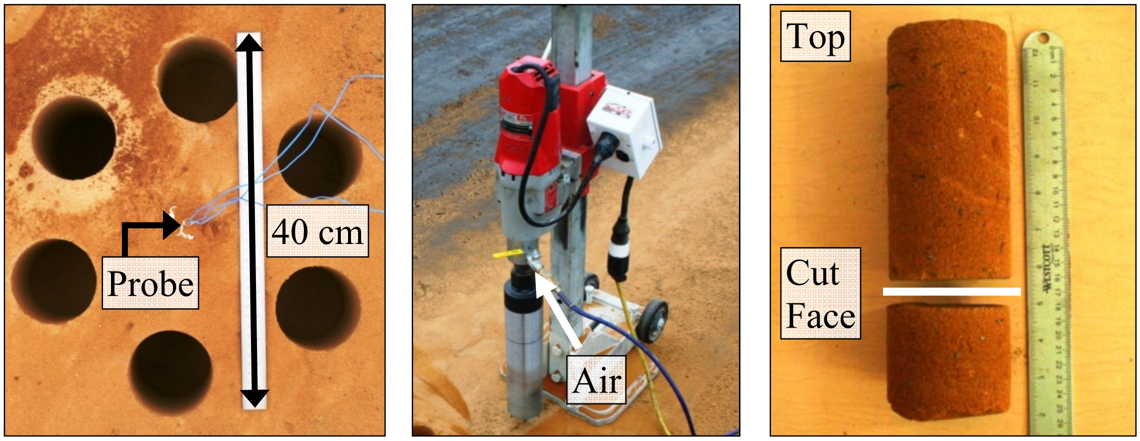


(a) Internal Thermocouple Probes (b) Internal Probe and Sensor Locations

Figure 4.15 Photos of In-Situ Probes and Probe Sensor Locations

4.7.5 Soil-Cement Cores

After curing 7 days, field cores were cut from the roadway. At each field trial location, six 78.8 mm diameter cores were cut around the location of the in-situ probe (Figure 4.16a). Field cores were cut using an ordinary wet-bit coring device where air pressure was used instead of water to remove cut material and cool the bit during cutting. The water attachment was replaced with an air hose attachment, and low pressure air was routed through the inside of the bit (Figure 4.16b). This method was effective for cutting soil-cement field cores at early cure times with minimal specimen damage. Field cores were sealed in plastic bags to preserve the in-situ moisture content. In the lab, cores were trimmed to the proper height using a dry cut saw (Figure 4.16c). Density measurements and strength testing were performed according to Sections 4.8 and 4.9.

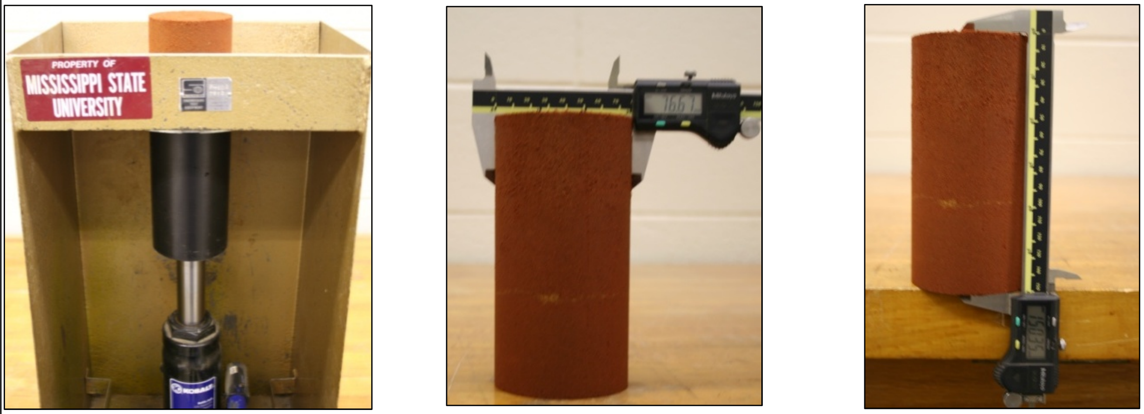


(a) Coring Pattern (b) Modified Coring Device (c) Trimmed Core Specimen

Figure 4.16 Soil-Cement Field Cores

4.8 Density Measurements

After plastic mold removal, specimen weight and dimensions were measured to determine specimen density (Figure 4.17). Typically, density measurements were performed after 24 hours of curing inside the sealed plastic molds. Field prepared and field core specimens were measured shortly prior to strength testing. The specimen diameter was taken to be the average of four diameter readings (two top and two bottom), and the specimen height was taken to be the average of four height readings.



(a) Specimen Extraction (b) Diameter Measurement (c) Height Measurement

Figure 4.17 Specimen Dimension Measurements

4.9 Compressive Strength Testing

After curing, Unconfined Compression (*UC*) testing was performed in accordance with *ASTM D 1633* Method B and *MT-26*. Note that soil-cement specimens in the current work were not soaked before testing as described in *ASTM D 1633* and *MT-26*, but the procedures for conducting *UC* tests were the same. Tested specimens had a height to diameter (*h*/*d*) ratio of 1.98:1. Typically, soil-cement specimens have a *h*/*d* ratio of 1.15 (101.6 mm diameter and 116.4 mm height). For this study, an approximate 2:1 *h*/*d* ratio was chosen to better interface thermal measurement and compressive strength testing. According to *ASTM D 1633*, 2:1 ratio compressive strengths can be adjusted to 1.15:1 ratio strengths by multiplying by 1.10.

UC testing (Figure 4.18) occurred immediately after removing from the moisture curing room or soon after removing from plastic molds. None of the soil-cement specimens tested required capping to meet smoothness requirements. Specimens were tested using a proving ring and spherically seated swiveling load head. Specimens were loaded at a constant rate of 1.27 mm/min, and max load was recorded to the nearest 40 N.

(a) Specimen Ready to Test (b) *UC* Specimen Before and After Testing

Figure 4.18 Unconfined Compression (*UC*) Testing

4.10 Specimens Tested

4.10.1 Laboratory Thermal Profile Specimens Tested

A total of 714 laboratory thermal profile specimens were tested (Series 1 to 34 and 47 to 49). Table 4.7 shows the test matrix for laboratory thermal profile specimens and gives a brief description of the analysis purpose. The number of replicate σ_{max} tests is also provided. A few specimens are used in multiple series of data (these specimens are noted in Appendix B).

Table 4.7 Laboratory Thermal Profile Test Matrix

Series	Soil	Compaction Type	Additive	T_i (°C)	T_{BL} (°C)	Target ω (%)	C_I (%)	Description	$t_{\sigma max}$ (day) 1	3	7	14
1	*A*	*PM-CF*	*TH*	≈ 21	≈ 21	Optimum	5	Profile Variability	--	--	30	--
2	*A*	*PM-CF*	*GV*	≈ 21	≈ 21	Optimum	5	Profile Variability	--	--	30	--
18	*A*	*PM-CF*	*TH, GGBFS*	≈ 21	≈ 21	Optimum	4	Profile Variability	--	--	30	--
3	*A*	*PM-CF*	*TH*	≈ 10	≈ 21	Optimum	2, 4, 6, 8, 10	Effect of Cement Content	--	--	15	--
22	*A*	*PM-CF*	*TH*	≈ 21	≈ 21	Optimum	2, 4, 6, 8, 10	Effect of Cement Content	--	--	15	--
23	*A*	*PM-CF*	*TH*	≈ 32	≈ 21	Optimum	2, 4, 6, 8, 10	Effect of Cement Content	--	--	15	--
4	*A*	*PM-CF*	*TH*	≈ 21	≈ 21	Opt. ± 2	4, 5, 6	Effect of Cement & Water	--	--	21	--
5	*A*	*PM-CF*	*TH*	≈ 10	≈ 21	Optimum	4, 5, 6	Effect of Initial Temperature	9	9	9	--
6	*A*	*PM-CF*	*TH*	≈ 21	≈ 21	Optimum	4, 5, 6	Profile Correlation to σ_{max}	9	9	9	--
7	*A*	*PM-CF*	*TH*	≈ 32	≈ 21	Optimum	4, 5, 6	Effect of Initial Temperature	9	9	9	--
49	*A*	*PM-CF*	*TH*	≈ 32	≈ 32	Optimum	5	Effect of T_i and T_{BL}	6	6	6	--
20	*A*	*PM-CF*	*TH, GGBFS*	≈ 10	≈ 21	Optimum	3, 4, 5	Effect of Initial Temperature	--	--	9	--
19	*A*	*PM-CF*	*TH, GGBFS*	≈ 21	≈ 21	Optimum	3, 4, 5	Profile Correlation to σ_{max}	--	9	9	9
21	*A*	*PM-CF*	*TH, GGBFS*	≈ 32	≈ 21	Optimum	3, 4, 5	Effect of Initial Temperature	--	--	9	--
8	*B*	*PM-CF*	*TH*	≈ 21	≈ 21	Optimum	5	Profile Variability	--	--	60	--
9	*B*	*PM-CF*	*GV*	≈ 21	≈ 21	Optimum	5	Profile Variability	--	--	30	--
10	*B*	*PM-CF*	*TH*	≈ 21	≈ 21	Optimum	4, 5, 6	Profile Correlation to σ_{max}	9	9	9	--
13	*C*	*PM-CF*	*TH*	≈ 21	≈ 21	Optimum	4	Profile Variability	--	--	30	--
14	*C*	*PM-CF*	*GV*	≈ 21	≈ 21	Optimum	4	Profile Variability	--	--	30	--
27	*C*	*PM-CF*	*TH*	≈ 21	≈ 21	Optimum	4	Equip. Configuration	--	--	30	--
15	*C*	*PM-CF*	*TH*	≈ 21	≈ 21	Optimum	3, 4, 5	Profile Correlation to σ_{max}	9	9	9	--
12	*Hwy49-A*	*PM-CF*	*GV*	≈ 10	≈ 21	Optimum	4.5, 5.5, 6.5	Concept Validation	--	--	9	--
16	*Hwy49-A*	*PM-CF*	*GV*	≈ 21	≈ 21	Optimum	4.5, 5.5, 6.5	Concept Validation	--	--	9	--
17	*Hwy49-A*	*PM-CF*	*GV*	≈ 32	≈ 21	Optimum	4.5, 5.5, 6.5	Concept Validation	--	--	9	--
24	*Hwy49-B*	*PM-CF*	*GV*	≈ 10	≈ 21	Optimum	5, 6, 7	Concept Validation	--	--	9	--
25	*Hwy49-B*	*PM-CF*	*GV*	≈ 21	≈ 21	Optimum	5, 6, 7	Concept Validation	--	--	9	--
26	*Hwy49-B*	*PM-CF*	*GV*	≈ 32	≈ 21	Optimum	5, 6, 7	Concept Validation	--	--	9	--
11	*D*	*PM-P*	*NC*	≈ 21	≈ 21	Optimum	6.9	Specimen Density Correction	--	--	22	--
28	*D*	*PM-P*	*TH*	≈ 21	≈ 21	Optimum	6.9	Specimen Density Correction	--	--	18	--
29	*E*	*PM-P*	TH_{SR475}	≈ 21	≈ 21	Optimum	7	Specimen Density Correction	--	--	18	--
30	*E*	*PM-P*	*TH*	≈ 21	≈ 21	Optimum	7	Specimen Density Correction	--	--	18	--
31	*D*	*PM-P*	*NC*	≈ 21	≈ 21	Optimum	6.9	Specimen Time Delay	--	--	8	--
32	*D*	*PM-P*	*NC*	≈ 32	≈ 21	Optimum	6.9	Specimen Time Delay	--	--	10	--
33	*E*	*PM-P*	TH_{SR475}	≈ 21	≈ 21	Optimum	7	Specimen Time Delay	--	--	10	--
34	*E*	*PM-P*	TH_{SR475}	≈ 32	≈ 21	Optimum	7	Specimen Time Delay	--	--	10	--
47	*D*	*PM-P*	*NC*	≈ 26	≈ 21	Optimum	4, 6, 8	C_I Comparison for Field Work	--	--	6	--
48	*E*	*PM-P*	TH_{SR475}	≈ 26	≈ 21	Optimum	4, 6, 8	C_I Comparison for Field Work	--	--	6	--

4.10.2 Field Specimens Tested

A total of 114 field specimens were prepared or cored from field mixed materials from two different soil-cement projects (Series 35 to 46). Molded specimens were prepared with the *PM-P* approach and field cores were sampled using methods described in Section 4.7.4. Table 4.8 shows the field work test matrix, which indicates the number of specimens from each testing location and lane position.

Table 4.8 Field Work Test Matrix

					Position						**Specimen**	**Total**	
Series	**Soil**	**Additive**	C_I **(%)**	**Location**	**C**	**1**	**2**	**3**	**4**	**5**	**Type**	**Number**	$t_{\sigma max}$ **(day)**
35	*D*	*NC*	7	1	2	2	3	2	2	2	Molded	13	7
36	*D*	*NC*	7	1	-	-	-	6	-	-	Core	6	7
37	*D*	*NC*	7	2	2	2	2	3	2	2	Molded	13	7
38	*D*	*NC*	7	2	-	-	-	6	-	-	Core	6	7
39	*D*	*NC*	7	3	2	2	2	3	2	2	Molded	13	7
40	*D*	*NC*	7	3	-	-	-	6	-	-	Core	6	7
41	*E*	TH_{SR475}	7	1	2	2	2	3	2	2	Molded	13	7
42	*E*	TH_{SR475}	7	1	-	-	-	6	-	-	Core	6	7
43	*E*	TH_{SR475}	7	2	2	2	2	3	2	2	Molded	13	7
44	*E*	TH_{SR475}	7	2	-	-	-	6	-	-	Core	6	7
45	*E*	TH_{SR475}	7	3	2	2	2	3	2	2	Molded	13	7
46	*E*	TH_{SR475}	7	3	-	-	-	6	-	-	Core	6	7

CHAPTER 5

ANALYSIS OF LABORATORY SPECIMENS

5.1 Overview of Laboratory Specimen Analysis

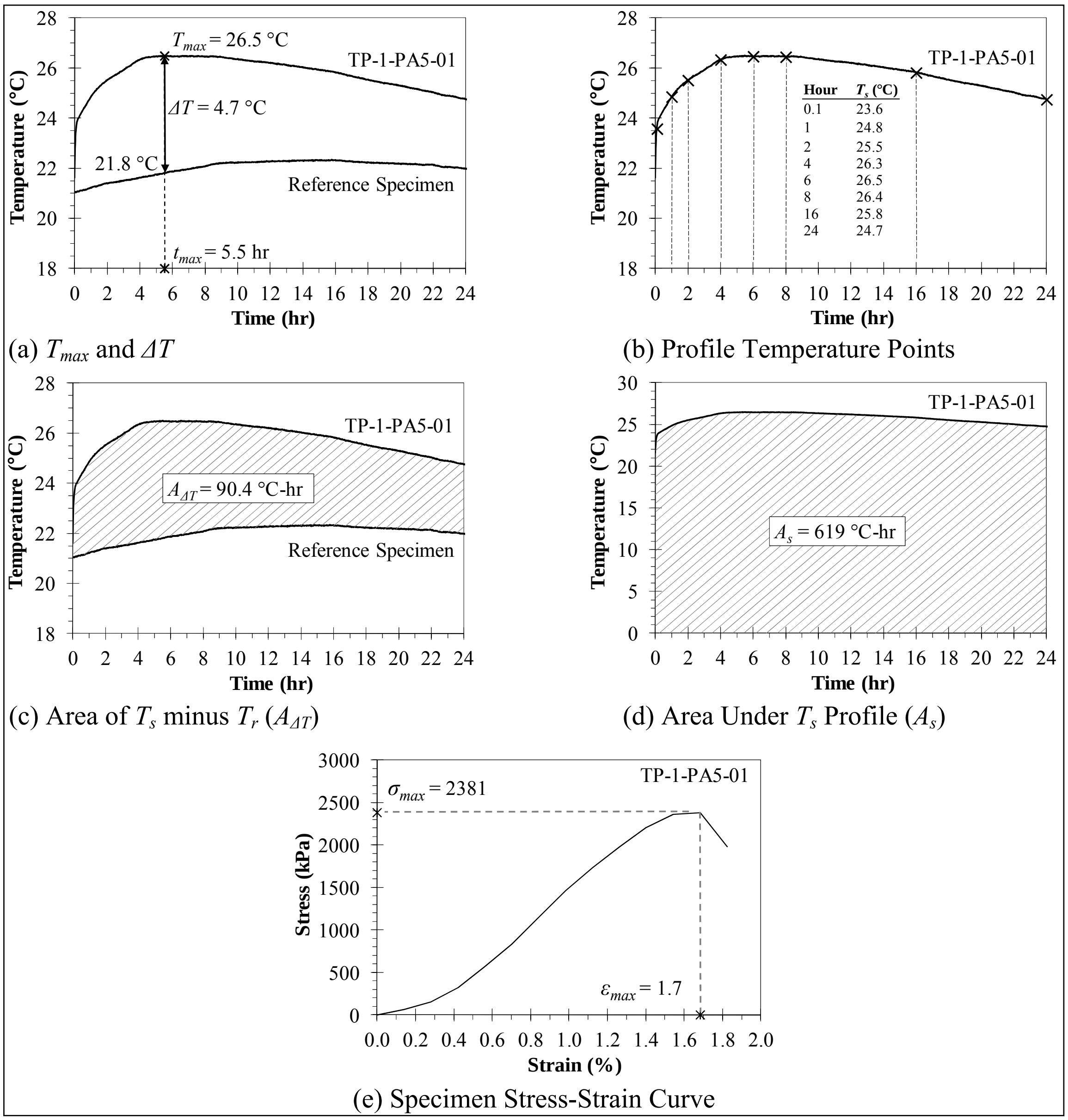
This chapter focuses on analysis of laboratory prepared specimens. Generally speaking, this chapter analyzes all 7 soils and all 5 cement blends tested. An exception is the field tests performed, which are analyzed in Chapter 6. A total of 688 laboratory prepared specimens were analyzed in this chapter, with raw data provided in Appendix B.

Before analysis, data outliers were identified for each data set using Tukey's Method, which distinguishes outliers by measuring the data's distance from the Inter Quartile Range (*IQR*). The *IQR* is the distance between the data set's 25th (Q_1) and 75th (Q_3) percentile. Data points falling outside the range of Q_1 - 1.5**IQR* and Q_3 + 1.5**IQR* were considered to be outliers and were not included in analysis. The number of outliers was denoted n_o.

5.2 Analysis Terminology

Seven variables were considered in analysis (Figure 5.1); five variables correspond to thermal profiles and two variables correspond to compressive strength. The example shown in Figure 5.1 represents the tested specimen given in the first row of Table B.1. For this thesis, the Nurse-Saul maturity function also known as the

Temperature-Time Factor (*TTF*) was used to express specimen maturity. Areas beneath or between thermal profile curves are considered to essentially be the same maturity approach as the Nurse-Saul maturity function or the *TTF*.



(a) T_{max} and ΔT
(b) Profile Temperature Points
(c) Area of T_s minus T_r ($A_{\Delta T}$)
(d) Area Under T_s Profile (A_s)
(e) Specimen Stress-Strain Curve

Figure 5.1 Analysis Terminology

5.3 Specimen Preparation Characteristics

The specimen preparation protocol (e.g. compaction in plastic molds) presented herein is a relatively new concept; therefore, an analysis was performed to examine the number of hammer blows (*PM-CF* approach) required to achieve a target density, and specimen volumes post compaction. 588 specimens compacted using the *PM-CF* approach were used to examine the number of hammer blows to reach a target density, and all 714 laboratory prepared specimens were used to analyze the post compaction specimen dimensions and specimen volumes.

5.3.1 Number of Hammer Blows

Pit soils (i.e. *A*, *B*, and *C*) and the in-place recycled material (i.e. *HWY49-A* and *B*) were compacted using the *PM-CF* approach. Relative frequency histograms were constructed of the blow count distribution (Table 5.1 summarizes the results). Variability in the blow counts per lift can be attributed to varying target densities for each mixture, but in general, the average blow counts were 10 to 13 per lift for the pit soils and 34 to 38 per lift for the in-place recycled material.

Table 5.1 Summary of *PM-CF* Blow Count Data

	Total	Blows per lift		
Soil	**Lifts**	**Mean**	***Stdev***	***COV* (%)**
Pit A	900	12.8	3.0	23.6
Pit B	351	12.1	1.9	15.7
Pit C	351	10.3	2.2	21.3
HWY49-A	81	34.0	13.8	40.5
HWY49-B	81	37.8	11.3	30.0

Note: Three lifts per specimen.

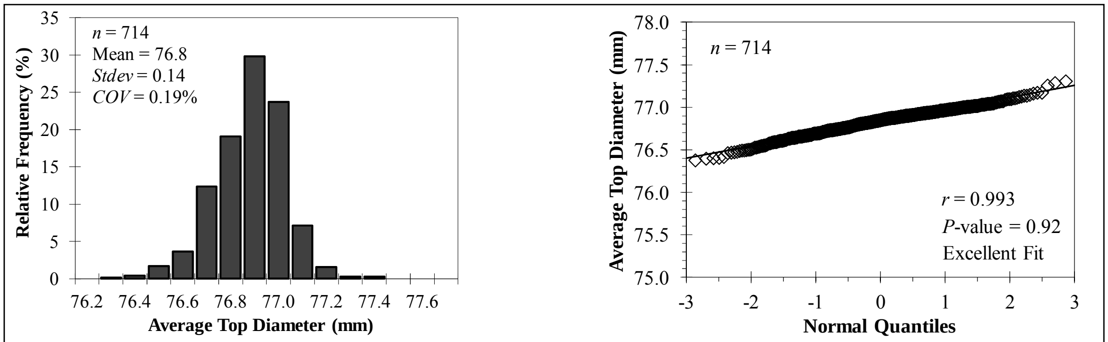
5.3.2 Specimen Dimensions

The plastic molds used to compact specimens may have slight variations with respect to dimensions that are allowed by *ASTM C 470*, and the plastic molds have the potential to deform during compaction. Specimen density measurements (described in Section 4.8) were used to evaluate the volumetric variability of specimens after compaction in the *PM* compactor assembly. This investigation encompassed all laboratory compacted specimens using both the *PM-CF* and *PM-P* compaction approaches.

Specimen dimensional measurements of interest include the average of two top diameter, average of two bottom diameter, overall average specimen diameter (average of top and bottom measurements), and the average height. From these measurements, the specimen *h/d* ratio and volume were calculated. Variability was evaluated by constructing relative frequency histograms and normality plots. Normality plots were analyzed using statistical methods developed by Filliben (1975) and presented in Ott and Longnecker (2010). This method uses the correlation coefficient (r) to estimate a P-value, which is used to assess the certainty that the data has a normal distribution (Table 5.2). Figure 5.2 shows an example of a relative frequency histogram and normality plot used to assess specimen volumetric variability, and Table 5.3 summarizes all results.

Table 5.2 Normal Distribution Assessment from Ott and Longnecker (2010)

***P*-Value**	**Assessment of Normality**
$P < 0.01$	Very Poor Fit
$0.01 \leq P < 0.05$	Poor Fit
$0.05 \leq P < 0.10$	Acceptable Fit
$0.10 \leq P < 0.50$	Good Fit
$P \geq 0.50$	Excellent Fit



(a) Example Histogram (b) Example Normality Plot

Figure 5.2 Examples of Constructed Histogram and Normality Plot

Table 5.3 Specimen Volumetric Variability

Variable	*n*	Mean	*Stdev*	*COV* (%)	*P*-value	Normality Fit
Avg. Top Diameter (mm)	714	76.8	0.14	0.19	0.92	Excellent
Avg. Bottom Diameter (mm)	714	76.4	0.19	0.25	0.98	Excellent
Overall Avg. Diameter (mm)	714	76.6	0.15	0.20	0.99	Excellent
Avg. Height (mm)	714	150.6	0.23	0.16	0.11	Good
h/d Ratio	714	1.97	0.005	0.24	0.99	Excellent
Percent of Expected Volume[1]	714	100.9	0.45	0.45	0.98	Excellent

1: The expected theoretical specimen volume is 687.8 cm^3 (diameter = 76.2 mm; height = 150.8 mm).

The Table 5.3 data demonstrates acceptable specimens can be compacted inside a plastic mold with the *PM* compactor assembly. The average overall diameter was 0.4 mm larger than the 76.2 mm target, and the specimen tapers 0.4 mm from the top to the bottom. A small taper is intuitive given the plastic molds are closed at the bottom and open at the top. Overall, the average specimen volume was 0.9% above the target and the *h/d* aspect ratio was 1.97. As per *ASTM C 470* requirements, no two specimen diameter measurements differ by more than 2 percent.

5.4 Compressive Strength and Thermal Measurement Variability

Variability of compressive strength and thermal measurement variables was evaluated using the same approach described in Section 5.3.2 using data from Series 1, 2, 8, 9, 13, 14, and 18.

5.4.1 Compressive Strength Variability

Variability of the *PM-CF* compaction approach was evaluated with compressive strength (σ_{max}) results. One outlier was identified in Series 1 and 2. After removing outliers, relative frequency histograms and normality plots were constructed (examples given in Figure 5.3). Table 5.4 contains variability results for all data sets.

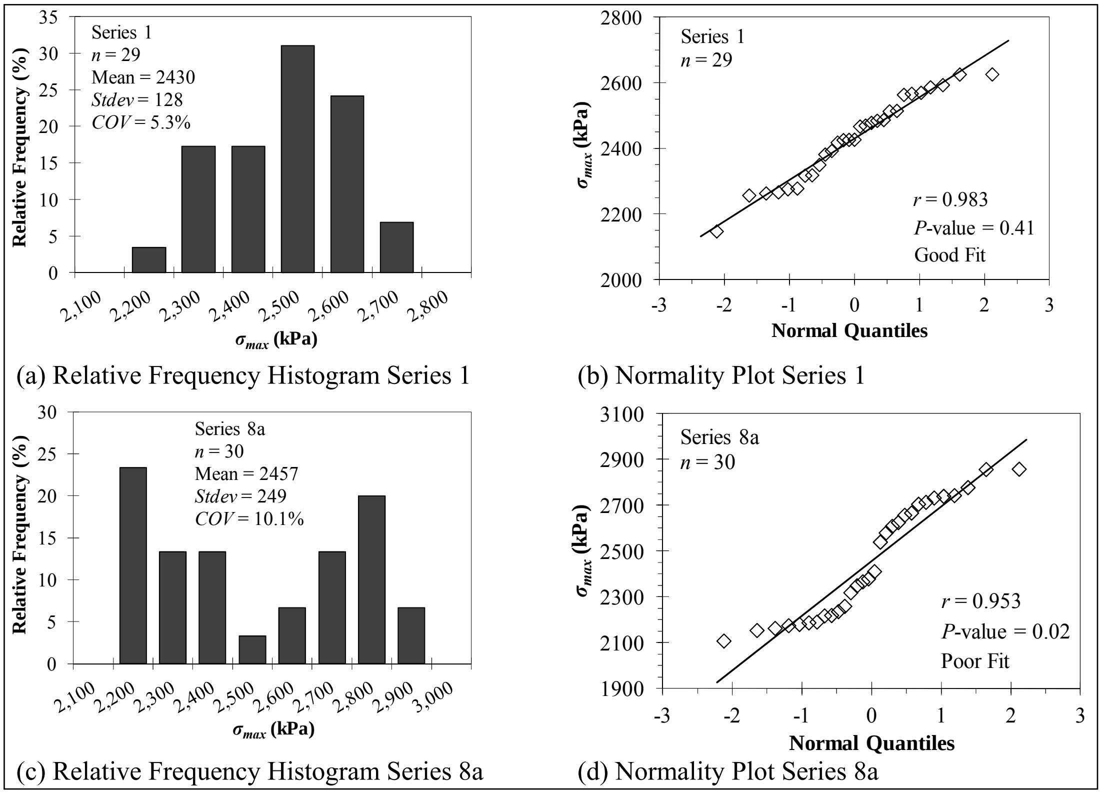


Figure 5.3 Examples of σ_{max} Histograms and Normality Plots

Table 5.4 Unconfined Compressive Strength (σ_{max}) Variability

Series	Pit	Cement Source	C_I (%)	n	n_o	$t_{\sigma max}$ (day)	Mean (kPa)	*Stdev* (kPa)	*COV* (%)	*P*-Value	Normality Fit
1	*A*	*TH*	5	29	1	7	2430	128	5.3	0.41	Good
2	*A*	*GV*	5	29	1	7	2317	95	4.1	0.44	Good
18	*A*	*TH,GGBFS*	4	30	0	7	1696	90	5.3	0.85	Excellent
8a	*B*	*TH*	5	30	0	7	2457	249	10.1	0.02	Poor
8b	*B*	*TH*	5	30	0	7	2672	255	9.5	0.03	Poor
9	*B*	*GV*	5	30	0	7	2831	200	7.1	0.26	Good
13	*C*	*TH*	4	30	0	7	3181	179	5.6	0.42	Good
14	*C*	*GV*	4	30	0	7	2668	297	11.1	0.41	Good

Notes: Data shown is after removal of mild outliers; and TH,GGBFS mixture (Series 18) achieves required 2070 kPa strength after 14 days, but tests were conducted at 7 days for direct comparison with other mixtures.

Pit A appeared to have the least σ_{max} variability, while *Pit B* appeared to have the most σ_{max} variability. *Pit B* treated with *TH* cement produced an average compressive strength of 2457 kPa with a *COV* of 10.1%. These results were suspect since they were more variable and not normally distributed. This series was repeated as a result. The repeated series produced an average compressive strength of 2672 kPa with a *COV* of 9.5%. These results were approximately 200 kPa greater than Series 8a data with approximately the same amount of variability. *Pit B* treated with *GV* cement produced an average compressive strength of 2831 kPa with a *COV* of 7.1%, and the data distribution was approximately normal. *Pit B* treated with *GV* cement appeared to reduce the amount of variability with respect to compressive strength. Overall, *Pit C* was less variable than *Pit B* and slightly more variable than *Pit A*. It appears that *Pit C* treated with *TH* cement is a little less variable than *Pit C* treated with *GV* cement. Both data sets were approximately normally distributed.

All σ_{max} *t*-tests were performed at a 0.05 level of significance (α) and were designed to investigate the statistical difference between cement sources (e.g. *TH* and

GV) with respect to mean compressive strength. All *t*-tests were performed assuming unequal variances with a two-tail approach, and Table 5.5 provides the results.

Table 5.5 Statistical *t*-test Results for σ_{max}

Term 1	μ_1 (kPa)	Term 2	μ_2 (kPa)	H_a	*df*	t_{crit}	t_{stat}	H_0 Conclusion
Pit A-TH (1)	2430	*Pit A-GV* (2)	2317	$\mu_1 \neq \mu_2$	52	2.01	3.83	Reject
Pit B-TH (8a)	2457	*Pit B-TH* (8b)	2672	$\mu_1 \neq \mu_2$	58	2.00	-3.32	Reject
Pit B-TH (8a)	2457	*Pit B-GV* (9)	2831	$\mu_1 \neq \mu_2$	55	2.00	-6.42	Reject
Pit B-TH (8b)	2672	*Pit B-GV* (9)	2831	$\mu_1 \neq \mu_2$	55	2.00	-2.69	Reject
Pit C-TH (13)	3181	*Pit C-GV* (14)	2668	$\mu_1 \neq \mu_2$	48	2.01	8.11	Reject

Notes: Series numbers are noted in parentheses; α = 0.05; H_0 was $\mu_1 = \mu_2$ for all t-tests; and unequal variances was assumed for all t-tests.

The *t*-test results showed cement source had a significant effect on the mean σ_{max} for all three soils. For *Pit A*, *TH* cement source produced a mean σ_{max} that was higher than specimens prepared with the *GV* cement source. As noted before, *Pit B* is more variable. Series 8a has a mean σ_{max} lower than Series 8b (both were treated with *TH* cement source). Compared to *GV* cement source, both data sets of *TH* cement source were determined to have lower mean σ_{max}. For *Pit C*, *TH* cement source produced a mean σ_{max} that was higher than specimens prepared with the *GV* cement source.

5.4.2 Thermal Measurement Variability

Tables 5.6 through 5.15 show the results from relative frequency histograms, normality plots, and statistical *t*-tests for the five thermal measurement variables in Figure 5.1. All *t*-tests were performed at α = 0.05 assuming unequal variances. Tables 5.6 and 5.7 show results for the recorded maximum temperature (T_{max}). The T_{max} measurement for all three soils stabilized with portland cement (i.e. *TH* and *GV*) was fairly consistent with mean values ranging from 25.7 to 27.2 °C and *COV*'s ranging from

1.1 to 3.5 %. *Pit A* stabilized with *GGBFS* recorded a lower mean T_{max} (22.9 °C) than portland cement mixtures, but the mixture was also less variable (*COV* = 0.8 %). *Pit B* appears to be slightly more variable than *Pits A* and *C* with respect to T_{max}. All soil and cement combinations, except for *Pit B* with *GV*, have a good to excellent normality fit.

Results from *t*-tests (Table 5.7) show no significant difference in mean T_{max} between cement sources for *Pit A* or one of the *Pit B* comparisons (Series 8b and Series 9). Results do show a significant difference in mean T_{max} for *Pit C* as well as one of the *Pit B* comparisons (Series 8a and Series 9). Also, there is a significant difference in mean T_{max} between the two Series 8 data sets.

Table 5.6 Thermal Profile Variability: T_{max}

Series	**Pit**	**Cement Source**	C_I **(%)**	n	n_o	**Mean (°C)**	***Stdev* (°C)**	***COV* (%)**	***P*-Value**	**Normality Fit**
1	*A*	*TH*	5	30	0	25.9	0.4	1.6	0.13	Good
2	*A*	*GV*	5	30	0	25.7	0.3	1.3	0.14	Good
18	*A*	*TH,GGBFS*	4	30	0	22.9	0.2	0.8	0.41	Good
8a	*B*	*TH*	5	30	0	27.2	0.5	1.9	0.37	Good
8b	*B*	*TH*	5	30	0	25.8	0.7	2.5	0.68	Excellent
9	*B*	*GV*	5	30	0	25.9	0.9	3.5	0.03	Poor
13	*C*	*TH*	4	30	0	26.6	0.4	1.6	0.87	Excellent
14	*C*	*GV*	4	30	0	25.7	0.3	1.1	0.72	Excellent

Table 5.7 Statistical *t*-test Results for Cement Source: T_{max}

Term 1	μ_1 **(°C)**	**Term 2**	μ_2 **(°C)**	H_a	df	t_{crit}	t_{stat}	H_0 **Conclusion**
Pit A-TH (1)	25.9	*Pit A-GV* (2)	25.7	$\mu_1 \neq \mu_2$	55	2.00	1.66	Accept
Pit B-TH (8a)	27.2	*Pit B-TH* (8b)	25.8	$\mu_1 \neq \mu_2$	55	2.00	9.50	Reject
Pit B-TH (8a)	27.2	*Pit B-GV* (9)	25.9	$\mu_1 \neq \mu_2$	46	2.01	7.10	Reject
Pit B-TH (8b)	25.8	*Pit B-GV* (9)	25.9	$\mu_1 \neq \mu_2$	53	2.01	-0.46	Accept
Pit C-TH (13)	26.6	*Pit C-GV* (14)	25.7	$\mu_1 \neq \mu_2$	52	2.01	9.47	Reject

Notes: Series numbers are noted in parentheses; α = 0.05; H_0 was $\mu_1 = \mu_2$ for all t-tests; and unequal variances was assumed for all t-tests.

Tables 5.8 and 5.9 contain results for the recorded change in temperature (ΔT) at the time T_{max} occurs. The mean ΔT range for portland cement mixtures (i.e. *TH* and *GV*) was 4.2 to 5.5 °C and the *COV*'s ranged from 7.0 to 13.3 percent. The mean ΔT for the *GGBFS* mixture was noticeably lower (2.0 °C) with a *COV* of 8.5 percent. *Pit B* was noticeably more variable than *Pits A* and *C* with respect to ΔT. All soil and cement combinations have a good to excellent normality fit. Table 5.9 shows *t*-test results which indicate a significant difference in mean ΔT between cement sources for all comparisons except for one *Pit B* comparison (Series 8b and 9).

Table 5.8 Thermal Profile Variability: ΔT

Series	Pit	Cement Source	C_I (%)	*n*	n_o	Mean (°C)	*Stdev* (°C)	*COV* (%)	*P*-Value	Normality Fit
1	*A*	*TH*	5	30	0	4.4	0.3	7.0	0.41	Good
2	*A*	*GV*	5	30	0	4.2	0.3	7.3	0.87	Excellent
18	*A*	*TH,GGBFS*	4	30	0	2.0	0.2	8.5	0.75	Excellent
8a	*B*	*TH*	5	30	0	5.5	0.4	6.7	0.62	Excellent
8b	*B*	*TH*	5	30	0	4.8	0.6	13.3	0.62	Excellent
9	*B*	*GV*	5	30	0	5.0	0.5	10.1	0.42	Good
13	*C*	*TH*	4	30	0	4.8	0.4	7.2	0.77	Excellent
14	*C*	*GV*	4	30	0	4.5	0.3	7.0	0.42	Good

Table 5.9 Statistical *t*-test Results for Cement Source: ΔT

Term 1	μ_1 (°C)	Term 2	μ_2 (°C)	H_a	*df*	t_{crit}	t_{stat}	H_0 Conclusion
Pit A-TH (1)	4.4	*Pit A-GV* (2)	4.2	$\mu_1 \neq \mu_2$	58	2.00	2.46	Reject
Pit B-TH (8a)	5.5	*Pit B-TH* (8b)	4.8	$\mu_1 \neq \mu_2$	47	2.01	5.75	Reject
Pit B-TH (8a)	5.5	*Pit B-GV* (9)	5.0	$\mu_1 \neq \mu_2$	53	2.01	5.06	Reject
Pit B-TH (8b)	4.8	*Pit B-GV* (9)	5.0	$\mu_1 \neq \mu_2$	55	2.00	-1.32	Accept
Pit C-TH (13)	4.8	*Pit C-GV* (14)	4.5	$\mu_1 \neq \mu_2$	57	2.00	3.93	Reject

Notes: Series numbers are noted in parentheses; $\alpha = 0.05$; H_0 was $\mu_1 = \mu_2$ for all t-tests; and unequal variances was assumed for all t-tests.

Tables 5.10 and 5.11 contain results for the recorded time (t_{max}) where T_{max} occurs. The t_{max} was noticeably more variable than other thermal profile variables. The mean t_{max} for portland cement mixtures ranged from 3.0 to 7.1 hours with *COV*'s ranging from 10.2 to 23.4 percent. The t_{max} for the *GGBFS* mixture was more variable than portland cement mixtures with a mean value of 3.4 hours and a *COV* of 30.4 percent. All soil and cement combinations have an acceptable to excellent normality fit. Results from *t*-tests (Table 5.11) show a significant difference in t_{max} between cement sources for all comparisons with exception of one *Pit B* comparison (Series 8b and 9).

Table 5.10 Thermal Profile Variability: t_{max}

Series	**Pit**	**Cement Source**	C_I **(%)**	n	n_o	**Mean (hr)**	***Stdev* (hr)**	***COV* (%)**	***P*-Value**	**Normality Fit**
1	*A*	*TH*	5	30	0	4.9	0.5	10.2	0.65	Excellent
2	*A*	*GV*	5	30	0	7.1	1.3	18.8	0.16	Good
18	*A*	*TH,GGBFS*	4	30	0	3.4	1.1	30.4	0.07	Acceptable
8a	*B*	*TH*	5	30	0	3.4	0.5	14.3	0.20	Good
8b	*B*	*TH*	5	30	0	4.0	0.9	23.4	0.10	Good
9	*B*	*GV*	5	30	0	4.4	1.0	22.8	0.05	Acceptable
13	*C*	*TH*	4	30	0	3.0	0.5	15.3	0.16	Good
14	*C*	*GV*	4	30	0	3.3	0.4	11.2	0.92	Excellent

Table 5.11 Statistical *t*-test Results for Cement Source: t_{max}

Term 1	μ_1 **(hr)**	**Term 2**	μ_2 **(hr)**	H_a	***df***	t_{crit}	t_{stat}	H_0 **Conclusion**
Pit A-TH (1)	4.9	*Pit A-GV* (2)	7.1	$\mu_1 \neq \mu_2$	37	2.03	-8.30	Reject
Pit B-TH (8a)	3.4	*Pit B-TH* (8b)	4.0	$\mu_1 \neq \mu_2$	44	2.02	-2.90	Reject
Pit B-TH (8a)	3.4	*Pit B-GV* (9)	4.4	$\mu_1 \neq \mu_2$	42	2.02	-4.80	Reject
Pit B-TH (8b)	4.0	*Pit B-GV* (9)	4.4	$\mu_1 \neq \mu_2$	58	2.00	-1.68	Accept
Pit C-TH (13)	3.0	*Pit C-GV* (14)	3.3	$\mu_1 \neq \mu_2$	56	2.00	-3.02	Reject

Notes: Series numbers are noted in parentheses; $\alpha = 0.05$; H_0 was $\mu_1 = \mu_2$ for all t-tests; and unequal variances was assumed for all t-tests.

Tables 5.12 and 5.13 show results for the recorded area beneath the thermal profile curve (A_s). The mean values of A_s for portland cement mixtures range from 585 to 616 °C-hr, and *COV*'s range from 0.9 to 2.8 percent. The mean value of A_s for the GGBFS mixture was lower than portland cement mixtures at 537 °C-hr with a *COV* of

0.6 percent. All soil and cement combinations have a good to excellent normality fit. Table 5.13 shows *t*-test results indicating no significant difference in mean A_s between cement sources for *Pit A* or one of the *Pit B* comparisons (Series 8b and Series 9). Although, *t*-test results indicate a significant difference in mean A_s between cement sources for the other *Pit B* comparisons and *Pit C* comparison.

Table 5.12 Thermal Profile Variability: A_s

Series	Pit	Cement Source	C_I (%)	*n*	n_o	Mean (°C-hr)	*Stdev* (°C-hr)	*COV* (%)	*P*-Value	Normality Fit
1	*A*	*TH*	5	30	0	602	9.1	1.5	0.77	Excellent
2	*A*	*GV*	5	30	0	601	7.8	1.3	0.33	Good
18	*A*	*TH,GGBFS*	4	30	0	537	3.5	0.6	0.87	Excellent
8a	*B*	*TH*	5	30	0	616	10.1	1.6	0.68	Excellent
8b	*B*	*TH*	5	30	0	591	11.7	2.0	0.75	Excellent
9	*B*	*GV*	5	30	0	594	16.6	2.8	0.15	Good
13	*C*	*TH*	4	30	0	602	8.6	1.4	0.33	Good
14	*C*	*GV*	4	30	0	585	5.4	0.9	0.42	Good

Table 5.13 Statistical *t*-test Results for Cement Source: A_s

Term 1	μ_1 (°C-hr)	Term 2	μ_2 (°C-hr)	H_a	*df*	t_{crit}	t_{stat}	H_0 Conclusion
Pit A-TH (1)	602	*Pit A-GV* (2)	601	$\mu_1 \neq \mu_2$	57	2.00	0.50	Accept
Pit B-TH (8a)	616	*Pit B-TH* (8b)	591	$\mu_1 \neq \mu_2$	57	2.00	8.61	Reject
Pit B-TH (8a)	616	*Pit B-GV* (9)	594	$\mu_1 \neq \mu_2$	48	2.01	6.01	Reject
Pit B-TH (8b)	591	*Pit B-GV* (9)	594	$\mu_1 \neq \mu_2$	52	2.01	-0.75	Accept
Pit C-TH (13)	602	*Pit C-GV* (14)	585	$\mu_1 \neq \mu_2$	49	2.01	8.96	Reject

Notes: Series numbers are noted in parentheses; α = 0.05; H_0 was $\mu_1 = \mu_2$ for all t-tests; and unequal variances was assumed for all t-tests.

Tables 5.14 and 5.15 provide results for the recorded area difference between the measured thermal profile and the reference specimen ($A_{\Delta T}$). The mean values of $A_{\Delta T}$ for portland cement mixtures ranged from 66.6 to 88.0, and *COV*'s range from 9.4 to 13.2 percent. The mean value of $A_{\Delta T}$ for the *GGBFS* mixture was lower at 31.4 °C-hr, and the *COV* was 9.9 percent. All soil and cement combinations have an acceptable to excellent normality fit. Results from *t*-tests (Table 5.15) show a significant difference in mean $A_{\Delta T}$ between the two *Pit B* data sets treated with *TH* cement (Series 8a and 8b), but all other comparisons were found to not be significantly different with respect to mean $A_{\Delta T}$.

Table 5.14 Thermal Profile Variability: $A_{\Delta T}$

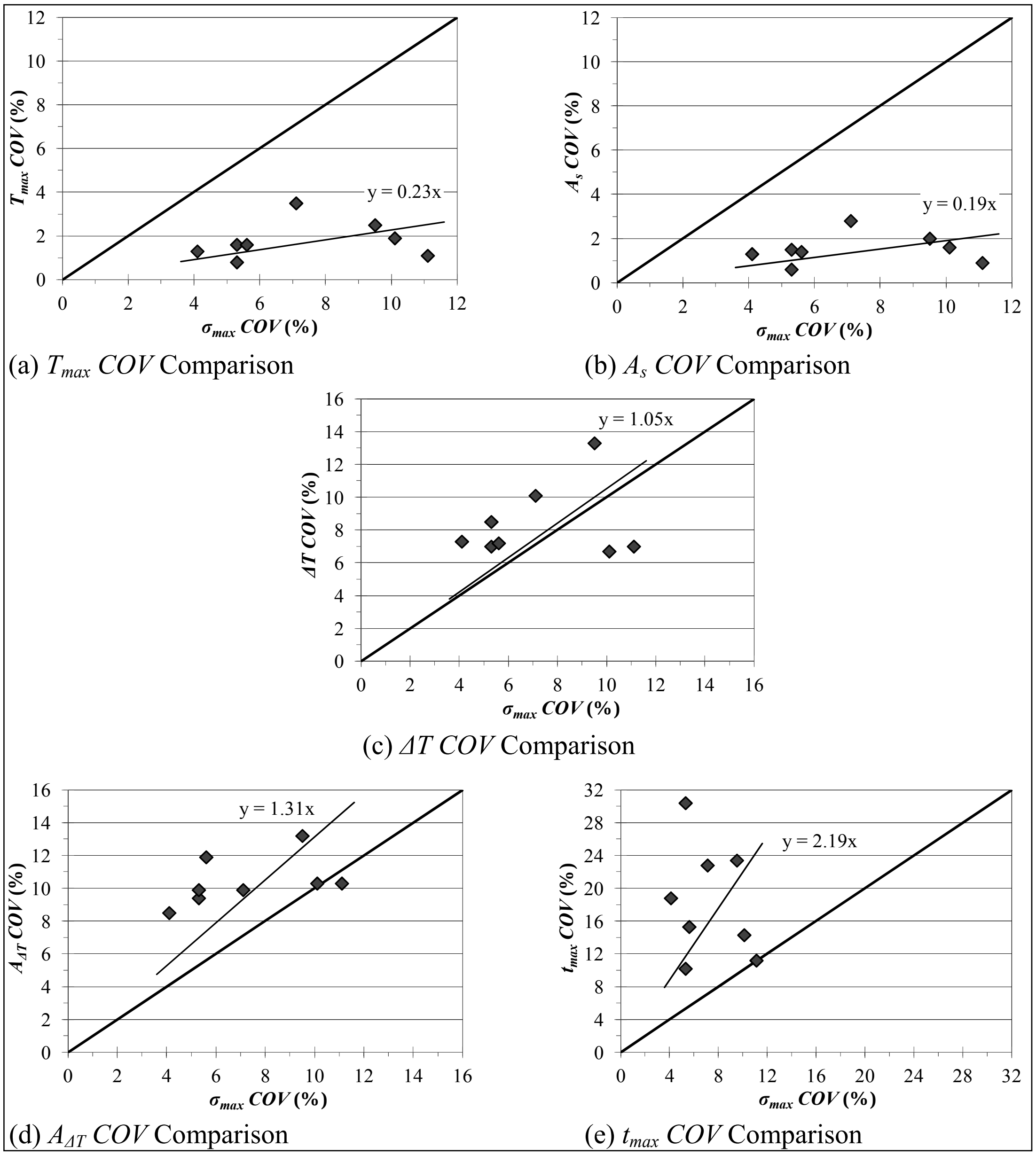
Series	Pit	Cement Source	C_I (%)	*n*	n_o	Mean (°C-hr)	*Stdev* (°C-hr)	*COV* (%)	*P*-Value	Normality Fit
1	*A*	*TH*	5	30	0	81.3	7.7	9.4	0.85	Excellent
2	*A*	*GV*	5	30	0	81.8	6.9	8.5	0.39	Good
18	*A*	*TH,GGBFS*	4	30	0	31.4	3.1	9.9	0.85	Excellent
8a	*B*	*TH*	5	30	0	88.0	9.0	10.3	0.80	Excellent
8b	*B*	*TH*	5	30	0	79.6	10.5	13.2	0.65	Excellent
9	*B*	*GV*	5	30	0	84.0	8.3	9.9	0.82	Excellent
13	*C*	*TH*	4	30	0	69.3	8.3	11.9	0.07	Acceptable
14	*C*	*GV*	4	30	0	66.6	6.9	10.3	0.39	Good

Table 5.15 Statistical *t*-test Results for Cement Source: $A_{\Delta T}$

Term 1	μ_1 (°C-hr)	Term 2	μ_2 (°C-hr)	H_a	*df*	t_{crit}	t_{stat}	H_0 Conclusion
Pit A-TH (1)	81.2	*Pit A-GV* (2)	81.8	$\mu_1 \neq \mu_2$	57	2.00	-0.30	Accept
Pit B-TH (8a)	88.0	*Pit B-TH* (8b)	79.6	$\mu_1 \neq \mu_2$	56	2.00	3.11	Reject
Pit B-TH (8a)	88.0	*Pit B-GV* (9)	84.0	$\mu_1 \neq \mu_2$	58	2.00	1.77	Accept
Pit B-TH (8b)	79.6	*Pit B-GV* (9)	84.0	$\mu_1 \neq \mu_2$	55	2.00	-1.82	Accept
Pit C-TH (13)	69.3	*Pit C-GV* (14)	66.6	$\mu_1 \neq \mu_2$	56	2.00	1.42	Accept

Notes: Series numbers are noted in parentheses; $\alpha = 0.05$; H_0 was $\mu_1 = \mu_2$ for all t-tests; and unequal variances was assumed for all t-tests.

Figure 5.4 presents equality plots comparing the *COV*'s of thermal measurement variables to those of compressive strength. Both T_{max} and A_s values demonstrate lower variability when compared to compressive strength. T_{max} and A_s (Figure 5.4a and 5.4b) have slopes of 0.23 and 0.19 which means that, generally speaking, variability was on the order of 20% that of compressive strength. ΔT (Figure 5.4c) had approximately the same amount of variability as compressive strength. $A_{\Delta T}$ and t_{max} both appear to have more variability than compressive strength with slopes of 2.19 and 1.31, respectively. Based on the variability analysis in this section, the thermal profile variables T_{max}, A_s, and ΔT were selected for further analysis in the following sections in this chapter.



(a) T_{max} *COV* Comparison

(b) A_s *COV* Comparison

(c) ΔT *COV* Comparison

(d) $A_{\Delta T}$ *COV* Comparison

(e) t_{max} *COV* Comparison

Figure 5.4 Variability Comparisons of Measured Variables

5.5 Effects of Equipment Configuration

An experiment was conducted to evaluate: 1) the effects of using different insulation for the thermal measurement device; and 2) the effects of using different sensor types. The thermal measurement device constructed with *XLPE* foam and different sensors is identified as Block C or *XLPE* device. The dimensions and fabrication are the same as discussed in Section 4.2.3. Each slot within Block C contained a thermocouple (*TC*) and a thermistor (*TM*) sensor without an attached metal washer. Thirty tests were conducted on *Pit C* treated with *TH* cement (Series 27). Series 27 testing was compared to Series 13 which tested the same mixture with the *EPS* devices (i.e. Blocks A and B). Table 5.16 contains a summary of the results from Series 27 and Series 13.

Table 5.16 Variability Comparison of *XLPE* device and *EPS* devices

Variable	Series[1]	Sensor Type	C_I (%)	n	n_o	Mean	*Stdev*	*COV* (%)	*P*-Value	Normality Fit
σ_{max}	27	*TC*	4	28	2	3215	153	4.8	0.14	Good
σ_{max}	27	*TM*	4	28	2	3215	153	4.8	0.14	Good
σ_{max}	13	*TC* with washer	4	30	0	3181	179	5.6	0.42	Good
T_{max}	27	*TC*	4	30	0	24.8	0.5	1.8	0.77	Excellent
T_{max}	27	*TM*	4	30	0	24.4	0.4	1.7	0.82	Excellent
T_{max}	13	*TC* with washer	4	30	0	26.6	0.4	1.6	0.87	Excellent
ΔT	27	*TC*	4	29	1	4.1	0.3	7.8	0.41	Good
ΔT	27	*TM*	4	29	1	4.0	0.3	6.4	0.92	Excellent
ΔT	13	*TC* with washer	4	30	0	4.8	0.4	7.2	0.77	Excellent
t_{max}	27	*TC*	4	30	0	3.4	0.8	22.6	0.17	Good
t_{max}	27	*TM*	4	29	1	3.1	0.4	12.8	0.54	Excellent
t_{max}	13	*TC* with washer	4	30	0	3.0	0.5	15.3	0.16	Good
A_s	27	*TC*	4	30	0	571	9.3	1.6	0.75	Excellent
A_s	27	*TM*	4	30	0	563	9.0	1.6	0.84	Excellent
A_s	13	*TC* with washer	4	30	0	602	8.6	1.4	0.33	Good
$A_{\Delta T}$	27	*TC*	4	30	0	62.7	6.2	9.9	0.82	Excellent
$A_{\Delta T}$	27	*TM*	4	30	0	60.4	6.6	10.9	0.17	Good
$A_{\Delta T}$	13	*TC* with washer	4	30	0	69.3	8.3	11.9	0.07	Acceptable

Notes: All test specimens are Pit C treated with TH cement source; and results reflect values after outlier removal.
1: Series 27 was tested using XLPE device (i.e. Block C) which has an $R_{SI} \approx 0.564$*, and Series 13 was tested using EPS devices (i.e. Blocks A and B) which have an* $R_{SI} = 0.775$*.*

The variability and data distribution of the measured results was about the same between both types of devices, but the *XLPE* device (Block C) produced slightly different results when compared to the *EPS* devices (Blocks A and B). The *XLPE* device measured a lower T_{max} (≈ 2 °C less), a lower ΔT (≈ 0.7 °C less), a lower A_s (≈ 35 °C-hr less), a lower $A_{\Delta T}$ (≈ 6 °C-hr less), and slightly higher t_{max} (≈ 0.3 hour higher) when compared to *EPS* devices. These differences in measured thermal profiles are likely due to the decreased amount of insulation provided by the *XLPE* block. In general, thermocouple (*TC*) and thermistor (*TM*) sensors have the same amount of variability, but *TM* sensors tended to record slightly lower temperatures than *TC* sensors. Table 5.17 contains results from *t*-tests performed to evaluate if there is a significant difference between *TC* and *TM* sensors. Table 5.17 shows there are significant differences in mean values of T_{max} and A_s between thermocouple (*TC*) and thermistor (*TM*) sensors.

Table 5.17 Statistical *t*-test Results for *XLPE* device Analysis (Series 27)

Term 1	μ_1	Term 2	μ_2	H_a	*df*	t_{crit}	t_{stat}	H_0 Conclusion
T_{max} (*TC*)	24.8	T_{max} (*TM*)	24.4	$\mu_1 \neq \mu_2$	57	2.00	3.81	Reject
ΔT (*TC*)	4.1	ΔT (*TM*)	4.0	$\mu_1 \neq \mu_2$	53	2.01	1.50	Accept
t_{max} (*TC*)	3.4	t_{max} (*TM*)	3.1	$\mu_1 \neq \mu_2$	50	2.01	1.45	Accept
A_s (*TC*)	571	A_s (*TM*)	563	$\mu_1 \neq \mu_2$	58	2.00	3.62	Reject
$A_{\Delta T}$ (*TC*)	62.7	$A_{\Delta T}$ (*TM*)	60.4	$\mu_1 \neq \mu_2$	58	2.00	1.39	Accept

Notes: Sensor type is noted in parentheses; α = 0.05; H_0 was $\mu_1 = \mu_2$ for all t-tests; and unequal variances was assumed for all t-tests.

5.6 Effect of Initial Material Temperature on Thermal Profiles

Series 5, 6, 7, 12, 16, 17, 19, 20, 21, 24, 25, and 26 were designed to investigate the effects of initial material temperature (T_i) on the measured thermal profiles at varying cement contents. Before testing, materials were preconditioned as described in Section

4.5, and the thermal measurement block was kept at a constant 21 °C during testing. The effects of T_i were evaluated by plotting T_i on the x-axis, plotting T_{max}, ΔT, and A_s on the y-axis, and fitting a linear trendline. For brevity, Table 5.18 shows all of the linear trendline equations and R^2 values for the plotted data. Overall, R^2 values for trendline equations ranged from 0.78 to 0.99, with exception to ΔT for *HWY49-A*. For *Pit A*, the slope of the trendline equation for T_{max} correlation to T_i was approximately 0.40; the slope for ΔT correlation was approximately 0.13; and the slope for A_s correlation was approximately 9.8 to 12.0. For the in-place recycled material, the slope for T_{max} correlation to T_i was approximately 0.32 to 0.38, and the slope for A_s correlation was approximately 10.0 to 12.2. The in-place recycled material ΔT results are unclear.

As shown in Table 5.18, the initial material temperature (T_i) has a considerable effect on T_{max}, ΔT, and A_s values. Almost all trendlines have high R^2 values except for the *HWY49-A* ΔT plots. Upon closer examination of the measured thermal profiles, it was clear that not only is T_i having a major effect on the thermal measurement results but also the initial temperature of the devices (T_{BL}) is having a large effect on the results. Both the cold T_i (≈10 °C) and hot T_i (≈32 °C) tests were affected by the T_{BL} temperature, which was 21 °C in every case. For the cold T_i tests, the T_{BL} contributed to hydration heat from the specimens, thus masked some of the heat generation. For the hot T_i tests, the T_{BL} cooled off the hydrating specimens, thus reducing the measured temperatures. The high R^2 values noted in Table 5.18, as well as data collected in Sections 5.7 and 5.10, could be misleading because the contributions of T_{BL} to the cold and hot tests were consistent for every test. To gain a better understanding of the effects of T_{BL} on the thermal profiles, and experiment was conducted which varied the T_{BL} during thermal measurement testing. Data was taken from Series 7 and 49. Figure 5.5 shows the effects of T_{BL} for specimens with $T_i \approx 32$ °C.

Table 5.18 Summary of Effects of Initial Material Temperature (T_i)

Soil	**Cement**	C_I **(%)**	***n***	**Trendline Equation**	R^2
Pit A	*TH*	4	27	$T_{max} = 0.40T_i + 17.74$	0.96
Pit A	*TH*	5	27	$T_{max} = 0.39T_i + 18.55$	0.96
Pit A	*TH*	6	27	$T_{max} = 0.40T_i + 19.24$	0.92
Pit A	*TH,GGBFS*	3	15	$T_{max} = 0.42T_i + 14.34$	0.84
Pit A	*TH,GGBFS*	4	15	$T_{max} = 0.39T_i + 15.57$	0.83
Pit A	*TH,GGBFS*	5	15	$T_{max} = 0.43T_i + 15.02$	0.86
HWY49-A	*GV*	4.5	9	$T_{max} = 0.33T_i + 19.31$	0.99
HWY49-A	*GV*	5.5	9	$T_{max} = 0.34T_i + 19.91$	0.99
HWY49-A	*GV*	6.5	9	$T_{max} = 0.32T_i + 20.81$	0.98
HWY49-B	*GV*	5	9	$T_{max} = 0.37T_i + 18.79$	0.94
HWY49-B	*GV*	6	9	$T_{max} = 0.38T_i + 19.26$	0.96
HWY49-B	*GV*	7	9	$T_{max} = 0.36T_i + 19.82$	0.95
Pit A	*TH*	4	27	$\Delta T = 0.15T_i + 0.19$	0.78
Pit A	*TH*	5	27	$\Delta T = 0.16T_i + 0.66$	0.87
Pit A	*TH*	6	27	$\Delta T = 0.13T_i + 1.65$	0.84
Pit A	*TH,GGBFS*	3	15	$\Delta T = 0.12T_i - 1.49$	0.97
Pit A	*TH,GGBFS*	4	15	$\Delta T = 0.11T_i - 0.68$	0.89
Pit A	*TH,GGBFS*	5	15	$\Delta T = 0.09T_i - 0.03$	0.78
HWY49-A	*GV*	4.5	9	$\Delta T = -0.02T_i + 2.83$	0.02
HWY49-A	*GV*	5.5	9	$\Delta T = 0.05T_i + 2.68$	0.33
HWY49-A	*GV*	6.5	9	$\Delta T = -0.06T_i + 4.34$	0.07
HWY49-B	*GV*	5	9	$\Delta T = 0.37T_i + 18.79$	0.94
HWY49-B	*GV*	6	9	$\Delta T = 0.38T_i + 19.26$	0.96
HWY49-B	*GV*	7	9	$\Delta T = 0.36T_i + 19.82$	0.95
Pit A	*TH*	4	27	$A_s = 11.89T_i + 321$	0.99
Pit A	*TH*	5	27	$A_s = 12.00T_i + 338$	0.99
Pit A	*TH*	6	27	$A_s = 11.36T_i + 367$	0.97
Pit A	*TH,GGBFS*	3	15	$A_s = 10.70T_i + 287$	0.98
Pit A	*TH,GGBFS*	4	15	$A_s = 10.40T_i + 308$	0.97
Pit A	*TH,GGBFS*	5	15	$A_s = 9.78T_i + 327$	0.99
HWY49-A	*GV*	4.5	9	$A_s = 11.58T_i + 322$	0.95
HWY49-A	*GV*	5.5	9	$A_s = 12.17T_i + 320$	0.95
HWY49-A	*GV*	6.5	9	$A_s = 11.55T_i + 346$	0.96
HWY49-B	*GV*	5	9	$A_s = 10.55T_i + 352$	0.99
HWY49-B	*GV*	6	9	$A_s = 11.07T_i + 357$	0.99
HWY49-B	*GV*	7	9	$A_s = 10.05T_i + 380$	0.99

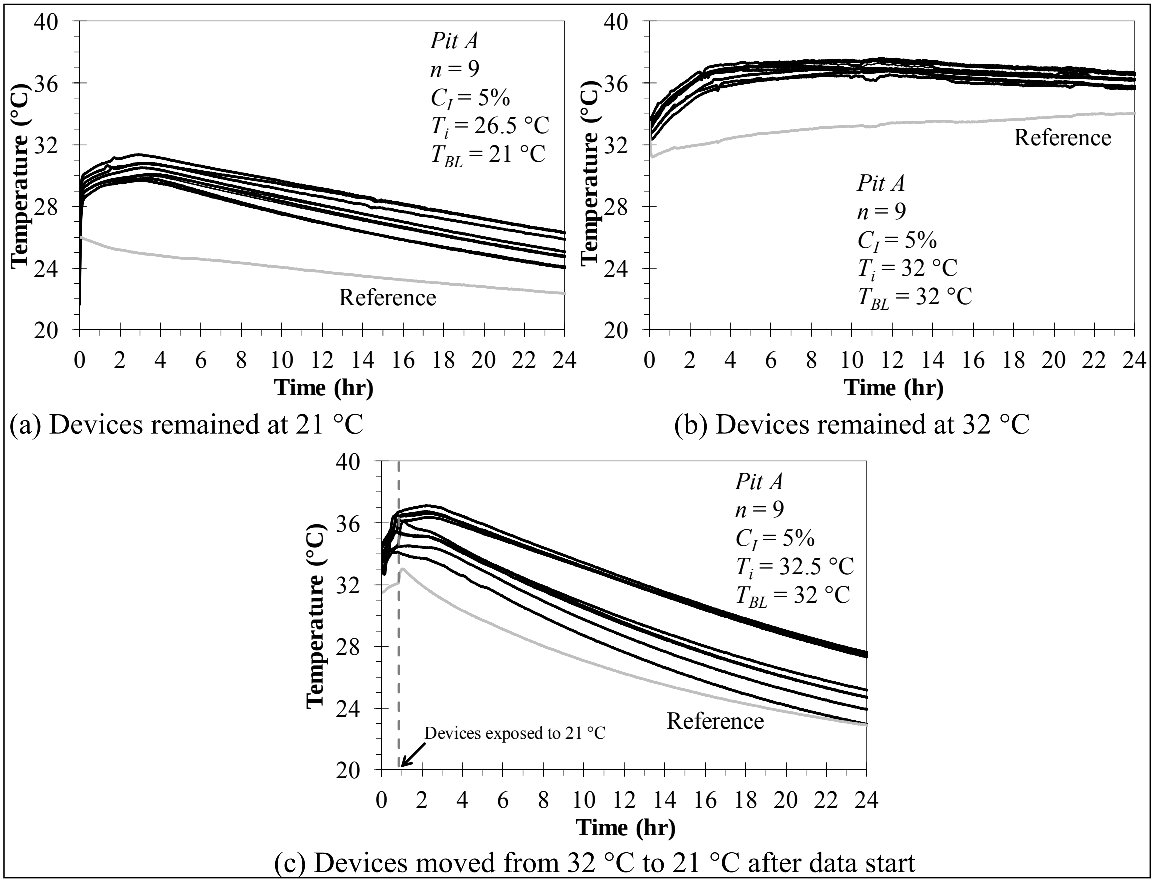


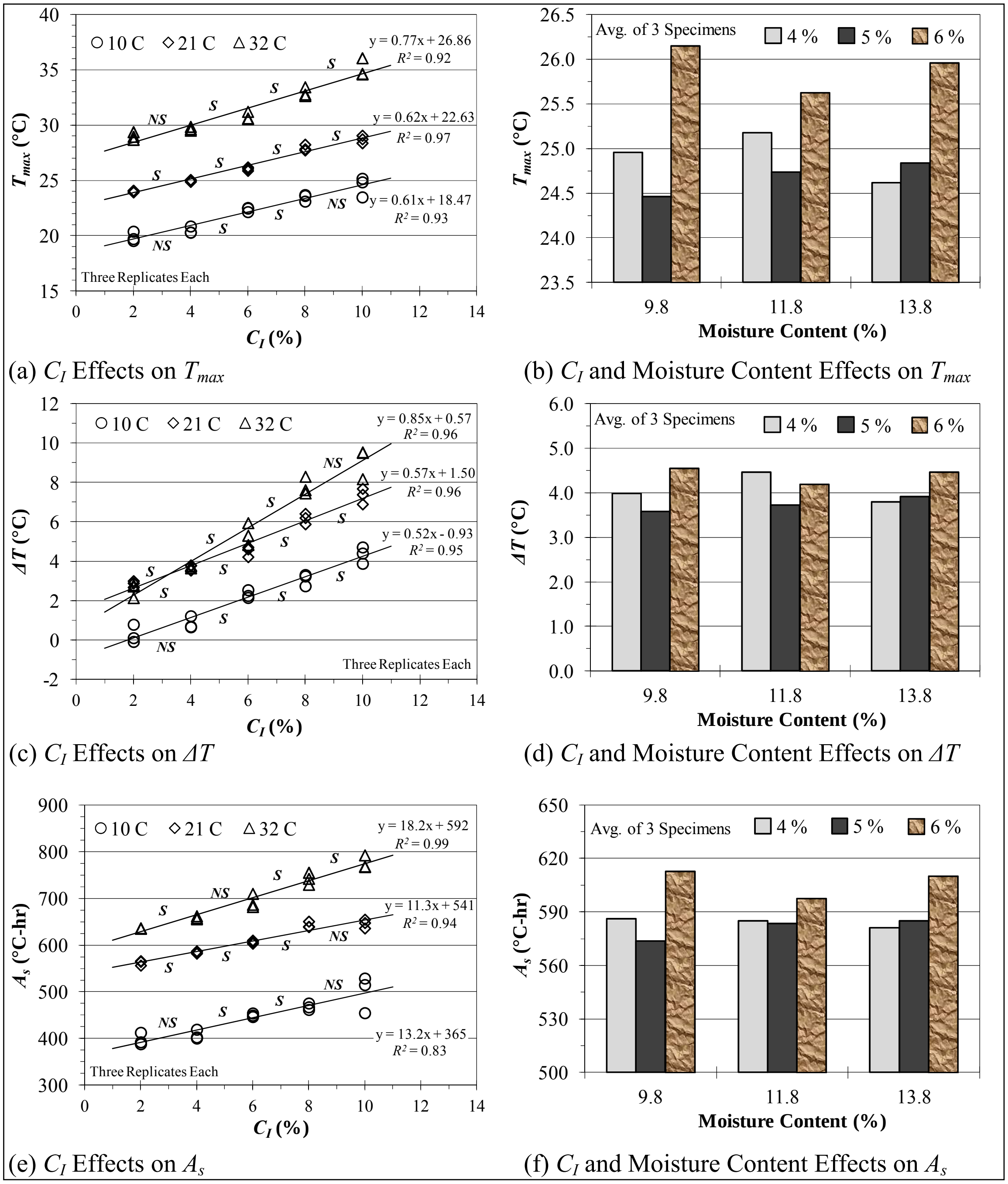
Figure 5.5 Effects of T_{BL} on Thermal Profiles with $T_i \approx 32$ °C

For Figure 5.5a, the initial material temperature (T_i) was approximately 26.5 °C and the initial temperature of the device (T_{BL}) was 21 °C. Thermal profiles in Figure 5.5a have an average T_{max} of about 30 °C. In Figure 5.5b, the T_i was 32 °C and the T_{BL} was also 32 °C. For Figure 5.5b specimens, the devices were exposed to ambient air temperatures of 32 °C for the duration of testing, and the average T_{max} was approximately 36 °C. In Figure 5.5c, the materials and devices were conditioned the same as Figure 5.5b specimens. After all specimens were prepared and inserted into the devices, the devices were removed from the 32 °C ambient air temperatures and exposed to 21 °C air temperatures. For Figure 5.5c, the average T_{max} was still approximately 36 °C, but there was a dramatic change to the thermal profiles after the devices were placed into the 21 °C environment. The implications of the effects of T_i and T_{BL} on the measured thermal profiles are as they relate to quality control not fully understood. Table 5.18 and Figure 5.5 may provide general guidance concerning the effects of T_i and T_{BL}, but additional investigation may be needed in this area to account for temperature effects.

5.7 Effect of Cement and Moisture Content on Thermal Profiles

The effects of cement content and the combined effects of cement and moisture content on thermal profiles were evaluated using data from Series 3, 4, 22, and 23. The effect of cement content was evaluated over a range of initial material temperatures (10, 21, and 32 °C) where the initial *EPS* block temperature (T_{BL}) was 21 °C. The combined effects of cement and moisture content were evaluated at 21 °C where the initial block temperature was 21 °C. Figure 5.6 shows the effects of varying C_I and the combined effects of cement content and moisture content on observed values of T_{max}, ΔT, and A_s.

Figure 5.6a shows the influence of cement content (C_I) on T_{max}. The overall increasing trend is consistent (i.e. similar trendline slopes) for all three initial material temperatures, and the trendline R^2 values range from 0.92 to 0.97. These results suggest that T_{max} is directly affected by the cement content and initial material temperature (T_i). Figure 5.6c shows the influence of C_I on ΔT. There is a clear increase in ΔT with increase in C_I for all three T_i with R^2 values ranging from 0.95 to 0.96. Figure 5.6e shows the influence of cement content on A_s. Again, the overall trend for all three T_i was an increase in cement content caused an increase in A_s. Trendline R^2 values for cement content and A_s range from 0.83 to 0.99. Statistical *t*-tests at $\alpha = 0.05$ and assuming unequal variances were performed on each incremental change in C_I to determine significant differences in values of T_{max}, ΔT, and A_s, and *t*-test results are shown in Figure 5.6. *S* denotes a significant change and *NS* denotes no significant change in mean value.



(a) C_I Effects on T_{max}
(b) C_I and Moisture Content Effects on T_{max}
(c) C_I Effects on ΔT
(d) C_I and Moisture Content Effects on ΔT
(e) C_I Effects on A_s
(f) C_I and Moisture Content Effects on A_s

Figure 5.6 Effects of Cement and Moisture Content on Thermal Profiles

Figures 5.6b, 5.6d, and 5.6f show the combined effects of cement content and moisture content on T_{max}, ΔT, and A_s. These plots show that there is no strong influence from moisture content change and only slight influences from small changes in cement content. Note the range of moisture contents tested only covers ±2% of *OMC*, which is a common acceptable moisture range in most soil-cement specifications.

5.8 Thermal Profile Correlation to σ_{max} and C_I

Series 5, 10, 15, and 19 examined thermal profile behaviors when C_I was varied by 1 percent from design. This data was also used to determine how thermal measurements relate to σ_{max}.

Figure 5.7 shows the compressive strength gain of *Pits A*, *B*, and *C* treated at design C_I and ± 1% C_I. All specimens had a T_i of approximately 21 °C and were compacted using the *PM-CF* approach. Each column represents an average of 3 replicates. According to *MT-25* results, the design cure time to reach a σ_{max} of 2070 kPa for *Pits A*, *B*, and *C* treated with portland cement (*TH*) was 7 days, and the design cure time for *Pit A* treated with *GGBFS* blend was 14 days. Note the compressive strengths for specimens compacted using the *PM-CF* approach were noticeably higher than similar specimens compacted using standard proctor compaction effort. This issue is investigated further in other works outside this thesis. For *Pits A*, *B*, and *C* (Figure 5.7a, 5.7b, and 5.7c), there is a noticeable difference in σ_{max} when the C_I is varied by 1% from the design C_I, particularly at the design cure time. This trend also holds true with the *GGBFS* blend mixture (Figure 5.7d). Also, σ_{max} gain of the *GGBFS* blend mixture is slow at early ages, but the strength gain between 7 and 14 days is considerable.

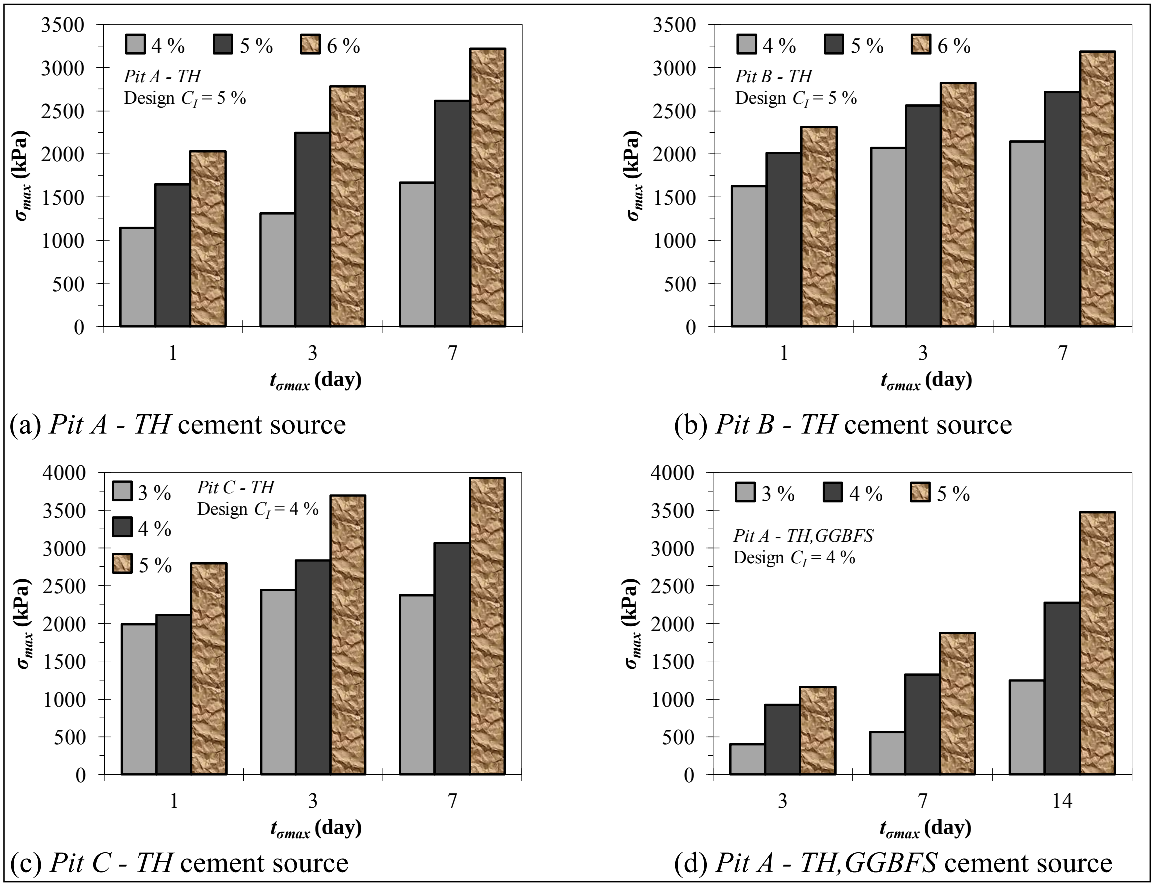


Figure 5.7 Compressive Strength Gain of Pit Soils (*PM-CF* Approach)

Statistical *t*-tests were conducted for T_{max}, ΔT, and A_s to determine if there were significant differences between 1 percent increments of C_I. Tables 5.19 through 5.21 provide *t*-test results. As shown in Table 5.19 with exception to *Pit C*, a 1% decrease in C_I from the design C_I produced a lower value for T_{max}, and a 1% increase in C_I from the design C_I did not produce a significantly different T_{max} value. For *Pit C*, a 1% incremental change in C_I did not produce a significantly different T_{max}, but a 2% incremental change did produce a significant change in T_{max}. For ΔT (Table 5.20), a 1% decrease in C_I from the design C_I produced a lower ΔT for pit soil *A*, *B*, and *C* stabilized with portland cement. For *Pits A* and *C*, there was no significant change in ΔT with a 1%

increase in C_I from the design C_I, but for *Pit B* there was an increase in ΔT. For *Pit A* stabilized with *GGBFS* blend, there was no change in ΔT with a 1% decrease in C_I from the design C_I, and there was an increase in ΔT with a 1% increase in C_I from the design C_I. Statistical *t*-test results for A_s were the same as T_{max} results (Table 5.21).

Table 5.19 Statistical *t*-test Results for Varying C_I: T_{max}

Term 1	μ_1 (°C)	**Term 2**	μ_2 (°C)	*df*	t_{crit}	t_{stat}	H_0 **Conclusion**
Pit A-TH 4%	25.0	*Pit A-TH* 5%	25.7	15	2.13	-6.72	Reject
Pit A-TH 5%	25.7	*Pit A-TH* 6%	25.9	9	2.26	-0.84	Accept
Pit B-TH 4%	26.3	*Pit B-TH* 5%	26.9	16	2.12	-3.71	Reject
Pit B-TH 5%	26.9	*Pit B-TH* 6%	27.3	11	2.20	-1.35	Accept
Pit C-TH 3%	25.6	*Pit C-TH* 4%	25.9	13	2.16	-1.92	Accept
Pit C-TH 4%	25.9	*Pit C-TH* 5%	26.2	13	2.16	-1.42	Accept
Pit C-TH 3%	25.6	*Pit C-TH* 5%	26.2	16	2.12	-4.62	Reject
Pit A-TH,GGBFS 3%	21.6	*Pit A-TH,GGBFS* 4%	22.5	9	2.26	-3.81	Reject
Pit A-TH,GGBFS 4%	22.5	*Pit A-TH,GGBFS* 5%	22.7	16	2.12	-0.39	Accept

Notes: Data from Series 5, 10, 15, and 19; α = 0.05; H_0 was $\mu_1 = \mu_2$ and H_a was $\mu_1 \neq \mu_2$ for all t-tests; and unequal variances was assumed for all t-tests.

Table 5.20 Statistical *t*-test Results for Varying C_I: ΔT

Term 1	μ_1 (°C)	**Term 2**	μ_2 (°C)	*df*	t_{crit}	t_{stat}	H_0 **Conclusion**
Pit A-TH 4%	4.21	*Pit A-TH* 5%	4.71	13	2.16	-4.16	Reject
Pit A-TH 5%	4.71	*Pit A-TH* 6%	4.53	9	2.26	0.70	Accept
Pit B-TH 4%	5.14	*Pit B-TH* 5%	5.66	16	2.12	-3.29	Reject
Pit B-TH 5%	5.66	*Pit B-TH* 6%	6.25	12	2.18	-2.48	Reject
Pit C-TH 3%	4.28	*Pit C-TH* 4%	4.71	13	2.16	-2.27	Reject
Pit C-TH 4%	4.71	*Pit C-TH* 5%	5.1	14	2.14	-2.03	Accept
Pit A-TH,GGBFS 3%	1.64	*Pit A-TH,GGBFS* 4%	1.83	16	2.12	-0.88	Accept
Pit A-TH,GGBFS 4%	4.21	*Pit A-TH,GGBFS* 5%	4.71	13	2.16	-4.16	Reject

Notes: Data from Series 5, 10, 15, and 19; α = 0.05; H_0 was $\mu_1 = \mu_2$ and H_a was $\mu_1 \neq \mu_2$ for all t-tests; and unequal variances was assumed for all t-tests.

Table 5.21 Statistical *t*-test Results for Varying C_I: A_s

Term 1	μ_1 **(°C-hr)**	**Term 2**	μ_2 **(°C-hr)**	***df***	t_{crit}	t_{stat}	H_0 **Conclusion**
Pit A-TH 4%	579	*Pit A-TH* 5%	601	14	2.14	-6.55	Reject
Pit A-TH 5%	601	*Pit A-TH* 6%	604	11	2.20	-0.76	Accept
Pit B-TH 4%	601	*Pit B-TH* 5%	613	16	2.12	-3.20	Reject
Pit B-TH 5%	613	*Pit B-TH* 6%	620	12	2.18	-1.27	Accept
Pit C-TH 3%	583	*Pit C-TH* 4%	591	14	2.14	-2.04	Accept
Pit C-TH 4%	591	*Pit C-TH* 5%	594	16	2.12	-0.69	Accept
Pit C-TH 3%	583	*Pit C-TH* 5%	594	15	2.13	-3.11	Reject
Pit A-TH,GGBFS 3%	512	*Pit A-TH,GGBFS* 4%	530	9	2.26	-3.47	Reject
Pit A-TH,GGBFS 4%	530	*Pit A-TH,GGBFS* 5%	532	16	2.12	-0.32	Accept

Notes: Data from Series 5, 10, 15, and 19; α = 0.05; H_0 was $\mu_1 = \mu_2$ and H_a was $\mu_1 \neq \mu_2$ for all t-tests; and unequal variances was assumed for all t-tests.

Table 5.22 summarizes the thermal profile test results. For all portland cement mixtures, the design C_I produced an average T_{max} that ranged from 25.7 to 26.9 °C, an average ΔT that ranged from 4.7 to 5.7 °C, and an average A_s that ranged from 591 to 613 °C-hr. For the *GGBFS* blend mixture, the design C_I produced an average T_{max} of 22.5 °C, an average ΔT of 1.6 °C, and an average A_s of 530 °C-hr. When the C_I is varied by plus or minus 1% C_I, the resultant average values for T_{max}, ΔT, and A_s change as shown in Table 5.22. Changes for *Pit A* values loosely follow the cement content effects trend line equations ($T_i \approx 21$°C) developed in Section 5.6, but changes in values for *Pits B*, *C*, and the *GGBFS* blend are different.

Table 5.22 Summary of Thermal Profile Results

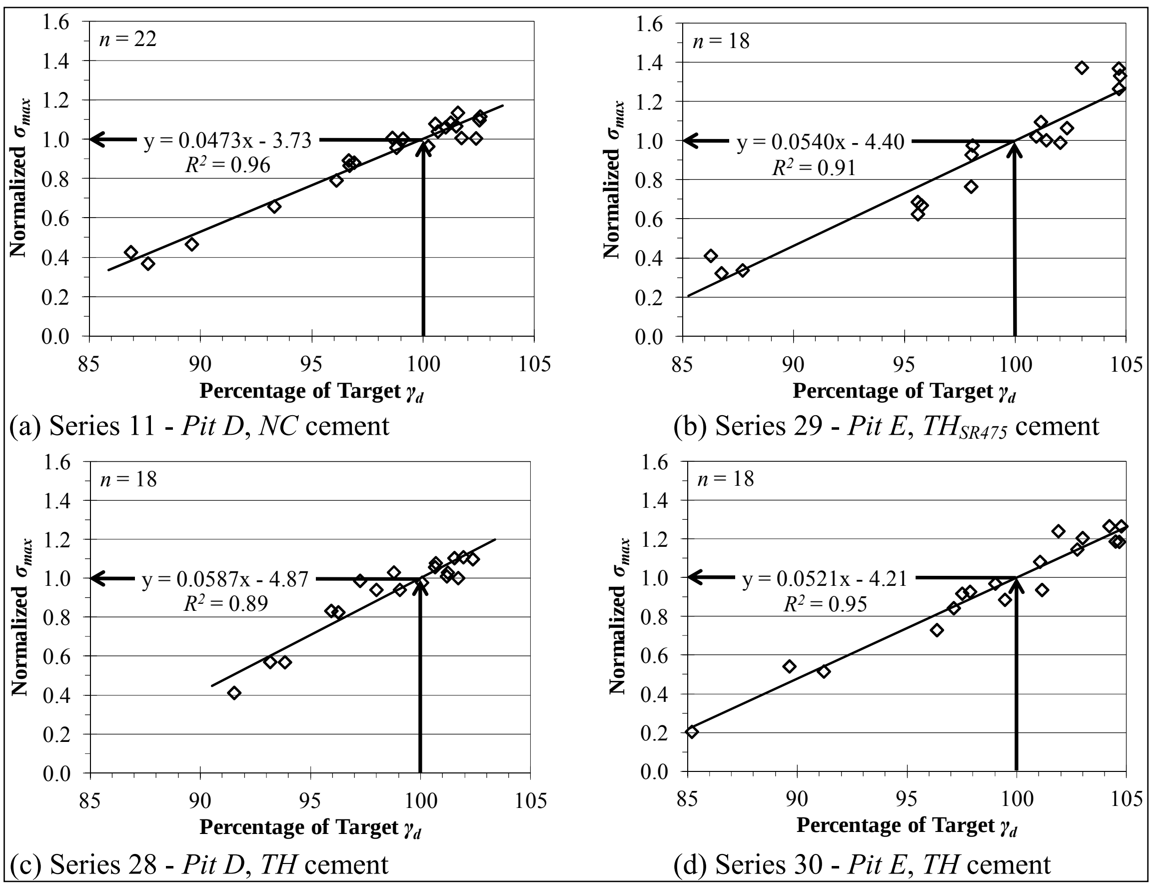
Series	Variable	Design C_I - 1%		Design C_I		Design C_I + 1%	
		Mean	*COV* (%)	Mean	*COV* (%)	Mean	*COV* (%)
5	T_{max} (°C)	25.0	1.0	25.7	0.7	25.9	2.7
5	ΔT (°C)	4.2	7.4	4.7	3.7	4.5	16.7
5	A_s (°C-hr)	579	1.4	601	0.9	604	2.3
10	T_{max} (°C)	26.3	1.2	26.9	1.3	27.3	3.0
10	ΔT (°C)	5.1	6.6	5.7	5.9	6.2	9.9
10	A_s (°C-hr)	601	1.1	613	1.3	620	2.4
15	T_{max} (°C)	25.6	1.2	25.9	1.9	26.2	1.1
15	ΔT (°C)	4.3	6.9	4.7	10.3	5.1	6.1
15	A_s (°C-hr)	583	1.0	591	1.6	594	1.4
19	T_{max} (°C)	21.6	0.9	22.5	3.1	22.7	3.4
19	ΔT (°C)	1.0	20.5	1.6	25.8	1.8	26.2
19	A_s (°C-hr)	512	0.5	530	2.7	532	2.3

5.9 Density Correction

In the field, specimens compacted with the *PM-P* approach did not always achieve 98 to 101 percent of the target maximum dry density (γ_d) due to the need for simplicity in the field. Therefore, laboratory test specimens were made to correlate percentage of target γ_d to σ_{max} and thermal profile measurements. Data for this analysis is contained in Series 11, 28, 29, and 30 which consist of *Pits D* and *E* treated with the corresponding field cement (*NC* or TH_{SR475}) and *TH* cement. Overall, specimen density appeared to have more of an effect on the compressive strength (7 day cure) than did the thermal profile measurements.

Figure 5.8 shows the effect of specimen density on the compressive strength (σ_{max}) for each combination of soil and cement. The measured σ_{max} was normalized so that σ_{max} of 1.0 corresponds to 100 percent of target γ_d. The σ_{max} at 100 percent of target γ_d was determined by plotting the measured σ_{max} (y-axis) versus the percentage of γ_d (x-axis) for each data series (not shown for brevity), and linear regression equations (R^2

ranged from 0.89 to 0.96) were used to calculate the predicted σ_{max} at 100 percent of target γ_d. Figure 5.8 shows a strong correlation (R^2 from 0.89 to 0.96) between the percentage of target γ_d and the normalized σ_{max} for all combinations of soil and cement source. Trendline slopes ranged from 0.048 to 0.059 for all four mixtures, and trendline slopes were very similar when *Pits D* and *E* were treated with the same cement source (i.e. *TH* cement).



(a) Series 11 - *Pit D*, *NC* cement

(b) Series 29 - *Pit E*, TH_{SR475} cement

(c) Series 28 - *Pit D*, *TH* cement

(d) Series 30 - *Pit E*, *TH* cement

Figure 5.8 Specimen Density Effects on Compressive Strength (σ_{max})

Figure 5.9 combines the data from Figure 5.8 to generalize the overall trend between percentage of γ_d and normalized σ_{max}. This allows for an overall correction for density which could be applied to any combination of soil type or cement source. Figure 5.9a combines the data from Figures 5.8a and 5.8c which includes *Pit D* treated with *NC* and *TH* cement sources. Figure 5.9b combines the data from Figures 5.8b and 5.8d which includes *Pit E* treated with TH_{SR475} and *TH* cement sources. Figure 5.9c combines Figures 5.9a and 5.9b to include all data points. Also shown in Figure 5.9c are the 95% confidence interval (dotted line) and 95% prediction interval (dashed line). The confidence interval (*CI*) indicates, with α = 0.05, the estimated mean value will fall between the dotted lines, and the prediction interval (*PRI*) indicates, with α = 0.05, any individual value will fall between the dashed lines. Figure 5.9d is an equality plot comparing the predicted normalized σ_{max} using the overall trendline (Figure 5.9c) and each individual trendline (Figures 5.8a, 5.8b, 5.8c, and 5.8d). All four trendlines fall close to the equality line which indicates that the overall average trendline equation closely depicts the strength-density relationship for all four mixtures tested. Until additional information becomes available, Figure 5.9c approach appears to be reasonable for density adjustment. Equation 5.1 is the compressive strength adjustment used for field prepared specimens in this thesis.

$$\sigma_{\max\,adj} = \sigma_{\max} \times \left(1 + \left(1 - \left(P_{\gamma d} \times 0.0521 - 4.21\right)\right)\right) \qquad \text{Eq 5.1}$$

Where:

$\sigma_{max\,adj}$ = Adjusted compressive strength (kPa)

σ_{max} = Measured compressive strength (kPa)

$P_{\gamma d}$ = Percentage of target maximum dry density (%)

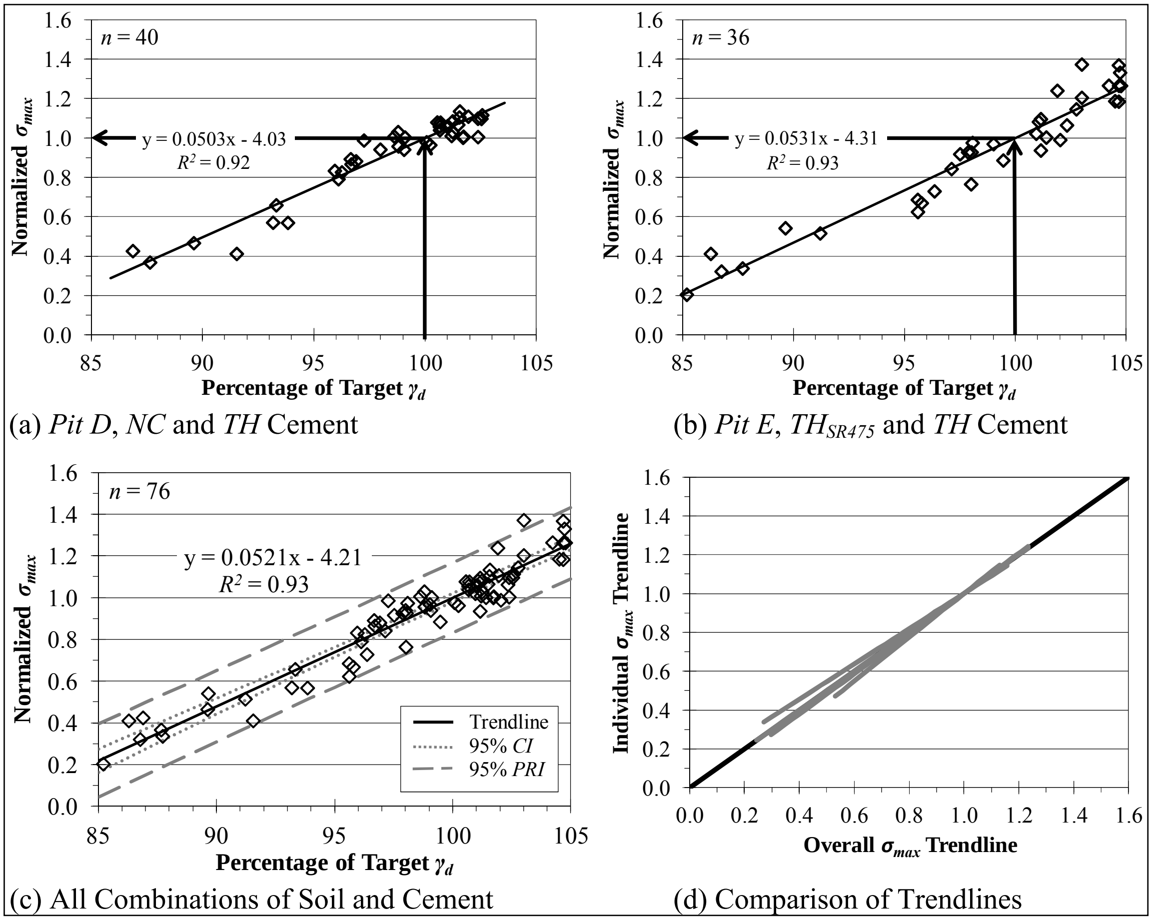


Figure 5.9 Generalization of Specimen Density Effects on σ_{max}

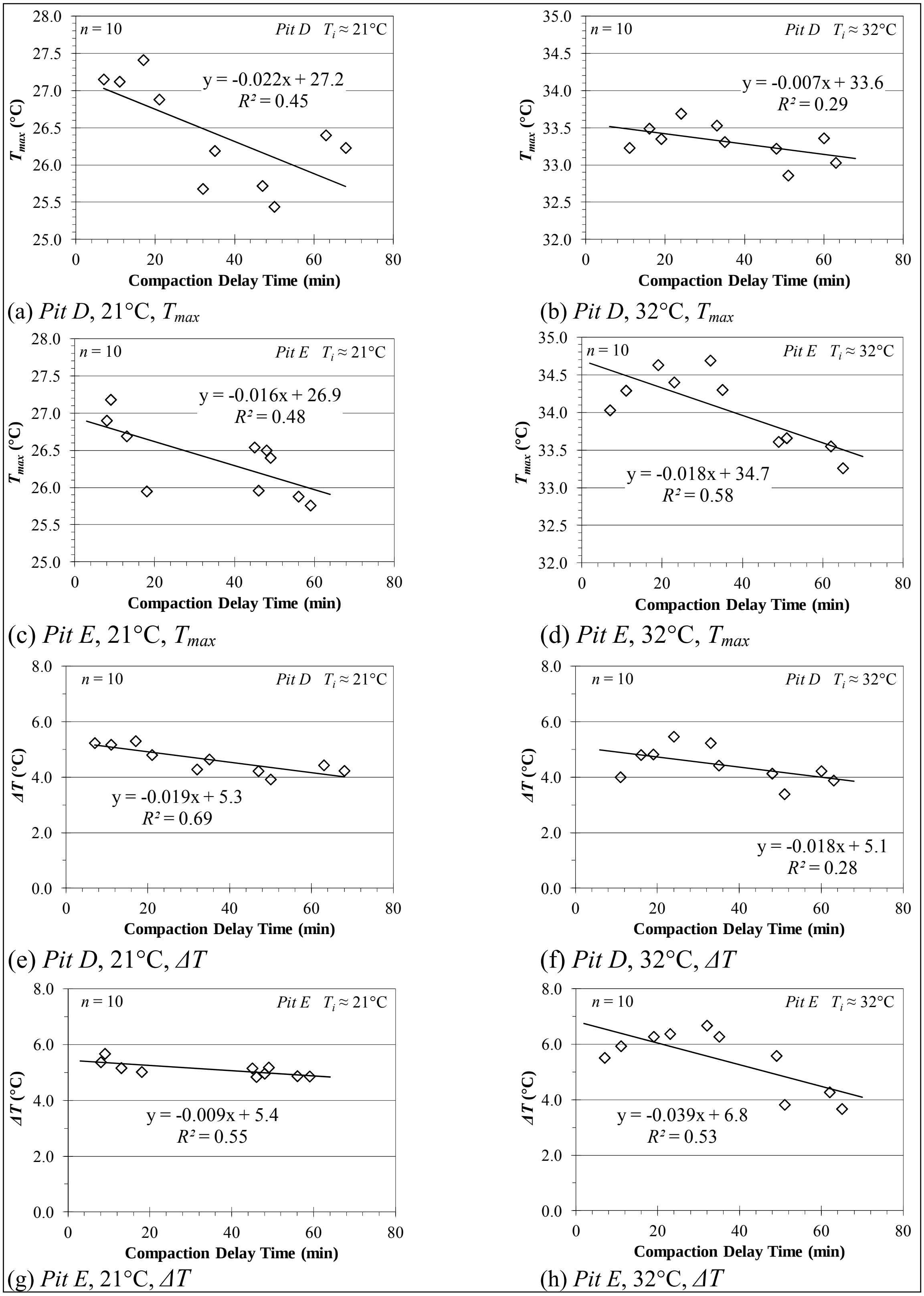
Table 5.23 contains the correlation between specimen density and thermal measurements. Overall, there were no strong trends between percentage of target γ_d ($P_{\gamma d}$) and any thermal measurement variable, but there is a weak trend showing that increasing specimen density will slightly increase T_{max}, ΔT, and A_s values. Little to no correction is likely needed to adjust thermal measurements for density.

Table 5.23 Correlation of Specimen Density and Thermal Measurements

Variable	Pit	Cement	Trendline Equation	R^2
T_{max}	*D*	*NC*	$T_{max} = 0.03P_{\gamma d} + 23.3$	0.13
ΔT	*D*	*NC*	$T_{max} = 0.03P_{\gamma d} + 1.87$	0.15
A_s	*D*	*NC*	$T_{max} = 0.67P_{\gamma d} + 551$	0.13
T_{max}	*D*	*TH*	$T_{max} = 0.08P_{\gamma d} + 19.2$	0.43
ΔT	*D*	*TH*	$T_{max} = 0.05P_{\gamma d} - 0.06$	0.35
A_s	*D*	*TH*	$T_{max} = 1.88P_{\gamma d} + 445$	0.44
T_{max}	*E*	TH_{SR475}	$T_{max} = 0.08P_{\gamma d} + 19.3$	0.62
ΔT	*E*	TH_{SR475}	$T_{max} = 0.03P_{\gamma d} + 1.93$	0.38
A_s	*E*	TH_{SR475}	$T_{max} = 2.07P_{\gamma d} + 416$	0.65
T_{max}	*E*	*TH*	$T_{max} = 0.05P_{\gamma d} + 22.6$	0.45
ΔT	*E*	*TH*	$T_{max} = 0.02P_{\gamma d} + 3.65$	0.14
A_s	*E*	*TH*	$T_{max} = 1.06P_{\gamma d} + 521$	0.40

5.10 Time Delay Correction

In the field, some specimens could not be compacted immediately after completion of cement mixing because of construction practices (i.e. multiple mixing passes, and similar); therefore, an analysis was conducted to take into account the effects of compaction delay time (t_d) between cement mixing and specimen preparation. Tested compaction delay times (i.e. the time from cement addition to the end of specimen compaction) varied from 5 to 65 minutes as this is similar to the time frame experienced in the field (Chapter 6). Tests were performed with *Pits D* and *E* at two initial material temperatures (21 and 32 °C). Overall, t_d appeared to have more of an effect on the thermal profile measurement than it did on compressive strength. Figures 5.10 and 5.11 show the effects of compaction delay on T_{max}, ΔT, and A_s.



(a) *Pit D*, 21°C, T_{max}
(b) *Pit D*, 32°C, T_{max}
(c) *Pit E*, 21°C, T_{max}
(d) *Pit E*, 32°C, T_{max}
(e) *Pit D*, 21°C, ΔT
(f) *Pit D*, 32°C, ΔT
(g) *Pit E*, 21°C, ΔT
(h) *Pit E*, 32°C, ΔT

Figure 5.10 Effects of Compaction Delay Time (t_d) on T_{max} and ΔT

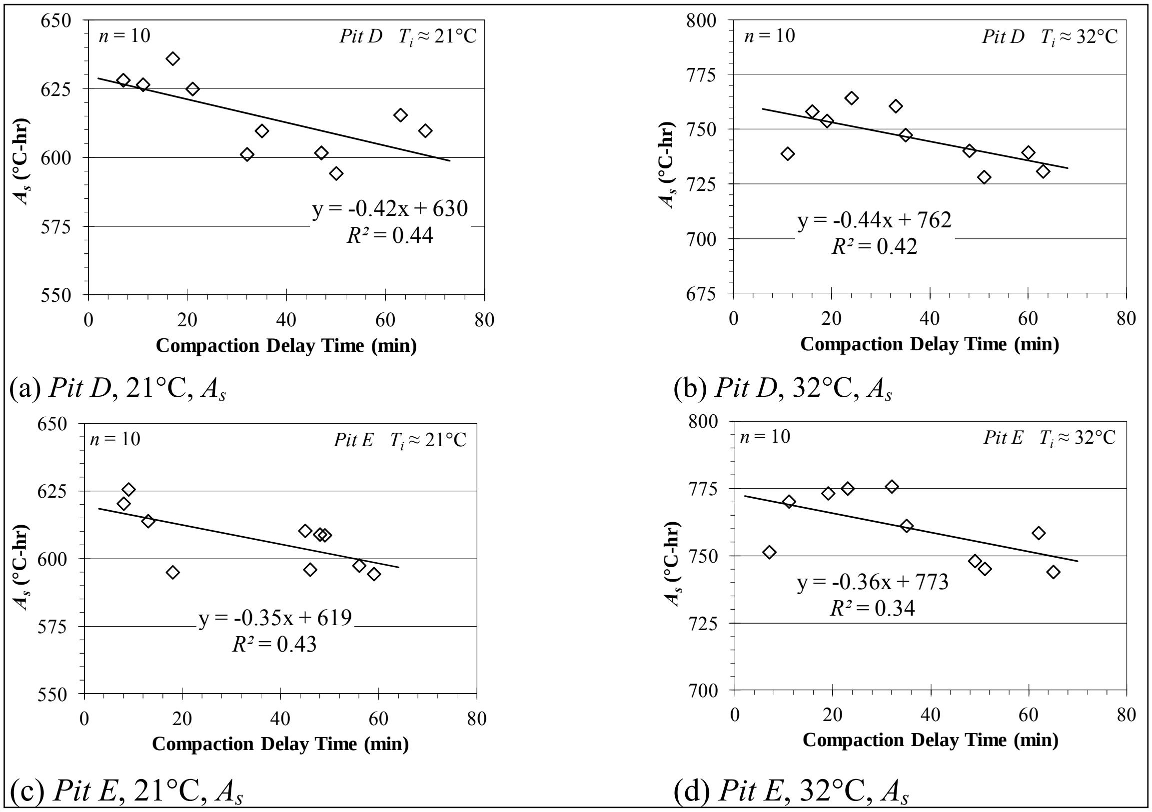


Figure 5.11 Effects of Compaction Delay Time (t_d) on A_s

In Figures 5.10 and 5.11, trends between compaction delay time and T_{max}, ΔT, or A_s were low to reasonable (R^2 = 0.28 to 0.69) due to data variability; therefore, further investigation may be needed to investigate the issue of compaction delay. In every case, the observed values of T_{max}, ΔT, and A_s decrease as the compaction delay time increases. With exception of one case (*Pit D* at 32 °C), the T_{max} decreases approximately 0.02 °C for every minute of delay. For *Pit D* at 32 °C, the T_{max} decreases approximately 0.01 °C for every minute of delay. With exception to one case (*Pit E* at 32 °C), the ΔT decreases approximately 0.015 °C every minute of delay. For *Pit E* at 32 °C, the ΔT decreased approximately 0.04 °C for every minute of delay. For *Pit D*, A_s decreases approximately

0.43 °C-hr for every minute of delay. For *Pit E*, A_s decreases approximately 0.36 °C-hr every minute of delay.

The effects of compaction delay on the compressive strength (σ_{max}) were evaluated by plotting compaction delay time (x-axis) versus the measure compressive strength (y-axis). Table 5.24 summarizes the trendline equations developed from these plots. Results show no correlation between compaction delay time (t_d) and compressive strength (σ_{max}). All recorded σ_{max} values fall within the expected range of variability for both mixtures.

Table 5.24 Effects of Compaction Delay on Compressive Strength

Soil	**Cement**	C_I **(%)**	T_i **(°C)**	**Trendline Equation**	R^2
Pit D	*NC*	7	21	$\sigma_{max} = 1.32t_d + 1587$	0.21
Pit D	*NC*	7	32	$\sigma_{max} = -0.05t_d + 1634$	0.00
Pit E	TH_{SR475}	7	21	$\sigma_{max} = 2.58t_d + 1884$	0.23
Pit E	TH_{SR475}	7	32	$\sigma_{max} = 1.71t_d + 2078$	0.87

CHAPTER 6

FIELD TEST RESULTS AND ANALYSIS

6.1 Overview of Field Work

Two soil-cement base course projects (MS State Route 9 and MS State Route 475) were selected to evaluate the feasibility and usefulness of performing field thermal measurements. Chapter 1 briefly illustrates and describes the construction procedures for *SR9* and *SR475*, while Table 6.1 contains an overall summary of the construction timing for both *SR9* and *SR475*. A traffic opening procedure was also investigated using these two projects.

All compressive strength (σ_{max}) data contained in this chapter was adjusted for specimen density using Equation 5.1 and adjusted for specimen size according to *ASTM D 1633*. The σ_{max} of nominal 76.2 mm diameter specimens (h/d = 2.00) were adjusted to equivalent strengths of 101.6 mm diameter specimens (h/d = 1.15) by multiplying by 1.10. The target σ_{max} is based on specimens with a h/d ratio of 1.15; therefore, all field σ_{max} results were adjusted to equivalent strengths of 1.15 h/d ratio specimens for a more direct comparison to the target σ_{max}. Raw field data can be found in Appendix B.

Table 6.1 Summary of Construction Timing for Field Work Projects

Project	Location	Station No.	Lane	Date	T_i (°C)	t_c	t_m	N_p	t_{vib}	t_{comp}
	1	122 + 00	North bound	04/20/2012	22.0	8:50 AM	9:45 AM	2	11:00 AM	12:30 PM
SR9	2	145 + 37	North bound	04/20/2012	26.3	1:25 PM	2:20 PM	2	3:50 PM	5:00 PM
	3	171 + 01	North bound	04/23/2012	11.0	7:20 AM	8:14 AM	2	9:35 AM	11:31 AM
	1	98 + 21	North bound	06/19/2012	24.0	7:25 AM	8:18 AM	3	9:40 AM	10:54 AM
SR475	2	93 + 12	South bound	06/19/2012	32.1	7:25 AM	12:29 PM	2	1:42 PM	2:15 PM
	3	24 + 00	Southeast exit ramp	06/21/2012	26.3	6:57 AM	7:47 AM	2	9:20 AM	10:10 AM

Notes: t_c is the time of start cement spread; t_m is the time of first mixing pass; N_p is the total number of mixing passes for each sample position; t_{vib} is the time of end vibratory compaction; and t_{comp} is the time of end compaction with rubber-tire roller.

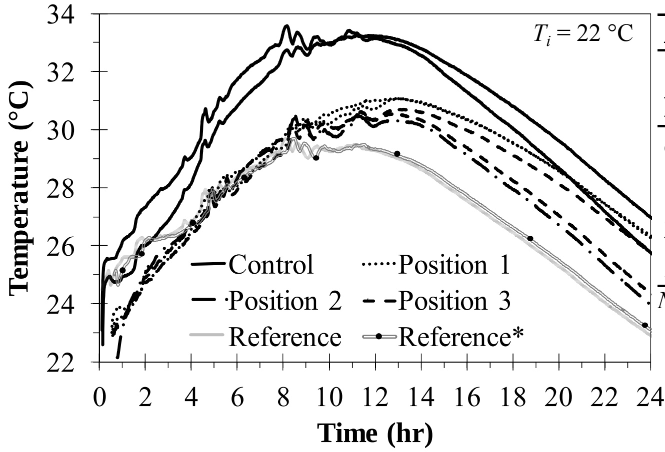
SR9 encompassed a large amount of treated material (68,000 m^3) and was constructed in a paving train fashion (see Figure 1.1). Typically, 10 to 12 truckloads of cement would be mixed and compacted per day. Cement was mixed into the soil within an hour of being spread onto the ground, and mixing was performed in two passes. Sheeps-foot and vibratory compaction was completed within 1.5 hours after the first pass of mixing. Shaping and finishing was performed in two phases (milling and grading) and final compaction was completed within 2 hours of the end of vibratory compaction.

SR475 encompassed a smaller amount of treated material (12,200 m^3) and was constructed using fewer pieces of equipment (see Figure 1.2). Typically, 3 to 4 truckloads of cement would be mixed and compacted per day. Unlike *SR9*, all truckloads of cement were spread onto the roadway at the beginning of the work day. In some cases the cement was mixed within an hour of being spread, but in other cases several hours passed before the cement was mixed. Mixing was performed with 2 or 3 passes. Sheeps-foot and vibratory compaction was typically completed within 1.5 hours of the first mixing pass. Shaping and finishing was performed with a motor grader, and final compaction was completed within an hour of end vibratory compaction.

6.2 Field Thermal Profiles

Field thermal profile specimens were prepared according to Section 4.7, and Figures 6.1 and 6.2 contain plots of thermal profiles alongside summary information and compressive strength results. Reported compressive strengths were adjusted for density using Equation 5.1 and specimen size as per *ASTM D 1633*. In Figures 6.1 and 6.2, thermal profiles are plotted with time zero as the cement addition time. Each location has two cement addition times, one for the control mixtures and one for the field mixtures. For comparison, all profiles were plotted together which creates an offset for the reference specimen profile. The offset was alleviated by plotting the reference specimen twice with time zero referencing each cement addition time individually. For example, at Location 1 on *SR475* (Figure 6.2a) the cement for the control mixture was added at 8:59 AM, and thermal measurements for that specimen and the reference specimen began at 9:04 AM. So 9:04 AM is Time = 0.08 hr on Figure 6.2a. The cement addition time for Position 1 was 8:18 AM, and thermal measurements began at 9:10 AM. So 9:10 AM for Position 1 specimens is Time = 0.9 hr on Figure 6.2a. Thermal measurements on all three specimens were started at approximately the same time, but the plot in Figure 6.2a shows a 0.68 hr shift between the control and position 1 specimens (because of the different cement addition times). The asterisked reference thermal profile shows the recorded reference specimen thermal profile synchronized with the cement addition time for the field mixed specimens (Positions 1, 2, and 3). For *SR9*, the reference and asterisked reference profiles are almost indistinguishable, but for *SR475* the difference is noticeable.

Overall, thermal measurements produced suitable profiles for relative comparison to control mixture profiles. Generally speaking, the thermal profile results align and agree with measured compressive strength results (e.g. higher average values of T_{max}, ΔT, and A_s yielded a higher average σ_{max}). Some locations experienced a 4 to 6 °C increase in the reference specimen which may suggest outside influences from ambient temperatures inside the van.

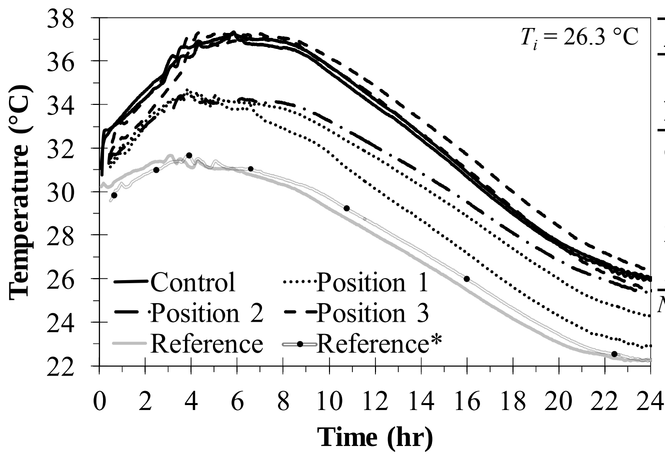


Average Test Results

Pos.	T_{max} (°C)	ΔT (°C)	A_s (°C-hr)	σ_{max} (kPa)	*n*
C	33.4	3.9	723	2273	2
1	31.1	1.9	672	1426	2
2	30.5	1.1	648	1528	1
3	30.7	1.4	657	1216	2

Note: σ_{max} was adjusted for specimen density.

(a) Thermal Profile - Location 1

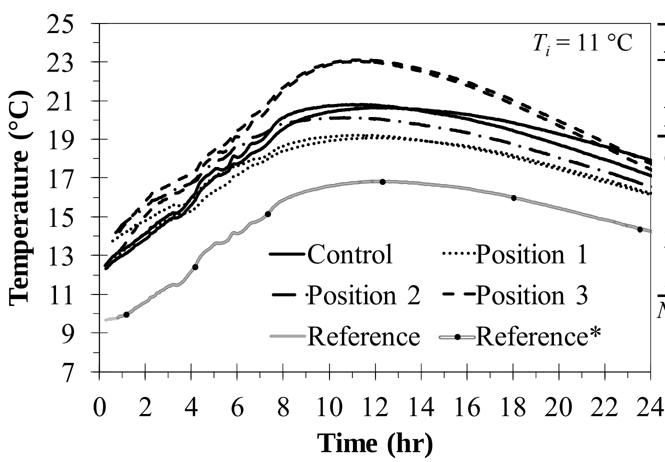


Average Test Results

Pos.	T_{max} (°C)	ΔT (°C)	A_s (°C-hr)	σ_{max} (kPa)	*n*
C	37.3	6.2	778	2226	2
1	34.6	3.0	707	893	2
2	34.4	2.8	726	910	1
3	37.2	6.0	771	1967	2

Note: σ_{max} was adjusted for specimen density.

(b) Thermal Profile - Location 2



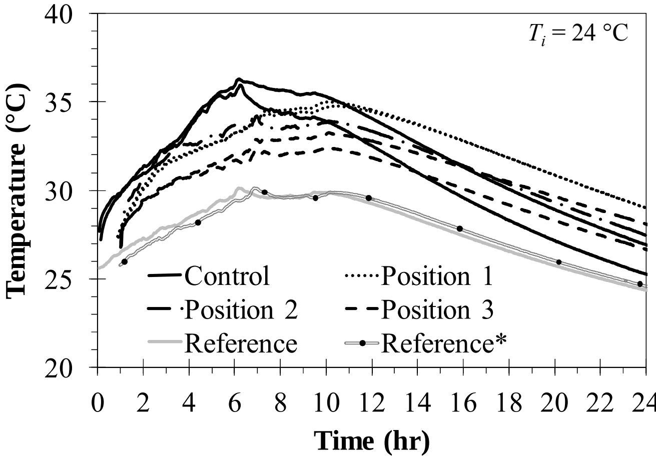
Average Test Results

Pos.	T_{max} (°C)	ΔT (°C)	A_s (°C-hr)	σ_{max} (kPa)	*n*
C	20.7	3.9	442	2590	2
1	19.2	2.4	413	875	2
2	20.1	3.4	431	1465	1
3	23.1	6.3	467	3728	2

Note: σ_{max} was adjusted for specimen density.

(c) Thermal Profile - Location 3

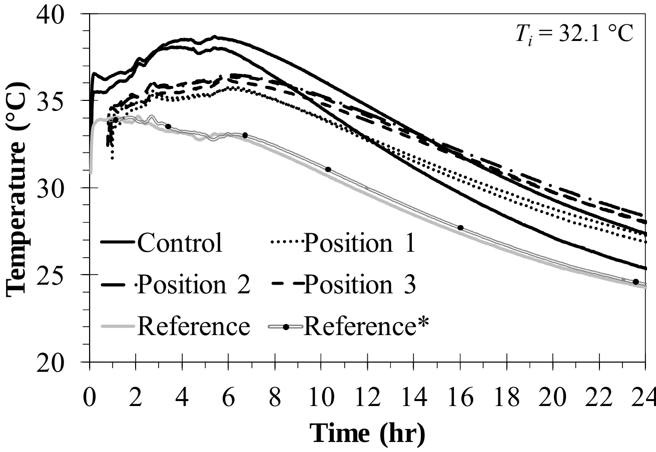
Figure 6.1 Measured Field Thermal Profiles for *SR9*



Average Test Results					
Pos.	T_{max} (°C)	ΔT (°C)	A_s (°C-hr)	σ_{max} (kPa)	*n*
C	36.1	6.0	752	1854	2
1	34.9	5.0	749	2673	2
2	34.2	4.1	724	2162	1
3	32.8	2.9	705	1114	2

Note: σ_{max} was adjusted for specimen density.

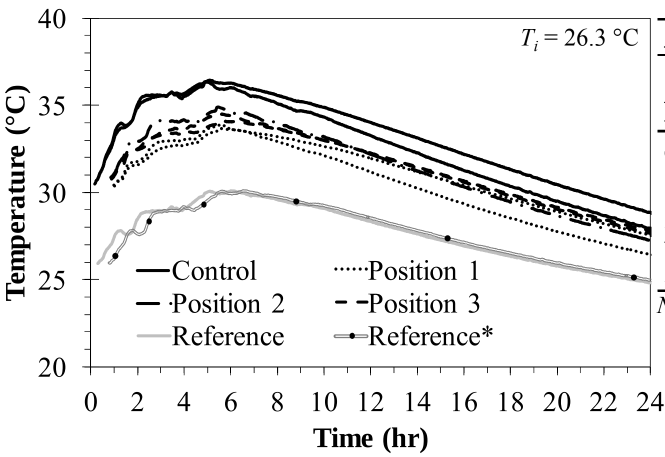
(a) Thermal Profile - Location 1



Average Test Results					
Pos.	T_{max} (°C)	ΔT (°C)	A_s (°C-hr)	σ_{max} (kPa)	*n*
C	38.4	5.2	794	2275	2
1	35.7	2.6	739	1486	2
2	36.5	3.5	769	1606	1
3	36.3	3.2	766	1766	2

Note: σ_{max} was adjusted for specimen density.

(b) Thermal Profile - Location 2



Average Test Results					
Pos.	T_{max} (°C)	ΔT (°C)	A_s (°C-hr)	σ_{max} (kPa)	*n*
C	36.4	6.5	786	2118	2
1	33.8	3.7	713	1045	2
2	34.9	4.9	728	1531	1
3	34.3	4.3	734	1228	2

Note: σ_{max} was adjusted for specimen density.

(c) Thermal Profile - Location 3

Figure 6.2 Measured Field Thermal Profiles for *SR475*

For *SR9* Location 1 (Figure 6.1a), the control specimen thermal profiles were much greater in magnitude than the field mixed thermal profiles, which may suggest a difference in cement content. The control specimens also have a greater average σ_{max} which supports the thermal profile findings. For *SR9* Location 2 (Figure 6.1b), the control specimen thermal profiles and position 3 profiles were approximately the same while positions 1 and 2 profiles were noticeable lower. Profile and σ_{max} data suggest position 3 and controls had about the same amount of cement and positions 1 and 2 contained less cement. For *SR9* Location 3 (Figure 6.1c), the position 3 profiles were noticeably higher than the control profiles, and positions 1 and 2 profiles were a little lower than the controls. Overall, the cement content difference suggested by the profiles is confirmed with average σ_{max} results.

For *SR475* Location 1 (Figure 6.2a), control profiles peaked slightly higher than field mixed specimens, but field mixed and control specimens had similar A_s values. Average σ_{max} values were also puzzling as positions 1 and 2 produced higher σ_{max} than the control specimens. For *SR475* Location 2 (Figure 6.2b), control profiles peaked higher than field mixed specimens, and field mixed profiles were all approximately the same magnitude. Average σ_{max} results show all field mixed specimens to be about the same, and average control σ_{max} was noticeable higher. For *SR475* Location 3 (Figure 6.2c), control profiles and average σ_{max} were greater than field mixed specimens. Field mixed profiles were closely grouped, and σ_{max} values were approximately the same.

An attempt was made to recreate two of the field thermal plots (Figures 6.1b and 6.2c) in the laboratory. Thermal profile data from Series 47 and 48 was plotted on the same plot as Series 37 and 45 in hopes of bounding the field profiles with lab profiles of known cement content. Laboratory materials were conditioned to the same initial material temperature (T_i) as the field specimens and the thermal device temperature (T_{BL}) was a constant 21 °C throughout testing. Figure 6.3 displays the thermal profile results. The laboratory prepared thermal profiles (noted by C_I values in Figure 6.3) do not resemble the measured field thermal profiles. The field and laboratory profiles differ with respect to magnitude and shape. These results further support the discussion in Section 5.7 concerning the effects of T_i and T_{BL}. Based on these results, it is unlikely field thermal profiles can be recreated in a laboratory setting using the current equipment and protocols.

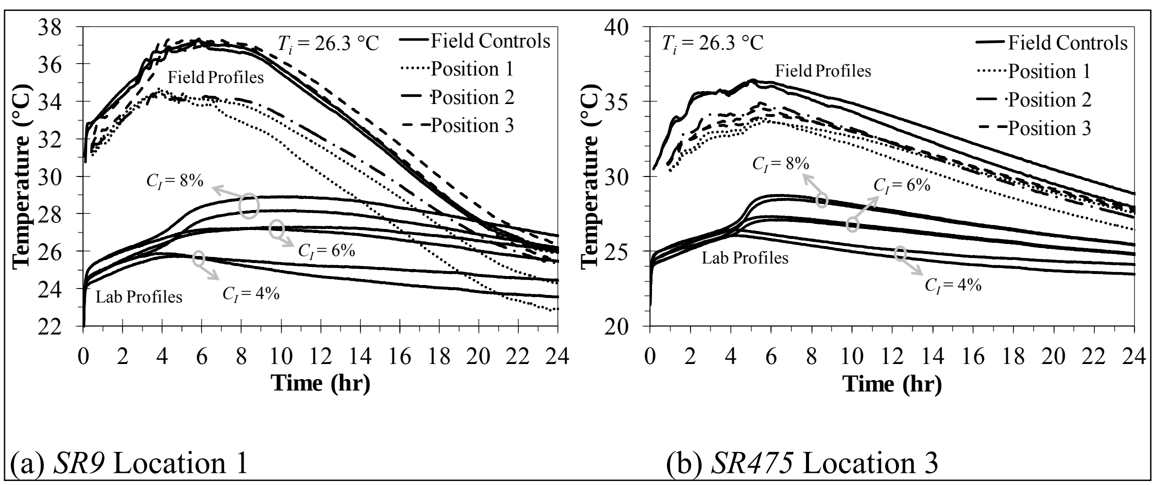
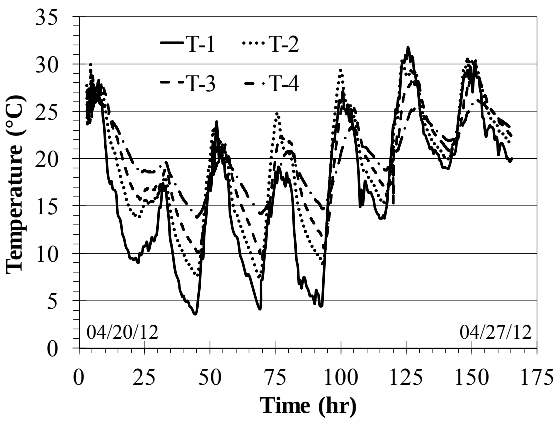


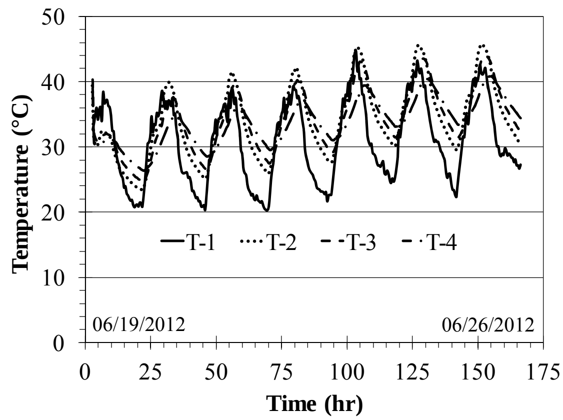
Figure 6.3 Field Thermal Profiles Overlaid with Lab Thermal Profiles

6.3 In-Situ Temperature Measurement

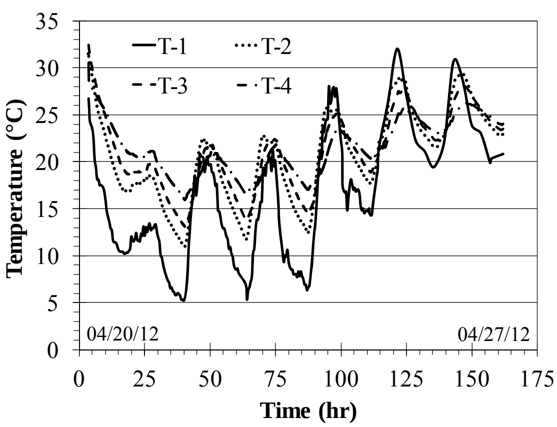
Figure 6.4 plots in-situ probe temperatures over time for each of the 6 locations, and time was synchronized to the first mixing pass at each location. Refer to Figure 4.15b for a schematic of probe sensor locations. Overall, in-situ probes were unable to detect temperature profiles produced from cement hydration. The ambient air temperature (T-1) experienced the most dramatic swings in temperature, and each of the thermocouple sensors located within the soil-cement layer (T-2, T-3, and T-4) recorded smaller swings in temperature. The magnitude of temperature swings recorded within the soil-cement layer was probably a function of the amount of insulation provided by the layer itself. For *SR9* (Figures 6.4a, 6.4c, and 6.4e), temperatures generally ranged between 5 and 35 °C. For *SR475* (Figures 6.4b, 6.4d, and 6.4f), temperatures generally ranged between 20 and 45 °C. The recorded ambient temperature (T-1) was used to calculate the *TTF* of molded field cured compressive strength specimens and field cores.



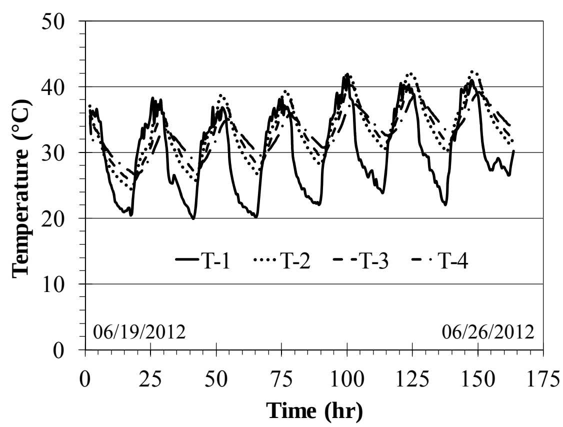
(a) *SR9* Location 1



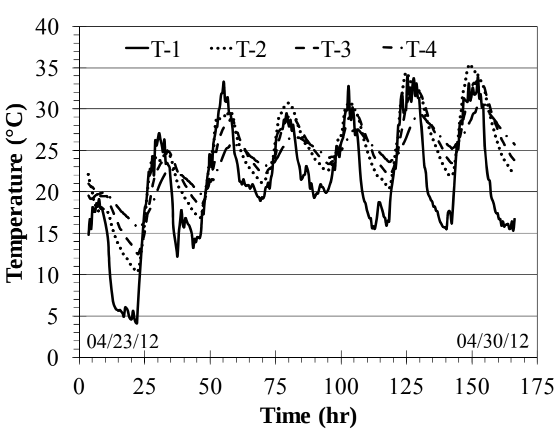
(b) *SR475* Location 1



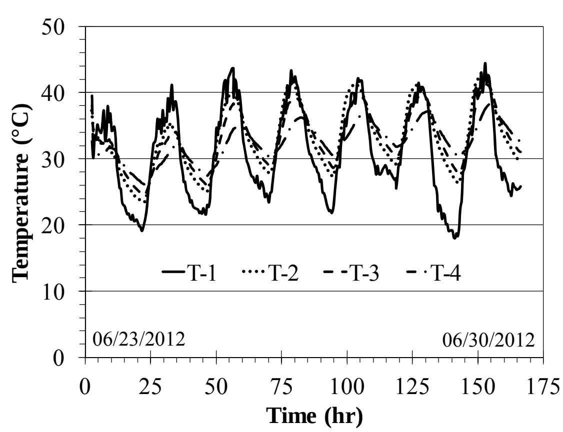
(c) *SR9* Location 2



(d) *SR475* Location 2



(e) *SR9* Location 3



(f) *SR475* Location 3

Figure 6.4 Temperature Plots of In-Situ Probes

6.4 Compressive Strength Specimens

Field compressive strength data analyzed in this section are from Series 35 through 46, and raw data is contained in Appendix B. All field made specimens were tested for compressive strength after 7 days of curing. Compressive strength specimens consist of thermal profile specimens (noted as lab cured), field cured specimens (molded using the *PM-P* hammer approach), and field cores cut from the roadway as described in Section 4.7.5. Figure 6.5 compares the average σ_{max} for lab cured, field cured, and field core specimens. The average *TTF* at the test time is reported in Figure 6.5. Reported σ_{max} values were adjusted for density (Eq 5.1) and specimen size (as per *ASTM D 1633*); so that, σ_{max} are comparable to the target σ_{max} of 2070 kPa. Table 6.2 expands upon the results shown in Figure 6.5 and presents a comparison between molded specimens and field cores. Both the field cured and field core specimens have approximately the same *TTF*.

For both *SR9* and *SR475*, the field cured specimens had a higher average σ_{max}, and with exception of one case, the field cores recorded average σ_{max} lower than both the lab and field cured specimens. For *SR9* (Figure 6.5a), the field cured specimens had a higher average σ_{max} with a lower *TTF* ($\approx$ 3000 °C-hr) than the lab cured ($\approx$ 4000 °C-hr), which is counter intuitive. Field cured specimens were prepared using mixed material from positions 4, 5, 3, and 2, and lab cured specimens were prepared using control mixtures and mixed material from positions 1, 2, and 3. Some discrepancy in Figure 6.5 could be attributed to varying cement contents among sample positions. For *SR475*, field cured specimens had a higher average σ_{max} and a higher *TTF*, which was expected.

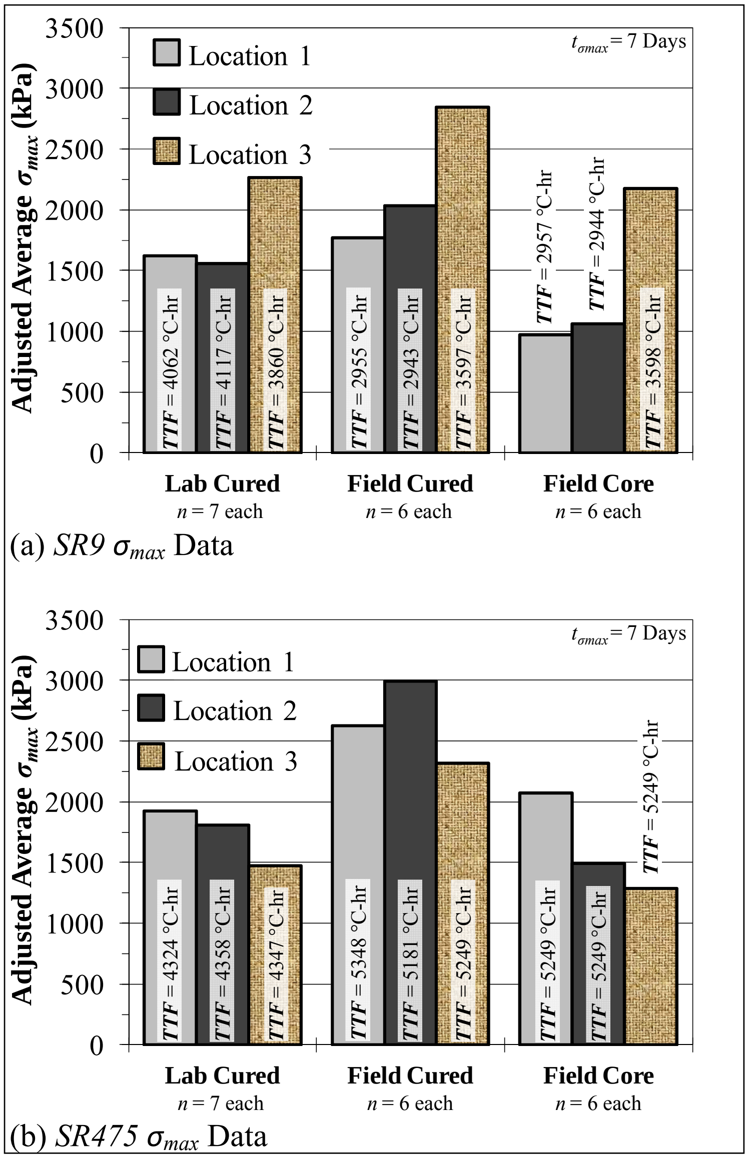


Figure 6.5 Field Compressive Strength Results

Table 6.2 Molded Specimens and Field Cores σ_{max} Comparison

		Field Cured		Field Cores	
Project	**Location**	**Mean (kPa)**	***COV* (%)**	**Mean (kPa)**	***COV* (%)**
SR9	1	1772	18.3	970	22.4
SR9	2	2032	37.9	1063	7.2
SR9	3	2844	32.7	2177	8.2
SR475	1	2627	6.0	2073	17.1
SR475	2	2993	18.1	1490	9.9
SR475	3	2315	19.2	1289	6.5

Note: Some SR475 cores req'd capping prior to testing (noted in Appendix B), and no SR9 cores req'd capping.

As seen in Table 6.2, the *SR9* field cured specimens have a noticeably high *COV* (18 to 38 %) suggesting a higher variability in σ_{max}. Thermal profile results in Section 6.2 indicate some variability in cement content for *SR9* at Locations 2 and 3; therefore, high *COV*'s could be the result of variations in cement content among sample positions. *SR9* field cores were less variable with *COV*'s from 7 to 22 %. On average, the *SR9* field core compressive strengths were 33 to 48 percent less than the field cured specimens, which were molded with the *PM-P* hammer approach. For *SR475*, the field cured specimens and the field cores had approximately the same *COV*'s (6 to 19 %). On average, compressive strengths of *SR475* field cores were 29 to 50 percent less than the molded field cured specimens.

6.5 Traffic Opening

This section provides general guidance for a potential method to determine when a soil-cement layer can be opened to traffic. The approach presented incorporates maturity methods coupled with conventional compressive strength testing. Laboratory specimens were used to develop generalized trendlines characterizing the strength gain of soil-cement mixtures having an *MT-25* required 7 day cure time. These curves could be used to estimate a *TTF* in which the design σ_{max} is achieved. Compressive strength data from field specimens prepared using the *PM-P* compaction technique was used to evaluate the traffic opening approach.

Three trendline bands (Figure 6.6) were developed using data from Chapter 5 (Series 5, 6, 7, 10, and 15). These specimens were prepared using the *PM-CF* compaction approach; therefore, the measured σ_{max} was adjusted to equivalent strengths observed using the *PM-P* compaction approach. Development of the adjustment factor is outside the scope of this thesis, but can be found in other efforts related to *MDOT* State Study 206. The multiplied adjustment factor for *Pit A*, *Pit B*, and *Pit C* was 0.94, 0.80, and 0.72, respectively. After adjusting the σ_{max} for compaction type and specimen size (*ASTM D 1633*), the σ_{max} was normalized to reflect the percentage of the design σ_{max} (2070 kPa).

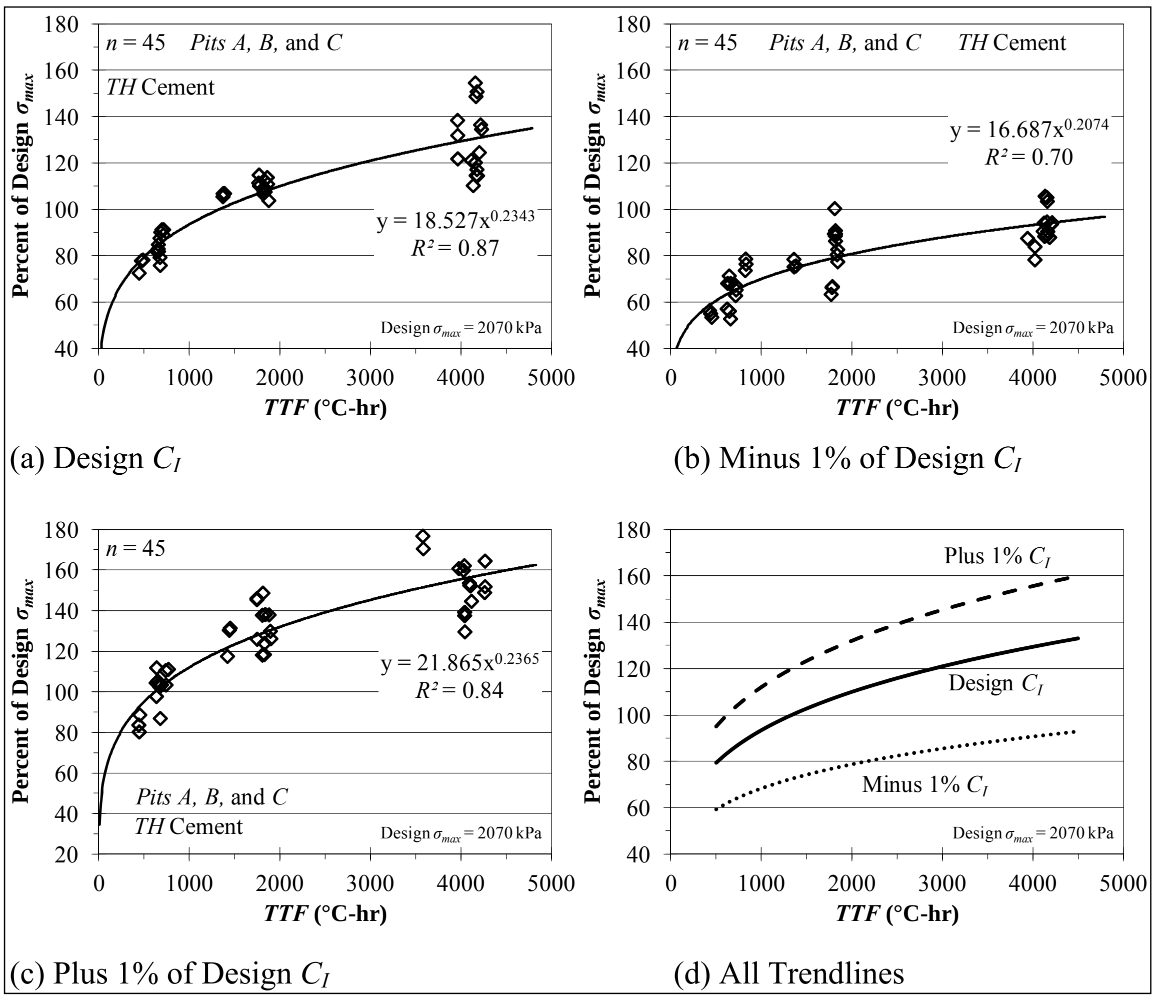


Figure 6.6 Development of Traffic Opening Guidance Trendlines

Figures 6.6a, 6.6b, and 6.6c show good power fits for the relationship between *TTF* and normalized σ_{max} (R^2 = 0.70 to 0.87). Figure 6.6d shows the trendlines from Figures 6.6a, 6.6b, and 6.6c. These three trendline bands are meant to provide insight to the level of maturity (*TTF*) required to achieve the design σ_{max}. Figure 6.7 shows the average σ_{max} of the lab cured and field cured specimens for *SR9* and *SR475* plotted against the trendline bands developed in Figure 6.6.

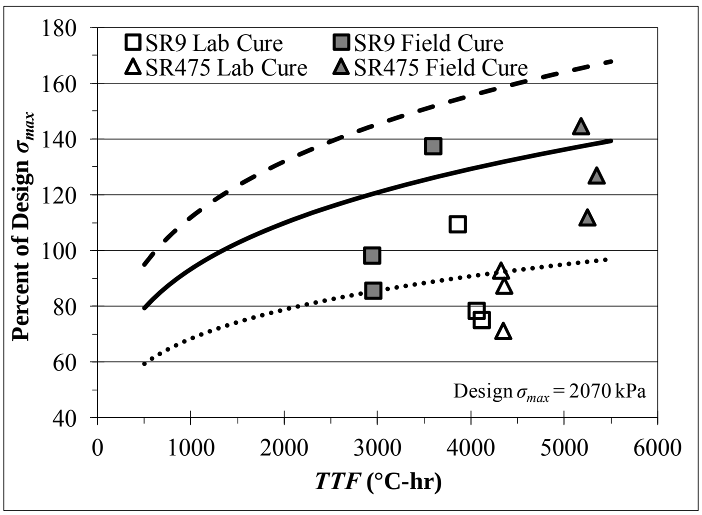


Figure 6.7 Traffic Opening Verification with Average *SR9* and *SR475* σ_{max} Results

As seen in Figure 6.7, all six averaged field cured σ_{max} data points fall between the design $C_I \pm 1\%$ trendlines. Four of the six averaged lab cured σ_{max} data points fall below the minus 1% of design C_I trendline. Lower strengths observed with some of the averaged lab cured specimens is not fully understood and may require further investigation by means of additional analysis and/or further testing.

CHAPTER 7

CONCLUSIONS AND RECOMMENDATIONS

7.1 Conclusions

Based on the information and test data presented in this thesis, the overall conclusions are: 1) the current *MDOT* soil-cement laboratory design procedures could benefit from enhancements with respect to lab protocols that allow coordination with a field quality control program; 2) thermal measurement techniques developed in this thesis have merit for characterizing soil-cement mixtures; and 3) incorporating the developed thermal measurement techniques and/or specimen compaction protocols into a field quality control program seems to offer some potential advantages that warrant further exploration. Specific conclusions from this thesis are provided in the following list.

- The *MDOT* soil-cement database (Chapter 3) proved to be very insightful to the current practice of soil-cement in the state of Mississippi. Archiving data in a manner suitable for quick analysis can be of great benefit. Specific observations derived from the database can be found in Section 3.5.

- The specimen compaction method developed in this thesis is capable of compacting soil-cement mixtures into 76.2 by 152.4 mm single-use plastic molds with manageable deformations. This approach allows thermal measurement and compressive strength tests to be performed on the same specimen.

- Thermal measurement analysis revealed that T_{max}, ΔT, and A_s are likely the most useful characteristics of the measured thermal profiles. In most cases, the thermal profile results were able to statistically differentiate between cement contents at 2% C_I intervals, and in some cases at 1% C_I intervals. Although, practically speaking the recorded differences are small.

- Additional thermal measurement analysis revealed that measured thermal profiles are sensitive to initial material temperatures (T_i) and the initial temperature of the thermal measurement device (T_{BL}). Thermal profiles are also sensitive to the ambient air temperatures surrounding the thermal measurement device during testing. These effects are not fully understood and warrant further investigation.

- Incorporating thermal measurements into a field quality control program may be feasible. Thermal profile results coupled with compressive strength data may be able to provide insight into the variability of cement content as well as performance of the constructed soil-cement layer.

7.2 Recommendations

Thermal measurements have shown promise as a potentially useful tool for characterizing soil-cement mixtures. It is recommended that further analysis and investigation be conducted to determine how thermal measurements can be effectively utilized in soil-cement practices. Specific recommendations are included in the following list.

- It is recommended that additional analysis and investigation be conducted to further understand the effects of initial material temperature (T_i) and initial temperature of the thermal measurement device (T_{BL}) on measured thermal profiles. It is also recommended that alternative equipment configurations and/or preparation protocols be explored to possibly reduce the influence of ambient temperatures on thermal measurements. For example, thermal measurement devices with higher insulation and/or a standardized conditioning regime for materials and devices.

- It is recommended that additional investigation be conducted to implement field measured thermal profiles and molded compressive strength specimens into an overall field quality control program. Future investigation should focus on using thermal measurements for a relative comparison between specimens contained within the same device at the same time. For example, compare field mixed materials with control mixed materials of known proportions of soil, water, and cement. Additional field studies using thermal measurements coupled with other accepted methods for determining cement contents of soil-cement mixtures (i.e. *ASTM D 806*) may provide a better indication of how well thermal measurements are able to distinguish between cement contents in the field.

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APPENDIX A

MDOT SOIL-CEMENT DATABASE

Table A.1 *MDOT* Soil-Cement Database: Soil Properties (1 of 2)

Mix ID[1]	*MDOT* District	Year	$\omega_{air-dried}$[2] (%)	Atterberg Limits[3]						Soil Gradation Percent Passing (mm)											
				LL	*PL*	*PI*	*SL*	*SR*	*VC*	63.0	50.0	45.0	37.5	25.0	12.5	9.50	4.75	2.00	0.425	0.250	0.075
1 A	5	2011	0.5	*NP*	*NP*	*NP*	--	--	--	100	100	100	100	100	100	100	100	100	83	64	21
2 B	1	2011	1.3	*NP*	*NP*	*NP*	--	--	--	100	100	100	100	100	100	100	100	100	96	65	25
3 C	7	2011	0.7	*NP*	*NP*	*NP*	--	--	--	100	100	100	100	100	100	100	100	100	93	59	29
4 (1A)	5	2010	0.5	*NP*	*NP*	*NP*	--	--	--	100	100	100	100	100	100	100	100	100	66	41	14
5 (2B)	1	2010	0.3	*NP*	*NP*	*NP*	--	--	--	100	100	100	100	100	100	100	100	100	97	62	11
6 (3C)	7	2011	1.1	23	14	9	11.9	1.84	20.2	100	100	100	100	100	100	100	100	100	95	67	40
7	7	2005	0.5	20	10	10	14.9	1.76	10.7	--	--	--	--	--	--	--	--	--	--	--	--
8	6	2005	1.0	18	11	7	13.6	1.84	7.7	100	100	100	100	100	99	--	94	87	72	43	21
9	7	2005	1.0	21	13	8	12.3	1.84	16.9	100	100	100	100	99	92	--	84	78	64	45	25
10	7	2005	1.5	20	14	6	12.1	1.82	13.7	--	--	--	--	--	--	--	--	--	--	--	--
11	7	2005	2.0	22	12	10	14.8	1.78	15.7	100	100	100	100	100	100	100	100	100	91	64	30
12	7	2005	1.8	20	11	9	11.4	1.88	15.4	100	100	100	100	100	100	100	100	100	92	66	36
13	1	2005	1.4	*NP*	*NP*	*NP*	--	--	--	100	100	100	100	100	100	100	100	100	96	80	15
14	3	2005	1.5	*NP*	*NP*	*NP*	--	--	--	100	100	100	100	100	100	100	100	100	93	73	19
15	2	2005	0.7	*NP*	*NP*	*NP*	--	--	--	100	100	100	100	95	83	-	75	72	62	50	12
16	2	2005	1.5	*NP*	*NP*	*NP*	--	--	--	100	100	100	100	100	100	100	100	100	96	51	13
17	2	2005	0.8	16	14	2	11.8	1.86	7.8	100	100	100	100	100	100	100	100	100	82	60	31
18	7	2005	1.7	*NP*	*NP*	*NP*	--	--	--	100	100	100	100	100	100	100	100	100	95	83	31
19	7	2005	3.2	*NP*	*NP*	*NP*	--	--	--	100	100	100	100	100	100	100	100	100	77	49	24
20	5	2005	0.9	22	13	9	12.6	1.85	15.5	100	100	100	100	100	100	100	100	100	62	36	23
21	5	2005	0.9	22	13	9	12.6	1.85	15.5	100	100	100	100	100	100	100	100	100	62	36	23
22	7	2005	0.7	*NP*	*NP*	*NP*	--	--	--	100	100	100	100	100	100	100	100	100	93	61	9
23	7	2005	0.8	*NP*	*NP*	*NP*	--	--	--	100	100	100	100	100	100	100	100	100	96	73	17
24	7	2005	0.5	*NP*	*NP*	*NP*	--	--	--	100	100	100	100	100	100	100	100	100	98	79	16
25	7	2005	0.8	*NP*	*NP*	*NP*	--	--	--	100	100	100	100	100	100	100	100	100	90	64	31
26	2	2005	0.8	19	12	7	12.5	1.81	10.3	100	100	98	--	96	85	--	76	68	42	15	11
27	7	2005	0.4	*NP*	*NP*	*NP*	--	--	--	100	100	100	100	100	100	100	100	100	88	54	19
28	7	2005	0.8	16	10	6	11.4	1.9	8.0	100	100	100	100	100	87	--	62	51	39	23	14
29	2	2005	0.9	20	13	7	11.4	1.82	14.9	100	100	100	100	99	93	--	80	70	47	22	14
30	7	2005	1.1	20	13	7	12.7	1.83	11.7	100	100	100	100	100	100	100	100	100	92	65	34
31	2	2005	0.7	20	12	8	13.3	1.75	10.9	100	100	100	99	92	77	77.0	56	45	33	15	9
32	7	2006	1.0	25	18	7	15.1	1.67	15.7	100	100	100	100	100	100	100	100	100	90	61	22
33	2	2006	0.7	19	10	9	11.2	1.89	14.6	100	100	100	99	92	75	--	60	51	31	18	12
34	5	2006	1.2	*NP*	*NP*	*NP*	--	--	--	100	100	100	100	100	100	100	100	100	98	75	20
35	2	2006	0.6	20	10	10	11.8	1.91	15.7	100	98	-	97	89	72	--	57	49	29	18	12
36	1	2006	0.7	*NP*	*NP*	*NP*	--	--	--	100	100	100	100	100	100	100	100	100	93	76	16

Table A.1 (continued)

Mix ID[1]	*MDOT* District	Year	$\omega_{air\text{-}dried}$[2] (%)	Atterberg Limits[3]						Soil Gradation Percent Passing (mm)											
				LL	*PL*	*PI*	*SL*	*SR*	*VC*	63.0	50.0	45.0	37.5	25.0	12.5	9.50	4.75	2.00	0.425	0.250	0.075
37	3	2006	1.0	*NP*	*NP*	*NP*	--	--	--	100	100	100	99	96	84.6	--	72	66	43	15	11
38	1	2006	1.2	*NP*	*NP*	*NP*	--	--	--	100	100	100	100	100	100	100	100	100	83	45	23
39	1	2006	1.3	*NP*	*NP*	*NP*	--	--	--	100	100	100	100	100	97	--	92	88	75	45	21
40	3	2006	0.4	22	11	10	11.6	1.88	19.4	100	100	100	100	100	100	100	100	100	66	41	34
41	1	2007	0.6	19	15	4	14.7	1.81	8.0	100	100	100	100	99	88	--	67	55	40	24	17
42	5	2007	0.5	*NP*	*NP*	*NP*	--	--	--	100	100	100	100	100	100	100	100	100	92	56	21
43	7	2007	1.6	21	12	9	11.5	1.85	21.8	100	100	100	100	100	100	100	100	100	91	71	40
44	7	2007	1.3	26	17	9	14.1	1.75	20.7	100	100	100	100	100	100	100	100	100	97	80	32
45	7	2007	0.5	*NP*	*NP*	*NP*	--	--	--	100	100	100	100	100	100	100	100	100	64	23	15
46	7	2007	1.0	*NP*	*NP*	*NP*	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
47	3	2007	0.9	*NP*	*NP*	*NP*	--	--	--	100	100	100	99	95	81	--	70	66	50	20	11
48	5	2007	1.0	*NP*	*NP*	*NP*	--	--	--	100	100	100	100	100	100	100	100	100	100	81	18
49	7	2007	1.3	*NP*	*NP*	*NP*	--	--	--	100	100	100	100	100	100	100	100	100	90	64	32
50	7	2007	2.4	*NP*	*NP*	*NP*	--	--	--	100	100	100	100	100	100	100	100	100	98	74	20
51	5	2008	0.7	*NP*	*NP*	*NP*	--	--	--	100	100	100	100	100	100	100	100	100	99	71	18
52	7	2008	0.8	23	14	9	12.9	1.82	18.6	100	100	100	100	100	100	100	100	100	92	70	33
53	7	2008	0.3	18	14	4	10.0	1.87	14.8	100	100	100	100	98	79	--	50	38	20	11	6
54	6	2008	0.6	*NP*	*NP*	*NP*	--	--	--	100	100	100	100	100	100	100	100	100	87	64	30
55	6	2008	1.2	18	14	4	13.1	1.85	8.5	100	100	100	100	100	100	100	100	100	92	65	38
56	7	2008	0.5	18	13	5	14.0	1.85	7.2	100	100	100	100	98	87	81	72	60	57	44	24
57	6	2008	0.5	*NP*	*NP*	*NP*	--	--	--	100	100	100	100	100	100	100	100	100	91	59	11
58	1	2008	1.0	*NP*	*NP*	*NP*	--	--	--	100	100	100	100	100	99	--	97	95	58	23	12
59	6	2008	1.2	*NP*	*NP*	*NP*	--	--	--	100	100	100	100	100	100	100	100	100	95	73	31
60	6	2008	2.3	*NP*	*NP*	*NP*	--	--	--	100	100	100	100	100	100	100	100	100	86	59	25
61	6	2008	0.5	*NP*	*NP*	*NP*	--	--	--	100	100	100	100	100	100	100	100	100	89	65	25
62[4]	6	2008	1.7	25	18	7	15.4	1.76	15.0	100	100	100	100	100	100	100	100	100	95	77	39
63[4]	6	2008	0.4	*NP*	*NP*	*NP*	--	--	--	100	100	100	100	100	100	100	100	100	94	71	33
64[4]	6	2008	1.4	*NP*	*NP*	*NP*	--	--	--	100	100	100	100	100	100	100	100	100	95	79	39
65	5	2009	0.5	*NP*	*NP*	*NP*	--	--	--	100	100	100	100	100	100	100	100	100	94	42	22
66	5	2009	1.3	20	14	6	12.4	1.79	12.7	100	100	100	100	94	76	76	60	53	40	20	13
67	6	2009	0.6	*NP*	*NP*	*NP*	--	--	--	100	100	100	100	100	100	100	100	100	89	62	26
68	6	2009	0.6	22	16	6	14.3	1.78	12.6	100	100	100	100	100	100	100	100	100	88	62	28
69	6	2009	2.9	*NP*	*NP*	*NP*	--	--	--	100	100	100	100	100	100	100	100	100	88	64	30
70	6	2009	1.6	*NP*	*NP*	*NP*	--	--	--	100	100	100	100	100	100	100	100	100	97	54	29
71	6	2009	0.4	*NP*	*NP*	*NP*	--	--	--	100	100	100	100	100	100	100	100	100	74	29	16
72	6	2009	1.2	*NP*	*NP*	*NP*	--	--	--	100	100	100	100	100	100	100	100	100	90	75	27

Table A.1 (continued)

Mix ID[1]	*MDOT* District	Year	$\omega_{air\text{-}dried}$[2] (%)	Atterberg Limits[3]						Soil Gradation Percent Passing (mm)											
				LL	*PL*	*PI*	*SL*	*SR*	*VC*	63.0	50.0	45.0	37.5	25.0	12.5	9.50	4.75	2.00	0.425	0.250	0.075
73	7	2009	0.9	*NP*	*NP*	*NP*	--	--	--	100	100	100	100	100	100	100	100	100	75	36	10
74	5	2009	0.6	*NP*	*NP*	*NP*	--	--	--	100	100	100	100	100	100	100	99	98	74	33	11
75	1	2009	0.1	*NP*	*NP*	*NP*	--	--	--	100	100	100	100	100	100	100	100	100	96	84	17
76	5	2009	0.2	*NP*	*NP*	*NP*	--	--	--	100	100	100	100	100	100	100	100	100	76	33	7
77	1	2009	1.2	*NP*	*NP*	*NP*	--	--	--	100	100	100	100	100	100	100	100	100	98	82	30
78	1	2009	0.2	*NP*	*NP*	*NP*	--	--	--	100	100	100	100	100	100	100	100	100	97	71	13
79	5	2010	0.2	*NP*	*NP*	*NP*	--	--	--	100	100	100	100	100	100	100	100	100	99	85	12
80	5	2010	1.6	26	16	10	14.5	1.81	20.3	100	100	100	100	100	100	100	100	100	74	50	31
81	2	2010	0.5	*NP*	*NP*	*NP*	--	--	--	100	100	100	100	100	100	100	100	100	92	72	33
82	5	2010	0.7	21	14	7	12.9	1.83	15.6	100	100	100	100	100	100	100	100	100	86	59	33
83	5	2010	0.8	*NP*	*NP*	*NP*	--	--	--	100	100	100	100	100	100	100	100	100	98	73	24
84	5	2010	1.1	*NP*	*NP*	*NP*	--	--	--	100	100	100	100	100	100	100	100	100	85	42	20
85	5	2010	0.5	*NP*	*NP*	*NP*	--	--	--	100	100	100	100	100	100	100	100	100	100	81	12
86	1	2010	0.7	*NP*	*NP*	*NP*	--	--	--	100	100	100	100	100	100	100	100	100	99	72	14
87	1	2010	1.7	28	18	10	15.4	1.74	21.9	100	100	100	100	100	89	89	73	66	49	31	21
88	5	2010	0.4	*NP*	*NP*	*NP*	--	--	--	100	100	100	100	100	100	100	100	100	87	53	26
89	6	2010	0.3	*NP*	*NP*	*NP*	--	--	--	100	100	100	100	100	100	100	100	100	67	24	13
90	3	2010	0.7	*NP*	*NP*	*NP*	--	--	--	100	100	100	100	100	100	100	100	100	76	23	15
91	7	2010	0.6	*NP*	*NP*	*NP*	--	--	--	100	100	100	100	100	100	100	100	100	87	48	18
92	7	2010	0.4	*NP*	*NP*	*NP*	--	--	--	100	100	100	99	96	87	87	78	72	44	11	6
93	7	2010	0.7	*NP*	*NP*	*NP*	--	--	--	100	100	100	100	100	92	92	83	77	66	38	16
94	7	2010	1.0	21	11	10	11.4	1.88	17.1	100	100	100	100	100	100	100	100	100	84	54	36

Note: Shading of table rows is for ease of reading.

1: Mix IDs 1, 2, and 3 are the pit soils tested in this work. Mix IDs 4, 5, and 6 are project mix designs that correspond to the pit soils tested in the current work.

2: Moisture Content of air-dried processed soil.

3: LL = Liquid Limit (%), PL = Plastic Limit (%), PI = Plasticity Index (%), SL = Shrinkage Limit (%), SR = Shrinkage Ratio, VC = Volume Change (%).

4: Mix design utilizes Type II portland cement. All other mixtures utilize Type I portland cement.

Table A.2 *MDOT* Soil-Cement Database: Soil Properties (2 of 2)

Mix ID[1]	*MDOT* District	Year	Soluble Sulfate (%)	Untreated Proctor			Treated Proctor			
				G_{sb}[2]	*OMC* (%)	γ_d (kg/m^3)	C_I (%)	G_{sb}[2]	*OMC* (%)	γ_d (kg/m^3)
1 A	5	2011	0.00	--	12.6	1910	5.0	--	11.8	1919
2 B	1	2011	0.00	--	13.4	1850	5.0	--	14.2	1873
3 C	7	2011	0.00	--	11.1	1956	5.0	--	11.0	1975
4 (1A)	5	2010	0.03	--	11.9	1863	5.0	--	10.6	1983
5 (2B)	1	2010	0.01	--	15.5	1725	6.5	--	15.2	1810
6 (3C)	7	2011	0.00	--	11.3	1962	4.0	--	11.7	1958
7	7	2005	--	--	11.2	1966	4.0	--	11.8	1948
8	6	2005	--	--	10.4	2014	4.0	--	10.4	2014
9	7	2005	--	--	11.0	1983	5.0	--	11.3	1967
10	7	2005	--	--	11.8	1945	4.0	--	11.4	1945
11	7	2005	0.00	--	11.6	1953	4.0	--	12.8	1921
12	7	2005	0.01	--	10.6	1988	4.0	--	10.9	1994
13	1	2005	0.02	--	14.0	1887	5.0	--	13.6	1886
14	3	2005	0.00	--	11.7	1885	4.0	--	11.1	1940
15	2	2005	0.01	2.51	11.5	1945	6.0	2.51	10.9	1978
16	2	2005	0.01	--	14.0	1765	5.0	--	14.0	1809
17	2	2005	0.09	--	10.5	1982	3.5	--	10.5	2015
18	7	2005	0.08	--	11.5	1935	4.0	--	11.2	1943
19	7	2005	0.08	--	16.5	1745	5.0	--	16.3	1762
20	5	2005	0.01	--	10.9	1983	4.0	--	10.5	1988
21	5	2005	0.01	--	10.9	1983	4.0	--	10.5	1988
22	7	2005	0.08	--	13.2	1765	6.0	--	12.1	1884
23	7	2005	0.00	--	11.1	1857	5.0	--	12.6	1927
24	7	2005	0.00	--	13.4	1740	5.0	--	10.5	1914
25	7	2005	0.00	--	9.5	2022	5.0	--	9.7	2019
26	2	2005	0.01	2.55	7.9	2087	6.0	2.55	8.0	2107
27	7	2005	0.01	--	10.7	1916	4.5	--	10.7	1977
28	7	2005	0.01	2.47	6.7	2145	4.0	2.47	6.8	2142
29	2	2005	0.01	2.50	9.2	2038	5.0	2.50	8.8	2022
30	7	2005	0.00	--	10.1	1977	5.0	--	10.8	1969
31	2	2005	0.02	2.47	6.3	2095	7.0	2.47	6.2	2134
32	7	2006	0.00	--	12.9	1892	6.0	--	12.2	1908
33	2	2006	0.00	2.48	6.7	2163	6.0	2.48	7.0	2168
34	5	2006	0.02	--	12.8	1833	6.0	--	12.5	1874
35	2	2006	0.00	2.48	6.2	2177	6.0	2.48	6.6	2185
36	1	2006	0.00	--	15.5	1775	6.0	--	15.1	1805

Table A.2 (continued)

Mix ID[1]	*MDOT* District	Year	Soluble Sulfate (%)	Untreated Proctor			Treated Proctor			
				G_{sb}[2]	*OMC* (%)	γ_d (kg/m^3)	C_I (%)	G_{sb}[2]	*OMC* (%)	γ_d (kg/m^3)
37	3	2006	0.00	2.53	7.9	2105	5.0	2.53	8.0	2143
38	1	2006	0.01	--	14.4	1842	5.0	--	15.3	1855
39	1	2006	0.00	--	14.3	1839	5.0	--	14.1	1852
40	3	2006	0.00	--	13.2	1876	7.0	--	14.7	1841
41	1	2007	0.03	2.61	8.3	2121	7.0	2.61	8.9	2083
42	5	2007	0.16	--	15.4	1733	6.0	--	14.0	1794
43	7	2007	0.06	--	10.1	2006	4.0	--	11.5	1948
44	7	2007	0.04	--	13.2	1882	4.5	--	13.9	1876
45	7	2007	0.07	--	10.3	1984	4.0	--	9.9	1997
46	7	2007	0.14	--	13.2	1836	5.0	--	11.9	1894
47	3	2007	0.14	2.58	7.9	2124	5.0	2.58	7.3	2143
48	5	2007	0.19	--	13.6	1809	5.5	--	13.9	1837
49	7	2007	0.09	--	9.9	2014	4.0	--	9.4	2028
50	7	2007	0.09	--	13.0	1868	4.0	--	12.8	1886
51	5	2008	0.02	--	14.1	1767	6.0	--	12.9	1837
52	7	2008	0.05	--	11.3	1969	7.0	--	13.5	1924
53	7	2008	0.02	2.52	6.9	2198	5.0	2.52	6.9	2193
54	6	2008	0.03	--	10.2	2010	5.0	--	9.9	2022
55	6	2008	0.05	--	10.5	2001	5.5	--	10.1	2011
56	7	2008	0.00	2.38	9.9	2003	5.0	2.38	10.1	2030
57	6	2008	0.00	--	12.3	1753	6.0	--	10.9	1844
58	1	2008	0.00	--	13.9	1828	5.0	--	13.0	1895
59	6	2008	0.00	--	11.2	1894	5.0	--	10.0	1953
60	6	2008	0.00	--	12.1	1922	4.0	--	11.2	1974
61	6	2008	0.00	--	11.7	1932	4.0	--	10.3	1966
62[3]	6	2008	0.00	--	12.8	1911	4.0	--	12.3	1895
63[3]	6	2008	0.00	--	9.0	1998	4.0	--	9.2	2009
64[3]	6	2008	0.00	--	10.8	1916	6.0	--	9.8	1956
65	5	2009	0.03	--	13.6	1842	6.0	--	14.2	1871
66	5	2009	0.07	2.53	7.0	2131	6.0	2.53	7.3	2131
67	6	2009	0.05	--	11.0	1943	4.0	--	11.2	1967
68	6	2009	0.05	--	10.9	1945	4.0	--	11.3	1951
69	6	2009	0.05	--	11.1	1943	4.0	--	11.3	1969
70	6	2009	0.00	--	14.5	1816	4.0	--	14.9	1829
71	6	2009	0.01	--	11.9	1892	5.0	--	10.9	1980
72	6	2009	0.03	--	12.5	1903	4.0	--	12.1	1935

Table A.2 (continued)

Mix ID[1]	*MDOT* District	Year	Soluble Sulfate (%)	Untreated Proctor			Treated Proctor			
				G_{sb}[2]	*OMC* (%)	γ_d (kg/m^3)	C_I (%)	G_{sb}[2]	*OMC* (%)	γ_d (kg/m^3)
73	7	2009	0.03	--	12.7	1818	7.0	--	11.0	1911
74	5	2009	0.03	--	14.0	1737	6.0	--	12.3	1820
75	1	2009	0.04	--	14.2	1775	6.5	--	12.1	1842
76	5	2009	0.01	--	15.9	1671	7.0	--	13.0	1813
77	1	2009	0.04	--	12.6	1876	5.0	--	12.2	1905
78	1	2009	0.08	--	13.6	1729	7.0	--	12.7	1821
79	5	2010	0.02	--	13.4	1778	6.0	--	12.4	1834
80	5	2010	0.02	--	11.3	1964	4.0	--	10.1	2009
81	2	2010	0.03	--	10.7	1994	4.0	--	10.1	1977
82	5	2010	0.05	--	10.8	1990	5.0	--	10.5	1988
83	5	2010	0.05	--	12.5	1892	5.0	--	11.6	1919
84	5	2010	0.02	--	12.7	1879	4.0	--	12.2	1914
85	5	2010	0.00	--	12.0	1759	6.0	--	11.1	1839
86	1	2010	0.00	--	15.3	1748	4.0	--	15.2	1785
87	1	2010	0.00	2.49	10.4	1978	6.0	2.49	12.4	1897
88	5	2010	0.00	--	11.7	1919	5.0	--	12.1	1935
89	6	2010	0.02	--	12.5	1843	5.0	--	11.6	1894
90	3	2010	0.00	--	12.5	1876	6.5	--	12.4	1919
91	7	2010	0.00	--	10.4	1934	5.0	--	10.8	1958
92	7	2010	0.00	2.60	7.8	1986	6.0	2.60	7.5	2065
93	7	2010	0.01	2.20	10.9	1953	5.0	2.20	9.8	1991
94	7	2010	0.01	--	9.4	2023	4.0	--	10.4	2019

Note: Shading of table rows is for ease of reading.

1: Mix IDs 1, 2, and 3 are the pit soils tested in this work. Mix IDs 4, 5, and 6 are project mix designs that correspond to the pit soils tested in the current work.

2: Bulk Specific Gravity of material retained on 12.5 mm sieve.

3: Mix design utilizes Type II portland cement. All other mixtures utilize Type I portland cement.

Table A.3 *MDOT* Soil-Cement Database: *MT-25* Batch Weights

Mix ID[1]	*MDOT* District	Year	Design Cement Index (%)	Design Curing Time (days)	Cement Index (%)			Weight of Cement (g)			Weight of Soil (g)			Weight of Water (g)		
					Mix 1	Mix 2	Mix 3	Mix 1	Mix 2	Mix 3	Mix 1	Mix 2	Mix 3	Mix 1	Mix 2	Mix 3
1 A	5	2011	5.0	14	4.0	5.0	6.0	--	--	--	--	--	--	--	--	--
2 B	1	2011	5.0	7	4.0	5.0	6.0	--	--	--	--	--	--	--	--	--
3 C	7	2011	4.0	7	4.0	5.0	6.0	--	--	--	--	--	--	--	--	--
4 (1A)	5	2010	5.0	7	4.0	5.0	6.0	150.3	189.3	229.4	4500.0	4500.0	4500.0	459.9	473.2	477.2
5 (2B)	1	2010	6.5	7	6.5	7.0	8.0	270.6	292.8	337.8	4500.0	4500.0	4500.0	529.5	532.0	532.2
6 (3C)	7	2011	4.0	7	4.0	4.5	5.0	142.5	160.9	198.3	4500.0	4500.0	4500.0	501.4	512.7	516.8
7	7	2005	4.0	7	4.0	5.0	6.0	142.3	179.2	216.8	4536.0	4536.0	4536.0	510.6	514.7	528.3
8	6	2005	4.0	14	3.0	4.0	5.0	105.2	141.3	178.0	4522.5	4522.5	4522.5	455.9	468.8	472.5
9	7	2005	5.0	7	--	--	--	--	--	--	--	--	--	--	--	--
10	7	2005	4.0	7	3.0	4.0	5.0	107.0	143.8	181.2	4563.0	4563.0	4563.0	460.7	473.7	477.5
11	7	2005	4.0	14	4.0	5.0	6.0	143.2	180.5	218.3	4545.0	4545.0	4545.0	547.9	561.7	566.2
12	7	2005	4.0	14	3.0	4.0	5.0	104.6	140.6	176.5	4558.5	4558.5	4558.5	442.0	454.8	458.3
13	1	2005	5.0	14	4.0	5.0	6.0	148.4	187.0	226.3	4612.5	4612.5	4612.5	516.0	529.6	534.1
14	3	2005	4.0	14	4.0	5.0	6.0	148.5	187.2	226.5	4540.5	4540.5	4540.5	474.1	487.5	491.6
15	2	2005	6.0	14	4.0	5.0	6.0	150.7	190.0	230.0	5625.0	5625.0	5625.0	548.8	553.4	558.1
16	2	2005	6.0	14	4.0	5.0	6.0	159.0	200.5	242.7	4536.0	4536.0	4536.0	615.0	629.9	635.5
17	2	2005	3.5	7	3.5	4.5	5.5	122.6	158.9	195.8	4545.0	4545.0	4545.0	439.2	451.9	460.2
18	7	2005	4.0	7	3.0	4.0	5.0	107.6	144.6	182.2	4500.0	4500.0	4500.0	433.1	450.2	454.2
19	7	2005	5.0	7	5.0	6.0	7.0	203.0	245.8	289.4	4500.0	4500.0	4500.0	498.5	512.5	517.3
20	5	2005	4.0	7	3.0	4.0	5.0	104.9	141.0	177.6	4500.0	4500.0	4500.0	442.1	445.5	449.0
21	5	2005	4.0	7	3.0	4.0	5.0	104.9	141.0	177.6	4500.0	4500.0	4500.0	442.1	445.5	449.0
22	7	2005	6.0	7	5.0	6.0	7.0	200.5	242.7	285.8	4500.0	4500.0	4500.0	535.9	550.2	555.1
23	7	2005	5.0	7	4.0	5.0	6.0	150.9	190.2	230.2	4500.0	4500.0	4500.0	553.5	567.5	577.1
24	7	2005	5.0	7	4.0	5.0	6.0	161.4	203.6	246.5	4500.0	4500.0	4500.0	219.0	322.0	466.0
25	7	2005	5.0	7	4.0	5.0	6.0	161.4	203.6	246.5	4500.0	4500.0	4500.0	461.5	475.1	484.1
26	2	2005	6.0	7	4.0	5.0	6.0	138.0	173.8	210.2	4536.0	4536.0	4536.0	371.0	383.3	386.2
27	7	2005	4.5	7	3.5	4.5	5.5	127.3	165.0	203.3	4518.0	4518.0	4518.0	476.6	489.8	493.8
28	7	2005	4.0	7	4.0	5.0	6.0	132.6	166.9	201.8	4522.5	4522.5	4522.5	315.0	326.7	329.1
29	2	2005	6.0	14	--	--	--	--	--	--	--	--	--	--	--	--
30	7	2005	5.0	14	4.0	5.0	6.0	140.7	177.3	214.4	4500.0	4500.0	4500.0	454.8	509.8	471.4
31	2	2005	7.0	14	5.0	6.0	7.0	175.7	212.5	249.8	4527.0	4527.0	4527.0	303.9	315.7	318.2
32	7	2006	6.0	14	4.0	5.0	6.0	--	--	--	--	--	--	--	--	--
33	2	2006	6.0	14	5.0	6.0	7.0	169.1	204.4	240.3	4500.0	4500.0	4500.0	373.5	385.8	388.7
34	5	2006	6.0	14	4.0	5.0	6.0	--	--	--	--	--	--	--	--	--
35	2	2006	6.0	14	4.0	5.0	6.0	--	--	--	--	--	--	--	--	--
36	1	2006	6.0	14	4.0	5.0	6.0	158.1	199.3	241.3	4500.0	4500.0	4500.0	66.1	681.4	687.5

Table A.3 (continued)

Mix ID[1]	*MDOT* District	Year	Design Cement Index (%)	Design Curing Time (days)	Cement Index (%)			Weight of Cement (g)			Weight of Soil (g)			Weight of Water (g)		
					Mix 1	Mix 2	Mix 3	Mix 1	Mix 2	Mix 3	Mix 1	Mix 2	Mix 3	Mix 1	Mix 2	Mix 3
37	3	2006	5.0	14	4.0	5.0	6.0	135.1	170.2	205.7	4500.0	4500.0	4500.0	389.3	401.6	404.7
38	1	2006	5.0	14	4.0	5.0	6.0	152.1	191.7	232.1	4500.0	4500.0	4500.0	637.3	652.2	657.8
39	1	2006	5.0	7	4.0	5.0	6.0	152.4	192.1	232.5	4500.0	4500.0	4500.0	604.8	619.4	624.7
40	3	2006	7.0	14	7.0	7.5	8.0	267.9	288.3	308.8	4500.0	4500.0	4500.0	591.2	603.3	605.9
41	1	2007	7.0	14	5.0	6.0	7.0	169.6	205.1	241.1	4500.0	4500.0	4500.0	429.6	442.3	445.7
42	5	2007	6.0	14	4.0	5.0	6.0	162.0	204.3	247.5	4513.5	4513.5	4513.5	638.7	653.9	659.9
43	7	2007	4.0	7	4.0	5.0	6.0	139.4	175.7	212.5	4500.0	4500.0	4500.0	477.9	490.9	494.8
44	7	2007	4.5	7	4.5	5.5	6.5	168.0	207.1	246.8	4500.0	4500.0	4500.0	597.5	611.9	617.1
45	7	2007	4.0	14	4.0	5.0	6.0	--	--	--	4500.0	4500.0	4500.0	--	--	--
46	7	2007	5.0	7	4.0	5.0	6.0	--	--	--	4500.0	4500.0	4500.0	--	--	--
47	3	2007	5.0	14	5.0	6.0	7.0	172.5	208.6	245.3	4500.0	4500.0	4500.0	350.4	362.6	365.4
48	5	2007	5.5	14	3.5	4.5	5.5	135.1	175.2	216.0	4500.0	4500.0	4500.0	602.6	621.8	627.2
49	7	2007	4.0	7	3.0	4.0	5.0	103.3	138.8	174.8	4500.0	4500.0	4500.0	391.3	408.2	411.4
50	7	2007	4.0	7	3.0	4.0	5.0	111.5	149.9	189.0	4500.0	4500.0	4500.0	525.7	544.0	548.6
51	5	2008	6.0	14	5.0	6.0	7.0	200.5	242.7	285.8	4500.0	4500.0	4500.0	573.5	592.8	598.2
52	7	2008	7.0	7	5.0	6.0	7.0	178.9	216.4	254.6	4500.0	4500.0	4500.0	603.6	608.4	608.6
53	7	2008	5.0	7	5.0	6.0	--	--	--	--	--	--	--	--	--	--
54	6	2008	5.0	7	5.0	6.0	7.0	140.6	177.1	214.2	4500.0	4500.0	4500.0	408.4	420.9	424.3
55	6	2008	5.5	7	5.5	6.5	7.5	174.5	211.0	248.2	4500.0	4500.0	4500.0	327.2	339.2	341.9
56	7	2008	5.0	14	--	--	--	--	--	--	--	--	--	--	--	--
57	6	2008	6.0	7	5.0	6.0	7.0	201.8	244.4	287.7	4500.0	4500.0	4500.0	503.1	517.1	521.9
58	1	2008	5.0	7	4.0	5.0	6.0	153.3	193.3	234.0	4500.0	4500.0	4500.0	563.1	577.3	582.3
59	6	2008	5.0	7	4.0	5.0	6.0	147.6	186.0	225.1	4500.0	4500.0	4500.0	422.9	435.8	439.4
60	6	2008	4.0	7	4.0	5.0	6.0	145.4	183.3	221.7	4500.0	4500.0	4500.0	422.7	435.5	439.1
61	6	2008	4.0	7	4.0	5.0	6.0	144.7	182.3	220.6	4500.0	4500.0	4500.0	447.3	460.3	464.0
62[2]	6	2008	4.0	7	4.0	5.0	6.0	146.6	184.7	223.5	4500.0	4500.0	4500.0	525.1	538.7	543.2
63[2]	6	2008	4.0	7	4.0	5.0	6.0	139.9	176.3	213.2	4500.0	4500.0	4500.0	399.0	411.5	414.8
64[2]	6	2008	6.0	7	4.0	5.0	6.0	146.1	184.1	222.7	4500.0	4500.0	4500.0	413.5	426.3	429.8
65	5	2009	6.0	14	4.0	5.0	6.0	152.1	191.7	232.1	4500.0	4500.0	4500.0	618.7	633.4	638.8
66	5	2009	6.0	14	4.0	5.0	6.0	137.5	173.2	209.5	4500.0	4500.0	4500.0	361.7	373.9	367.9
67	6	2009	4.0	7	4.0	5.0	6.0	143.8	181.2	219.2	4500.0	4500.0	4500.0	487.6	500.9	505.0
68	6	2009	5.0	7	4.0	5.0	6.0	143.6	180.9	218.9	4500.0	4500.0	4500.0	482.9	496.2	500.2
69	6	2009	4.0	7	4.0	5.0	6.0	143.8	181.2	219.2	4500.0	4500.0	4500.0	478.3	491.5	495.5
70	6	2009	4.0	7	4.0	5.0	6.0	154.2	194.4	231.3	4500.0	4500.0	4500.0	642.3	657.2	662.2
71	6	2009	5.0	7	4.0	5.0	6.0	147.7	186.2	225.3	4500.0	4500.0	4500.0	488.0	501.4	505.6
72	6	2009	4.0	7	4.0	5.0	6.0	147.0	185.2	224.6	4500.0	4500.0	4500.0	492.6	506.0	510.2

Table A.3 (continued)

Mix ID[1]	*MDOT* District	Year	Design Cement Index (%)	Design Curing Time (days)	Cement Index (%)			Weight of Cement (g)			Weight of Soil (g)			Weight of Water (g)		
					Mix 1	Mix 2	Mix 3	Mix 1	Mix 2	Mix 3	Mix 1	Mix 2	Mix 3	Mix 1	Mix 2	Mix 3
73	7	2009	7.0	14	7.0	7.5	8.0	276.9	298.0	319.3	4500.0	4500.0	4500.0	506.4	518.2	520.5
74	5	2009	6.0	14	5.0	6.0	7.0	204.0	247.0	290.8	4500.0	4500.0	4500.0	550.4	564.9	570.1
75	1	2009	6.5	14	4.5	5.5	6.5	--	--	--	4500.0	4500.0	4500.0	--	--	--
76	5	2009	7.0	14	7.0	7.5	8.0	303.0	326.2	349.7	4500.0	4500.0	4500.0	595.6	608.1	620.8
77	1	2009	5.0	7	4.0	5.0	6.0	149.4	188.3	227.9	4500.0	4500.0	4500.0	520.7	534.5	539.0
78	1	2009	7.0	7	6.0	7.0	8.0	248.2	292.2	337.1	4500.0	4500.0	4500.0	588.8	594.2	599.8
79	5	2010	6.0	14	4.5	6.0	6.5	178.3	--	262.1	4500.0	--	4500.0	491.2	--	509.5
80	5	2010	4.0	7	4.0	5.0	6.0	142.4	179.4	217.0	4500.0	4500.0	4500.0	441.0	453.9	457.5
81	2	2010	4.0	7	3.0	4.0	5.0	105.1	141.2	177.9	4500.0	4500.0	4500.0	442.1	454.8	458.4
82	5	2010	5.0	7	4.0	5.0	6.0	140.5	177.0	214.1	4500.0	4500.0	4500.0	454.8	467.7	471.4
83	5	2010	5.0	14	4.0	5.0	6.0	148.0	186.5	225.7	4500.0	4500.0	4500.0	496.4	509.9	514.2
84	5	2010	4.0	14	4.0	5.0	6.0	--	--	--	4500.0	4500.0	4500.0	--	--	--
85	5	2010	6.0	14	4.0	5.0	6.0	159.6	201.2	243.7	4500.0	4500.0	4500.0	503.2	517.1	521.8
86	1	2010	4.0	14	4.0	5.0	6.0	160.6	202.6	245.3	4500.0	4500.0	4500.0	559.3	564.3	569.4
87	1	2010	6.0	14	5.0	6.0	7.0	182.8	221.2	260.1	4576.5	4576.5	4576.5	557.3	571.3	576.0
88	5	2010	5.0	7	4.0	5.0	6.0	145.8	183.8	222.3	4500.0	4500.0	4500.0	532.9	546.6	551.1
89	6	2010	5.0	7	4.0	5.0	6.0	151.8	191.4	231.7	4500.0	4500.0	4500.0	525.7	539.5	544.1
90	3	2010	6.5	14	4.0	5.0	6.0	149.3	188.2	227.7	4500.0	4500.0	4500.0	553.3	567.3	581.5
91	7	2010	5.0	7	4.0	5.0	6.0	144.7	182.3	220.6	4500.0	4500.0	4500.0	483.0	496.3	500.4
92	7	2010	6.0	14	4.0	5.0	6.0	145.9	183.9	222.5	4500.0	4500.0	4500.0	367.0	379.4	382.5
93	7	2010	5.0	7	4.0	5.0	6.0	144.7	182.3	220.6	4500.0	4500.0	4500.0	459.8	472.9	476.8
94	7	2010	4.0	7	4.0	5.0	6.0	138.0	173.8	210.2	4500.0	4500.0	4500.0	445.2	458.0	461.6

Note: Shading of table rows is for ease of reading.

1: Mix IDs 1, 2, and 3 are the pit soils tested in this work. Mix IDs 4, 5, and 6 are project mix designs that correspond to the pit soils tested in the current work.

2: Mix design utilizes Type II portland cement. All other mixtures utilize Type I portland cement.

Table A.4 *MDOT* Soil-Cement Database: *MT-25* Results

Mix ID[1]	*MDOT* District	Year	Design Cement Index (%)	Cement Index (%)			7 Day Cure[2]						14 Day Cure[2]					
				Mix 1	Mix 2	Mix 3	P_1 (N)	P_2 (N)	P_3 (N)	σ_1(kPa)	σ_2(kPa)	σ_3(kPa)	P_1 (N)	P_2 (N)	P_3 (N)	σ_1(kPa)	σ_2(kPa)	σ_3(kPa)
1 A[3]	5	2011	5.0	4.0	5.0	6.0	8309	10275	12353	1027	1269	1524	9782	12282	14541	1207	1517	1793
2 B	1	2011	5.0	4.0	5.0	6.0	11463	17175	16071	1413	2117	1986	14737	19844	24643	1820	2448	3041
3 C	7	2011	4.0	4.0	5.0	6.0	19216	26249	28780	2372	3241	3551	24523	29154	26449	3027	3599	3261
4 (1A)	5	2010	5.0	4.0	5.0	6.0	17646	21996	23180	1627	2710	2861	15613	21819	26534	1924	2689	3275
5 (2B)	1	2010	6.5	6.5	7.0	8.0	20471	21200	23918	2523	2613	2951	--	--	--	--	--	--
6 (3C)	7	2011	4.0	4.0	4.5	5.0	21200	20626	23940	2613	2544	2951	25742	25097	30933	3178	3096	3813
7	7	2005	4.0	4.0	5.0	6.0	18126	19203	24361	2236	2369	3005	20888	21983	27627	2577	2712	3408
8	6	2005	4.0	3.0	4.0	5.0	12408	15410	17760	1530	1901	2191	14916	17899	19770	1840	2208	2438
9	7	2005	5.0	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
10	7	2005	4.0	3.0	4.0	5.0	13509	13455	22068	1669	1662	2723	10671	16988	21774	1441	2324	2979
11	7	2005	4.0	4.0	5.0	6.0	17099	19937	24007	2110	2461	2958	19603	22699	25760	2420	2799	3178
12	7	2005	4.0	3.0	4.0	5.0	15075	21859	22622	1859	2696	2790	17639	26349	29667	2176	3250	3659
13	1	2005	5.0	4.0	5.0	6.0	11588	14982	16748	1427	1848	2068	12557	17321	12575	1551	2137	1551
14	3	2005	4.0	4.0	5.0	6.0	13290	18447	24485	1639	2275	3020	17744	23060	28535	2189	2844	3520
15	2	2005	6.0	4.0	5.0	6.0	7691	9836	14369	949	1213	1772	9739	12823	17216	1201	1582	2124
16	2	2005	6.0	4.0	5.0	6.0	8409	11987	15931	1037	1479	1965	10381	14441	18346	1280	1781	2263
17	2	2005	3.5	3.5	4.5	5.5	16927	20142	25014	2088	2484	3085	21819	26253	30128	2691	3238	3716
18	7	2005	4.0	3.0	4.0	5.0	15315	21258	27041	1889	2620	3337	1978	26124	31004	2441	3220	3820
19	7	2005	5.0	5.0	6.0	7.0	37863	37143	37490	4668	4585	4626	34701	41239	37049	4282	5088	4571
20	5	2005	4.0	3.0	4.0	5.0	18029	22121	24425	2227	2730	3006	22517	27419	30751	2772	3378	3792
21	5	2005	4.0	3.0	4.0	5.0	18029	22121	24425	2227	2730	3013	22517	27414	30751	2779	3385	3792
22	7	2005	6.0	5.0	6.0	7.0	14110	21876	24910	1737	2696	3075	17216	22773	30224	2123	2809	3728
23	7	2005	5.0	4.0	5.0	6.0	15729	17806	19403	1937	2193	2392	17788	20279	19403	2193	2503	2923
24	7	2005	5.0	4.0	5.0	6.0	12268	17993	26044	1510	2220	3213	13084	19680	26416	1614	2428	3258
25	7	2005	5.0	4.0	5.0	6.0	12268	17993	26044	1510	2220	3213	13082	19679	26414	1510	2220	3213
26	2	2005	6.0	4.0	5.0	6.0	7514	15738	19570	927	1941	2414	11708	14510	22767	1444	1790	2808
27	7	2005	4.5	3.5	4.5	5.5	12519	16907	21061	1544	2085	2598	--	--	--	--	--	--
28	7	2005	4.0	4.0	5.0	6.0	17077	17993	19376	2110	2220	2392	--	--	--	--	--	--
29	2	2005	6.0	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
30	7	2005	5.0	4.0	5.0	6.0	13789	15057	19270	1703	1855	2379	17255	17944	21930	2130	2213	2703
31	2	2005	7.0	5.0	6.0	7.0	10190	15125	15294	1261	1866	1886	11900	16071	17441	1468	1979	2151
32	7	2006	6.0	4.0	5.0	6.0	11828	13838	16490	1462	1703	2034	14848	15858	20097	1834	1958	2482
33	2	2006	6.0	5.0	6.0	7.0	11837	15302	13896	1462	1882	1710	17290	18856	20008	2130	2324	2468
34	5	2006	6.0	4.0	5.0	6.0	7864	9728	12050	972	1200	1482	11045	12802	17050	1365	1579	2103
35	2	2006	6.0	4.0	5.0	6.0	9805	13972	14870	1207	1724	1834	11521	12753	18878	1420	1572	2330
36	1	2006	6.0	4.0	5.0	6.0	8300	10756	13536	1027	1324	1669	10436	12967	16752	1289	1600	2068

Table A.4 (continued)

Mix ID[1]	*MDOT* District	Year	Design Cement Index (%)	Cement Index (%)			7 Day Cure[2]						14 Day Cure[2]					
				Mix 1	Mix 2	Mix 3	P_1 (N)	P_2 (N)	P_3 (N)	σ_1(kPa)	σ_2(kPa)	σ_3(kPa)	P_1 (N)	P_2 (N)	P_3 (N)	σ_1(kPa)	σ_2(kPa)	σ_3(kPa)
37	3	2006	5.0	4.0	5.0	6.0	9510	9804	14959	1172	1207	1848	12522	18776	21463	1544	2317	2648
38	1	2006	5.0	4.0	5.0	6.0	11138	13914	15876	1372	1717	1958	14635	18336	21218	1806	2261	2620
39	1	2006	5.0	4.0	5.0	6.0	15235	18256	19492	1882	2255	2406	--	--	--	--	--	--
40	3	2006	7.0	7.0	7.5	8.0	15235	22049	15378	1880	2723	1896	19029	24305	20079	2344	2999	2475
41	1	2007	7.0	5.0	6.0	7.0	13861	13812	17139	1710	1703	2117	14079	15627	17326	1737	1931	2130
42	5	2007	6.0	4.0	5.0	6.0	7638	9995	14950	945	1234	1848	9524	12913	19416	1172	1593	2392
43	7	2007	4.0	4.0	5.0	6.0	17450	22019	24163	2151	2717	2979	19844	28446	28829	2448	3509	3558
44	7	2007	4.5	4.5	5.5	6.5	20239	20924	24060	2496	2579	2965	23762	26494	30506	2930	3268	3765
45	7	2007	4.0	4.0	5.0	6.0	16650	22899	26543	2055	2827	3275	20235	28010	31734	2496	3454	3916
46	7	2007	5.0	4.0	5.0	6.0	14199	12099	22299	1758	2110	2751	14799	18798	26400	1827	2537	3247
47	3	2007	5.0	5.0	6.0	7.0	16321	12873	21476	2013	1586	2648	18006	20773	25622	2220	2565	3158
48	5	2007	5.5	3.5	4.5	5.5	10507	12780	14630	1296	1579	1806	14270	16240	19403	1758	2006	2392
49	7	2007	4.0	3.0	4.0	5.0	15698	21125	24439	1931	2606	3013	20426	25457	27784	2517	3137	3427
50	7	2007	4.0	3.0	4.0	5.0	13447	15302	17255	1662	1889	2130	16783	21258	22779	2068	2620	2813
51	5	2008	6.0	5.0	6.0	7.0	--	--	--	--	--	--	16543	21129	24430	2041	2668	3013
52	7	2008	7.0	5.0	6.0	7.0	--	--	22917	--	--	2827	--	--	--	--	--	--
53	7	2008	5.0	5.0	6.0	--	22975	23896	--	2834	2951	--	22117	24532	--	2730	3027	--
54	6	2008	5.0	5.0	6.0	7.0	18789	26276	30283	2317	3241	3737	22855	31649	33451	2820	3902	4123
55	6	2008	5.5	5.5	6.5	7.5	18376	21294	24287	2248	2627	2992	23713	24550	29603	2923	3027	3654
56	7	2008	5.0	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
57	6	2008	6.0	5.0	6.0	7.0	14212	17504	28985	1751	2158	3516	13674	17757	28220	1689	2193	3482
58	1	2008	5.0	4.0	5.0	6.0	13118	17846	19194	1613	2199	2365	15822	17762	20626	1951	2193	2544
59	6	2008	5.0	4.0	5.0	6.0	15079	18336	17686	1862	2248	2179	18856	21383	21218	2317	2641	2620
60	6	2008	4.0	4.0	5.0	6.0	17188	22174	28282	2117	2737	3489	21930	23300	28308	2703	2861	3461
61	6	2008	4.0	4.0	5.0	6.0	20489	22846	28357	2517	2820	3503	22157	27388	30942	2730	3378	3820
62[4]	6	2008	4.0	4.0	5.0	6.0	17726	23184	24221	2186	2861	2985	20546	20702	22802	2537	2551	2813
63[4]	6	2008	4.0	4.0	5.0	6.0	20057	22980	24238	2475	2834	2992	18011	26369	31017	2220	3254	3827
64[4]	6	2008	6.0	4.0	5.0	6.0	13985	16641	19372	1724	2055	2392	11605	13701	21409	1434	1689	2641
65	5	2009	6.0	4.0	5.0	6.0	8790	16036	16454	1082	1979	2027	15555	21636	21240	1917	2668	2620
66	5	2009	6.0	4.0	5.0	6.0	8096	7993	9088	1000	986	1117	7153	11797	--	883	1455	--
67	6	2009	4.0	4.0	5.0	6.0	18767	22744	26071	2130	2813	3213	20351	25488	34825	2510	3137	4302
68	6	2009	5.0	4.0	5.0	6.0	14359	21067	26818	1772	2599	3309	20413	22864	26761	2517	2820	3303
69	6	2009	4.0	4.0	5.0	6.0	18380	19163	19550	2268	2365	2413	23531	23923	28059	2903	2951	3461
70	6	2009	4.0	4.0	5.0	6.0	19563	33540	33744	2413	4137	4158	14043	19617	22939	1731	2420	2827
71	6	2009	5.0	4.0	5.0	6.0	15048	17495	23206	1862	2158	2861	14083	21649	29994	1737	2668	3702
72	6	2009	4.0	4.0	5.0	6.0	17944	20964	25853	2213	2592	3192	17842	25342	28188	2199	3123	3482

Table A.4 (continued)

Mix ID[1]	*MDOT* District	Year	Design Cement Index (%)	Cement Index (%)			7 Day Cure[2]						14 Day Cure[2]					
				Mix 1	Mix 2	Mix 3	P_1 (N)	P_2 (N)	P_3 (N)	σ_1(kPa)	σ_2(kPa)	σ_3(kPa)	P_1 (N)	P_2 (N)	P_3 (N)	σ_1(kPa)	σ_2(kPa)	σ_3(kPa)
73	7	2009	7.0	7.0	7.5	8.0	16587	14159	13180	2048	1744	1627	20649	24910	29919	2544	3075	3689
74	5	2009	6.0	5.0	6.0	7.0	11436	15551	20013	1413	1917	2468	12028	16948	17909	1482	2089	2206
75	1	2009	6.5	4.5	5.5	6.5	--	--	--	--	--	--	11543	16209	20622	1420	1999	2544
76	5	2009	7.0	7.0	7.5	8.0	12873	16022	18353	1758	2193	2510	18687	22121	22922	2558	3027	3137
77	1	2009	5.0	4.0	5.0	6.0	14652	17446	16681	1999	2379	2282	17099	22228	23758	2337	3041	3254
78	1	2009	7.0	6.0	7.0	8.0	10129	17295	21663	1386	2365	2965	13127	16325	23985	1800	2234	3261
79	5	2010	6.0	4.5	6.0	6.5	8928	--	15493	1103	--	1910	13416	19452	21236	1655	2399	2620
80	5	2010	4.0	4.0	5.0	6.0	18376	22744	25582	2268	2806	3158	22254	23020	20996	2744	2834	2592
81	2	2010	4.0	3.0	4.0	5.0	15462	16476	19150	1903	2027	2365	16623	18629	20462	2048	2296	2523
82	5	2010	5.0	4.0	5.0	6.0	15520	18344	21934	1917	2261	2703	--	--	--	--	--	--
83	5	2010	5.0	4.0	5.0	6.0	15111	16685	17637	1862	2055	2172	16739	17379	20119	2062	2144	2482
84	5	2010	4.0	4.0	5.0	6.0	13015	16957	16463	1606	2089	2006	18540	19701	19083	2289	2427	2351
85	5	2010	6.0	4.0	5.0	6.0	8234	10618	15925	1014	1310	1965	9243	13536	19559	1138	1669	2413
86	1	2010	4.0	4.0	5.0	6.0	15177	19118	18754	1875	2358	2310	19283	25777	25987	2379	3178	3206
87	1	2010	6.0	5.0	6.0	7.0	14390	13723	11806	1772	1689	1455	12148	18278	--	1496	2248	--
88	5	2010	5.0	4.0	5.0	6.0	16387	17504	19394	2020	2158	2392	--	--	--	--	--	--
89	6	2010	5.0	4.0	5.0	6.0	12500	17099	21000	1538	2110	2592	12802	19999	22899	1593	2468	2758
90	3	2010	6.5	4.0	5.0	6.0	9697	11863	12824	1193	1462	1586	11921	14297	16192	1469	1765	1999
91	7	2010	5.0	4.0	5.0	6.0	13296	20764	23020	1634	2565	2834	16796	25680	28798	2068	3165	3551
92	7	2010	6.0	4.0	5.0	6.0	8407	12927	16890	1034	1593	2082	12153	15302	18398	1496	1882	2268
93	7	2010	5.0	4.0	5.0	6.0	15809	17989	19025	1944	2220	2344	14047	17624	22557	1731	2172	2785
94	7	2010	4.0	4.0	5.0	6.0	16409	22428	23798	2027	2772	2951	--	--	--	--	--	--

Note: Shading of table rows is for ease of reading.

1: Mix IDs 1, 2, and 3 are the pit soils tested in this work. Mix IDs 4, 5, and 6 are project mix designs that correspond to the pit soils tested in the current work.

2: P = compressive load, σ = unconfined compressive strength. Subscript numbers refer to mix number. Specimens were tested in accordance with Mississippi Test Method 26.

3: Mix design did not meet the design criteria of 2070 kPa. Further testing by Mississippi State University demonstrated that a design index of 5 percent would produce the adequate strength; therefore, the design index was taken as 5 percent.

4: Mix design utilizes Type II portland cement. All other mixtures utilize Type I portland cement.

APPENDIX B

THERMAL PROFILE AND COMPRESSIVE STRENGTH RAW DATA

Table B.1 Thermal Profile Raw Data: Series 1

Specimen	Channel	T_{max}	ΔT	t_{max}	Profile Temperature (°C) at Time Indicated (hr)								A_s	$A_{\Delta T}$	*TTF*	$t_{\sigma max}$	σ_{max}	ε_{max}
ID	ID	(°C)	(°C)	(hr)	0.1	1	2	4	6	8	16	24	(°C-hr)	(°C-hr)	(°C-hr)	(day)	(kPa)	(%)
TP-1-PA5-01	A-6	26.5	4.7	5.5	23.6	24.8	25.5	26.3	26.5	26.4	25.8	24.7	619	90.4	4135	7	2381	1.7
TP-1-PA5-02	A-7	26.3	4.5	5.4	23.9	24.8	25.4	26.2	26.2	26.2	25.5	24.4	613	84.2	4129	7	2567	1.7
TP-1-PA5-03	A-8	26.4	4.6	4.9	23.8	25.0	25.6	26.3	26.3	26.2	25.4	24.3	612	83.5	4153	7	2593	1.7
TP-1-PA5-04	B-1	26.0	4.6	4.5	23.8	24.9	25.4	25.9	25.9	25.8	24.9	23.8	602	78.9	4118	7	2625	1.7
TP-1-PA5-05	B-3	26.1	4.5	5.1	23.6	24.6	25.2	25.9	26.1	26.0	25.3	24.2	608	84.9	4125	7	2426	1.5
TP-1-PA5-06	B-4	25.6	4.0	5.3	23.2	24.3	24.8	25.5	25.6	25.5	24.8	23.8	596	72.9	4113	7	2625	1.7
TP-1-PA5-07	B-5	26.0	4.3	5.9	23.4	24.5	25.1	25.9	26.0	25.9	25.2	24.2	606	82.2	4122	7	2484	1.7
TP-1-PA5-08	B-6	26.3	4.6	5.8	23.8	24.8	25.3	26.1	26.3	26.2	25.5	24.5	613	89.5	4130	7	2426	1.5
TP-1-PA5-09	B-7	26.2	4.6	5.2	23.9	25.0	25.5	26.1	26.2	26.0	25.1	24.1	607	83.1	4148	7	2318	1.5
TP-1-PA5-10	B-8	26.2	4.5	5.2	23.9	24.8	25.4	26.1	26.2	26.1	25.3	24.2	609	84.7	4101	7	2147	1.5
TP-1-PA5-11	A-1	25.9	4.5	4.1	23.4	24.5	25.2	25.9	25.8	25.5	24.6	23.7	597	76.8	4123	7	2569	1.7
TP-1-PA5-12	A-3	26.1	4.6	5.0	23.7	24.6	25.2	26.0	26.0	25.9	25.3	24.3	608	87.8	4158	7	2586	1.7
TP-1-PA5-13	A-4	25.9	4.4	4.2	23.4	24.5	25.1	25.8	25.8	25.6	24.8	23.9	600	79.7	4150	7	2425	1.5
TP-1-PA5-14	A-5	25.6	4.1	5.0	23.1	24.2	24.8	25.5	25.6	25.5	24.9	24.0	598	77.8	4124	7	1874*	1.4
TP-1-PA5-15	A-6	26.0	4.4	4.8	23.3	24.5	25.1	25.9	25.9	25.8	25.1	24.2	605	84.4	4131	7	2392	1.5
TP-1-PA5-16	A-7	25.6	4.1	4.7	23.2	24.3	24.8	24.3	25.5	25.4	24.6	23.8	594	73.2	4120	7	2513	1.7
TP-1-PA5-17	A-8	26.0	4.4	4.5	23.5	24.7	25.2	26.0	25.8	25.6	24.7	23.8	599	78.6	4125	7	2514	1.7
TP-1-PA5-18	B-1	25.5	4.1	4.1	23.4	24.4	24.9	25.5	25.3	25.1	24.1	23.2	586	68.9	4112	7	2263	1.4
TP-1-PA5-19	B-3	26.3	4.8	4.5	23.8	24.9	25.5	26.2	26.2	26.0	25.3	24.4	610	92.4	4160	7	2317	1.5
TP-1-PA5-20	B-4	25.8	4.4	4.7	23.5	24.5	25.1	25.8	25.7	25.6	24.9	24.0	600	82.1	4126	7	2418	1.7
TP-1-PA5-21	B-5	26.4	5.0	4.3	23.9	25.0	25.7	26.4	26.3	26.2	25.5	24.6	614	96.5	4140	7	2349	1.5
TP-1-PA5-22	B-6	26.2	4.7	4.6	23.7	24.7	25.4	26.1	26.1	26.0	25.3	24.5	610	92.5	4136	7	2266	1.5
TP-1-PA5-23	B-7	26.3	4.8	4.2	23.9	25.1	25.7	25.1	26.1	25.9	24.9	24.0	604	86.3	4130	7	2275	1.5
TP-1-PA5-24	B-8	26.0	4.6	4.5	23.8	24.8	25.4	26.0	25.9	25.7	24.8	23.9	601	83.2	4127	7	2277	1.5
TP-1-PA5-25	A-1	25.0	3.7	5.5	22.5	23.6	24.2	24.8	24.9	24.6	24.1	23.3	581	63.0	4116	7	2256	1.5
TP-1-PA5-26	A-3	25.1	3.8	5.4	22.4	23.5	24.1	24.9	25.1	25.0	24.6	23.9	589	71.4	4124	7	2478	1.5
TP-1-PA5-27	A-4	25.1	3.9	4.8	22.6	23.7	24.3	25.0	25.1	24.9	24.5	23.8	588	69.8	4123	7	2563	1.5
TP-1-PA5-28	A-5	25.4	4.1	5.5	22.7	23.7	24.4	25.2	25.4	25.3	25.0	24.3	598	79.8	4157	7	2469	1.5
TP-1-PA5-29	A-6	25.7	4.4	5.2	22.9	24.0	24.6	25.4	25.6	25.6	25.1	24.4	602	83.2	4136	7	2466	1.5
TP-1-PA5-30	A-7	25.4	4.1	4.8	22.9	23.9	24.5	25.2	25.3	25.3	24.8	24.0	594	75.4	4129	7	2486	1.5

Notes: Shading of table rows is for ease of reading; asterisked values indicate an outlier that was removed from the respective analysis.

Table B.2 Thermal Profile Raw Data: Series 2

Specimen ID	Channel ID	T_{max} (°C)	ΔT (°C)	t_{max} (hr)	Profile Temperature (°C) at Time Indicated (hr) 0.1	1	2	4	6	8	16	24	A_s (°C-hr)	$A_{\Delta T}$ (°C-hr)	*TTF* (°C-hr)	$t_{\sigma max}$ (day)	σ_{max} (kPa)	ε_{max} (%)
TP-2-PA5-01	A-8	25.7	4.2	7.8	23.1	24.1	24.7	25.4	25.7	25.7	25.0	24.0	599	81.7	4134	7	2394	1.5
TP-2-PA5-02	B-1	25.5	4.3	5.6	23.0	24.0	24.6	25.2	25.4	25.4	24.7	23.7	593	76.5	4128	7	2494	1.5
TP-2-PA5-03	B-3	25.5	4.0	9.3	22.7	23.6	24.3	25.1	25.4	25.5	25.1	24.2	599	81.9	4133	7	2330	1.4
TP-2-PA5-04	B-4	25.1	3.6	8.6	22.3	23.3	23.9	24.7	25.0	25.0	24.7	23.8	589	71.6	4123	7	2394	1.5
TP-2-PA5-05	B-5	25.6	4.1	8.3	22.7	23.7	24.4	25.2	25.5	25.6	25.2	24.2	600	82.7	4134	7	2462	1.5
TP-2-PA5-06	B-6	25.8	4.2	9.8	22.9	23.8	24.5	25.3	25.7	25.8	25.4	24.5	605	88.0	4140	7	2387	1.5
TP-2-PA5-07	B-7	25.7	4.3	6.7	23.0	24.0	24.7	25.4	25.6	25.6	25.0	24.1	600	82.3	4134	7	2431	1.7
TP-2-PA5-08	B-8	25.8	4.4	6.7	23.0	24.1	24.8	25.5	25.7	25.7	25.1	24.2	602	84.5	4137	7	2504	1.5
TP-2-PA5-09	A-1	25.6	4.1	6.1	23.0	23.9	24.5	25.1	25.5	25.5	24.9	23.9	596	75.1	4092	7	1864*	1.7
TP-2-PA5-10	A-3	25.7	3.9	9.4	22.7	23.6	24.2	25.1	25.6	25.7	25.4	24.5	603	82.0	4099	7	2217	1.4
TP-2-PA5-11	A-4	25.4	3.8	6.7	22.7	23.6	24.3	25.0	25.4	25.4	25.0	24.1	596	74.0	4091	7	2238	1.4
TP-2-PA5-12	A-5	25.5	3.8	8.0	22.5	23.4	24.1	24.9	25.4	25.5	25.2	24.3	598	76.3	4069	7	2180	1.5
TP-2-PA5-13	A-6	26.0	4.3	7.8	22.9	23.9	24.6	25.5	25.9	26.0	25.6	24.6	609	86.5	4103	7	2199	1.4
TP-2-PA5-14	A-7	25.5	3.8	7.7	22.7	23.6	24.3	25.1	25.5	25.5	25.1	24.1	598	75.6	4092	7	2416	1.5
TP-2-PA5-15	A-8	25.9	4.4	5.6	23.3	24.2	24.9	25.6	25.9	25.8	25.2	24.2	605	82.0	4099	7	2337	1.5
TP-2-PA5-16	B-1	25.5	4.0	5.4	23.0	23.9	24.6	23.9	25.5	25.3	24.5	23.5	591	70.1	4085	7	2367	1.5
TP-2-PA5-17	B-3	26.3	4.7	6.8	23.6	24.4	25.1	25.9	26.3	26.3	25.7	24.6	614	93.2	4084	7	2276	1.5
TP-2-PA5-18	B-4	25.8	4.3	5.9	23.3	24.2	24.8	25.5	25.8	25.8	25.2	24.2	604	83.0	4074	7	2283	1.7
TP-2-PA5-19	B-5	26.5	4.9	6.8	23.6	24.7	25.4	26.2	26.5	26.5	25.9	24.8	620	98.3	4113	7	2348	1.5
TP-2-PA5-20	B-6	26.4	4.8	6.5	23.6	24.6	25.3	26.0	26.4	26.4	25.9	24.8	618	96.5	4111	7	2334	1.5
TP-2-PA5-21	B-7	26.1	4.5	6.1	23.4	24.5	25.1	25.8	26.1	26.0	25.2	24.2	607	85.1	4100	7	2210	1.5
TP-2-PA5-22	B-8	26.1	4.5	6.2	23.5	24.5	25.1	25.9	26.1	26.0	25.2	24.2	607	85.6	4100	7	2304	1.5
TP-2-PA5-23	A-1	25.4	4.0	5.0	22.9	23.8	24.4	23.8	25.3	25.2	24.4	23.4	589	71.4	4070	7	2275	1.4
TP-2-PA5-24	A-3	25.5	3.9	8.9	22.6	23.5	24.2	25.1	25.4	25.4	25.0	24.0	596	79.0	4078	7	2380	1.4
TP-2-PA5-25	A-4	25.5	4.0	6.5	22.7	23.7	24.4	25.1	25.4	25.4	24.9	23.9	596	78.5	4077	7	2165	1.4
TP-2-PA5-26	A-5	25.7	4.1	8.5	22.7	23.6	24.4	25.1	25.6	25.7	25.3	24.3	602	84.6	4107	7	2338	1.5
TP-2-PA5-27	A-6	26.0	4.4	7.5	23.0	24.1	24.8	25.6	25.9	26.0	25.4	24.4	608	90.3	4113	7	2238	1.4
TP-2-PA5-28	A-7	25.7	4.2	5.9	23.2	24.1	24.7	25.4	25.7	25.6	25.0	24.0	600	81.8	4080	7	2238	1.4
TP-2-PA5-29	A-8	25.7	4.2	5.8	23.1	24.0	24.7	25.4	25.7	25.6	24.8	23.8	597	79.2	4078	7	2227	1.5
TP-2-PA5-30	B-1	25.5	4.2	5.5	23.2	24.0	24.7	25.3	25.5	25.4	24.4	23.4	591	76.8	4072	7	2222	1.5

Notes: Shading of table rows is for ease of reading; asterisked values indicate an outlier that was removed from the respective analysis.

Table B.3 Thermal Profile Raw Data: Series 3

Specimen ID	Channel ID	T_{max} (°C)	ΔT (°C)	t_{max} (hr)	Profile Temperature (°C) at Time Indicated (hr)								A_s (°C-hr)	$A_{\Delta T}$ (°C-hr)	*TTF* (°C-hr)	$t_{\sigma max}$ (day)	σ_{max} (kPa)	ε_{max} (%)
					0.1	1	2	4	6	8	16	24						
TP-3-PA2-01	A-1	20.4	0.8	24.0	10.9	11.4	12.5	14.4	15.6	16.4	19.0	20.4	413	26.9	3921	7	974	1.3
TP-3-PA2-02	A-3	19.7	0.1	23.9	10.3	10.6	11.6	13.4	14.6	15.5	18.2	19.7	392	5.4	3901	7	1033	1.3
TP-3-PA2-03	A-4	19.5	-0.1	23.9	10.3	10.4	11.4	13.2	14.4	15.3	18.0	19.5	388	0.0	3897	7	974	1.3
TP-3-PA4-04	A-5	20.3	0.7	23.9	10.0	10.6	11.7	13.7	15.1	16.1	18.6	20.3	403	12.5	3911	7	1849	1.4
TP-3-PA4-05	A-6	20.3	0.7	23.8	9.8	10.3	11.5	13.5	15.0	15.9	18.5	20.3	400	9.5	3909	7	1750	1.4
TP-3-PA4-06	A-7	20.9	1.2	23.7	10.1	10.9	12.1	14.3	15.8	16.9	19.4	20.8	419	27.2	3927	7	1765	1.4
TP-3-PA6-07	A-8	22.2	2.5	23.5	10.6	11.5	12.9	15.1	16.7	18.3	20.9	22.2	449	56.0	3958	7	3083	1.8
TP-3-PA6-08	B-1	22.5	2.3	23.9	11.0	11.7	13.1	15.2	16.8	18.4	21.1	22.5	454	52.7	3962	7	3077	1.7
TP-3-PA6-09	B-3	22.5	2.2	24.0	10.8	11.8	13.0	14.8	16.2	17.7	20.8	22.5	446	43.4	3955	7	2678	1.7
TP-3-PA8-10	B-4	23.1	2.7	24.0	11.0	11.8	13.0	14.8	16.5	18.3	21.8	23.1	462	56.7	3970	7	4247	2.3
TP-3-PA8-11	B-5	23.6	3.2	24.0	10.8	11.7	12.9	14.8	16.5	18.4	22.2	23.6	467	61.4	3975	7	4566	2.3
TP-3-PA8-12	B-6	23.7	3.3	23.9	11.3	12.3	13.6	15.3	16.9	18.7	22.5	23.7	475	67.9	4009	7	4053	2.1
TP-3-PA10-13	B-7	24.8	4.4	23.9	12.5	13.5	14.7	16.6	18.6	20.7	24.3	24.8	515	105.7	4023	7	5476	2.4
TP-3-PA10-14	B-8	25.2	4.7	24.0	13.2	14.4	15.6	17.5	19.4	21.5	24.7	25.2	529	118.9	4036	7	6074	2.5
TP-3-PA10-15	A-1	23.5	3.9	24.0	9.0	9.7	11.1	13.3	15.4	17.4	22.4	23.5	455	88.6	4216	7	5976	2.5

Note: Shading of table rows is for ease of reading.

Table B.4 Thermal Profile Raw Data: Series 4

Specimen ID	Target ω (%)	Chan. ID	T_{max} (°C)	ΔT (°C)	t_{max} (hr)	Profile Temperature (°C) at Time Indicated (hr) 0.1	1	2	4	6	8	16	24	A_s (°C-hr)	$A_{\Delta T}$ (°C-hr)	TTF (°C-hr)	$t_{\sigma max}$ (day)	σ_{max} (kPa)	ε_{max} (%)
TP-4-PA4-13	9.8	A-5	25.0	4.0	4.8	22.7	23.6	24.3	24.9	24.9	24.8	24.5	24.1	587	70.5	4241	7	2229	1.5
TP-4-PA4-14	9.8	A-6	24.9	4.0	4.7	22.6	23.5	24.2	24.9	24.9	24.7	24.5	24.2	588	70.4	4241	7	2141	1.7
TP-4-PA4-15	9.8	A-7	25.0	4.0	4.6	22.8	23.7	24.3	24.9	24.9	24.7	24.2	23.9	584	66.4	4237	7	2288	1.5
TP-4-PA4-22	11.8	B-5	25.5	4.8	3.2	23.3	24.3	25.0	25.4	25.2	25.0	24.4	23.8	590	84.8	4023	7	1678	1.3
TP-4-PA4-23	11.8	B-6	25.2	4.5	3.2	23.1	24.1	24.8	25.2	25.1	24.9	24.4	23.9	589	83.6	4022	7	1565	1.3
TP-4-PA4-24	11.8	A-1	24.9	4.1	3.8	22.8	23.8	24.4	24.8	24.6	24.4	23.7	23.2	575	62.4	3941	7	3251	1.8
TP-4-PA4-10	13.8	A-1	24.5	3.8	3.6	22.6	23.4	24.1	24.5	24.4	24.3	24.0	23.7	576	60.5	4230	7	1330	1.8
TP-4-PA4-11	13.8	A-3	24.6	3.6	5.3	22.4	23.3	24.0	24.5	24.5	24.5	24.4	24.1	583	67.1	4236	7	1643	1.5
TP-4-PA4-12	13.8	A-4	24.8	3.9	4.0	22.7	23.5	24.2	24.8	24.7	24.6	24.4	24.0	584	67.2	4237	7	1682	1.5
TP-4-PA5-01	9.8	A-7	24.5	3.7	5.5	22.0	23.0	23.6	24.3	24.5	24.5	24.2	23.6	578	66.3	4022	7	2876	1.7
TP-4-PA5-02	9.8	A-8	24.4	3.4	6.5	21.9	22.8	23.4	24.1	24.4	24.4	24.1	23.5	575	64.0	4020	7	3234	1.7
TP-4-PA5-03	9.8	B-1	24.4	3.6	5.8	22.1	23.0	23.6	24.1	24.4	24.3	23.6	22.9	568	61.5	4013	7	2772	1.5
TP-4-PA5-04	11.8	B-3	24.8	4.0	5.7	22.3	23.3	23.9	24.6	24.8	24.8	24.5	23.7	585	78.1	4030	7	2683	1.5
TP-4-PA5-05	11.8	B-4	24.5	3.2	9.5	22.0	23.0	23.5	24.3	24.4	24.4	24.3	23.5	578	71.4	4023	7	2766	1.5
TP-4-PA5-06	11.8	B-5	24.9	4.0	6.6	22.3	23.3	23.8	24.6	24.9	24.9	24.6	23.9	587	79.7	4032	7	2776	1.7
TP-4-PA5-07	13.8	B-6	25.0	4.0	6.3	22.8	23.7	24.2	23.7	25.0	25.0	24.7	24.1	591	83.2	4036	7	1282	2.0
TP-4-PA5-08	13.8	B-7	24.6	3.7	5.5	22.5	23.3	23.8	24.5	24.6	24.6	24.3	23.7	580	72.4	4025	7	1553	1.8
TP-4-PA5-09	13.8	B-8	24.9	4.0	5.6	22.4	23.4	23.9	24.8	24.9	24.9	24.4	23.8	585	76.7	4030	7	2013	1.5
TP-4-PA6-19	9.8	B-4	26.1	4.5	8.8	22.8	24.0	24.6	25.4	26.0	26.1	25.8	25.1	613	90.8	4267	7	2944	1.8
TP-4-PA6-20	9.8	B-5	26.1	4.4	9.1	22.8	23.9	24.5	25.3	26.0	26.1	25.8	25.0	612	89.9	4266	7	3310	2.0
TP-4-PA6-21	9.8	B-6	26.2	4.7	8.0	23.1	24.1	24.7	25.4	26.2	26.2	25.8	25.0	613	90.5	4267	7	3245	2.0
TP-4-PA6-25	11.8	B-8	26.5	5.1	6.8	23.4	24.5	25.1	25.9	26.4	26.4	25.6	24.5	613	99.5	3978	7	3217	1.8
TP-4-PA6-26	11.8	A-1	25.0	3.6	11.2	21.7	22.8	23.4	22.8	24.8	24.9	24.6	23.9	585	75.2	4029	7	3199	1.7
TP-4-PA6-27	11.8	A-3	25.4	3.9	12.1	21.6	22.6	23.2	24.1	24.9	25.1	25.3	24.6	594	83.9	4038	7	3246	1.7
TP-4-PA6-16	13.8	A-8	25.9	4.6	7.0	22.8	23.8	24.4	25.4	25.8	25.8	25.5	24.8	607	89.6	4261	7	1869	2.4
TP-4-PA6-17	13.8	B-1	25.6	4.3	6.9	22.7	23.7	24.3	25.1	25.6	25.5	25.3	24.7	603	81.5	4257	7	2098	2.0
TP-4-PA6-18	13.8	B-3	26.4	4.6	10.4	22.9	23.9	24.6	25.5	26.1	26.2	26.2	25.5	620	98.0	4274	7	2287	1.8

Notes: Shading of table rows is for ease of reading; TP-4-PA4-22 is also TP-5-PA4-07; TP-4-PA4-23 is also TP-5-PA4-08; TP-4-PA4-24 is also TP-5-PA4-28; TP-4-PA6-25 is also TP-5-PA6-22; TP-4-PA6-26 is also TP-5-PA6-23; and TP-4-PA6-27 is also TP-5-PA6-24.

Table B.5 Thermal Profile Raw Data: Series 5

Specimen ID	Channel ID	T_{max} (°C)	ΔT (°C)	t_{max} (hr)	Profile Temperature (°C) at Time Indicated (hr) 0.1	1	2	4	6	8	16	24	A_s (°C-hr)	$A_{\Delta T}$ (°C-hr)	*TTF* (°C-hr)	$t_{\sigma max}$ (day)	σ_{max} (kPa)	ε_{max} (%)
TP-5-PA4-01	A-6	25.1	4.2	4.1	22.7	23.8	24.5	25.1	25.0	24.8	24.3	23.6	586	72.7	661	1	1160	1.4
TP-5-PA4-02	A-7	24.7	3.8	3.9	22.5	23.5	24.2	24.7	24.5	24.3	23.7	23.1	573	60.0	648	1	1122	1.4
TP-5-PA4-03	A-8	24.9	4.0	3.8	22.8	23.9	24.5	24.9	24.6	24.3	23.6	23.0	574	60.2	624	1	1141	1.3
TP-5-PA4-04	B-1	24.7	4.0	3.8	22.8	23.8	24.3	24.6	24.3	24.0	23.2	22.6	565	60.3	1771	3	1266	1.3
TP-5-PA4-05	B-3	25.1	4.4	3.6	23.1	24.1	24.7	25.1	24.8	24.6	23.9	23.2	580	75.1	1786	3	1334	1.3
TP-5-PA4-06	B-4	24.9	4.2	3.4	22.9	23.9	24.5	24.8	24.6	24.4	23.7	23.1	576	70.3	1782	3	1326	1.3
TP-5-PA4-07	B-5	25.5	4.8	3.2	23.3	24.3	25.0	25.4	25.2	25.0	24.4	23.8	590	84.8	1796	7	1678	1.3
TP-5-PA4-08	B-6	25.2	4.5	3.2	23.1	24.1	24.8	25.2	25.1	24.9	24.4	23.9	589	83.6	4022	7	1565	1.3
TP-5-PA4-28	A-1	24.9	4.1	3.8	22.8	23.8	24.4	24.8	24.6	24.4	23.7	23.2	575	62.4	3941	7	1750	1.4
TP-5-PA5-11	A-4	25.6	4.7	4.5	23.1	24.3	24.9	25.5	25.5	25.4	24.9	24.1	599	85.4	1766	3	2228	1.5
TP-5-PA5-12	A-5	25.7	4.6	5.4	23.1	24.2	24.8	25.6	25.7	25.6	25.3	24.5	604	90.5	1771	3	2297	1.7
TP-5-PA5-13	A-6	26.0	4.9	5.1	23.2	24.6	25.2	25.9	25.9	25.9	25.4	24.6	608	94.5	1775	3	2203	1.5
TP-5-PA5-14	A-7	25.6	4.6	4.8	23.1	24.3	24.9	25.5	25.5	25.4	24.8	24.0	597	83.0	3963	7	2769	1.8
TP-5-PA5-15	A-8	25.8	4.8	4.3	23.4	24.6	25.2	25.8	25.7	25.6	24.9	24.0	600	85.4	3965	7	2639	1.7
TP-5-PA5-29	A-3	25.6	4.5	5.7	23.0	24.1	24.7	25.4	25.6	25.5	25.0	24.2	600	86.7	3966	7	2437	1.7
TP-5-PA5-16	B-1	25.5	4.6	4.0	23.4	24.5	25.0	25.5	25.4	25.2	24.4	23.5	590	77.2	639	1	1640	1.5
TP-5-PA5-17	B-3	26.0	5.0	4.7	23.5	24.6	25.2	25.9	25.9	25.9	25.3	24.4	608	94.6	656	1	1659	1.5
TP-5-PA5-18	B-4	25.6	4.6	4.8	23.3	24.3	24.8	24.3	25.6	25.5	25.0	24.1	600	86.3	648	1	1636	1.5
TP-5-PA6-19	B-5	26.8	5.5	7.0	23.6	24.8	25.4	26.2	26.7	26.8	26.1	25.0	624	110.3	672	1	2050	1.5
TP-5-PA6-20	B-6	26.8	5.4	6.9	23.7	24.7	25.2	26.2	26.7	26.7	26.1	25.0	623	109.4	672	1	2076	1.5
TP-5-PA6-21	B-7	26.4	5.1	6.7	23.5	24.6	25.2	26.0	26.4	26.3	25.5	24.4	612	98.6	637	1	1955	1.5
TP-5-PA6-22	B-8	26.5	5.1	6.8	23.4	24.5	25.1	25.9	26.4	26.4	25.6	24.5	613	99.5	3978	7	3217	1.8
TP-5-PA6-23	A-1	25.0	3.6	11.2	21.7	22.8	23.4	24.2	24.8	24.9	24.6	23.9	585	75.2	4029	7	3199	1.7
TP-5-PA6-24	A-3	25.4	3.9	12.1	21.6	22.6	23.2	24.1	24.9	25.1	25.3	24.6	594	83.9	4038	7	3246	1.7
TP-5-PA6-25	A-4	25.4	3.9	11.3	22.0	23.1	23.7	23.1	25.1	25.2	25.2	24.4	595	84.6	1747	3	2910	1.8
TP-5-PA6-26	A-5	25.4	4.0	11.4	21.7	22.7	23.3	24.2	25.0	25.2	25.3	24.6	595	84.2	1747	3	2922	1.7
TP-5-PA6-27	A-6	25.6	4.2	10.0	21.9	22.9	23.6	24.3	25.2	25.5	25.3	24.6	598	87.0	1750	3	2520	1.8

Note: Shading of table rows is for ease of reading.

Table B.6 Thermal Profile Raw Data: Series 6

Specimen ID	Channel ID	T_{max} (°C)	ΔT (°C)	t_{max} (hr)	Profile Temperature (°C) at Time Indicated (hr)								A_s (°C-hr)	$A_{\Delta T}$ (°C-hr)	*TTF* (°C-hr)	$t_{\sigma max}$ (day)	σ_{max} (kPa)	ε_{max} (%)
					0.1	1	2	4	6	8	16	24						
TP-6-PA4-01	A-3	20.5	0.7	24.0	8.5	9.3	10.4	12.5	14.2	15.3	18.4	20.5	390	18.0	440	1	1100	1.4
TP-6-PA4-02	A-4	20.0	0.3	24.0	8.4	8.8	10.0	12.0	13.7	14.9	17.9	20.0	378	8.4	429	1	1127	1.4
TP-6-PA4-03	A-5	19.9	0.3	23.9	7.8	9.1	10.1	12.0	13.7	14.9	17.8	19.9	378	6.1	453	1	1069	1.4
TP-6-PA4-04	A-1	20.2	1.2	24.0	6.3	7.1	8.5	10.9	12.9	14.6	18.1	20.1	372	23.2	1383	3	1512	1.3
TP-6-PA4-05	A-3	19.5	0.5	24.0	5.8	6.5	7.7	9.8	11.7	13.5	17.2	19.5	350	0.0	1361	3	1569	1.4
TP-6-PA4-06	A-4	19.4	0.3	24.0	6.7	7.0	8.0	10.4	11.8	13.5	17.2	19.4	351	0.0	1362	3	1505	1.3
TP-6-PA4-07	A-6	19.9	0.2	23.9	7.8	8.6	9.6	11.6	13.4	14.7	17.7	19.9	373	0.3	4135	7	2114	1.5
TP-6-PA4-08	A-7	20.5	0.8	24.0	8.3	9.5	10.3	12.5	14.4	15.7	18.6	20.5	394	19.4	4156	7	2103	1.4
TP-6-PA4-09	A-8	20.8	1.0	23.9	7.6	9.3	10.0	12.5	14.5	15.8	18.9	20.8	397	21.5	4159	7	2069	1.5
TP-6-PA5-10	B-1	21.3	1.7	24.0	9.0	9.4	10.8	13.1	15.1	16.5	19.6	21.3	413	35.8	489	1	1564	1.5
TP-6-PA5-11	B-3	20.9	1.3	24.0	7.9	9.0	10.2	12.3	14.1	15.6	18.9	20.9	396	17.5	472	1	1557	1.4
TP-6-PA5-12	B-4	20.7	1.0	23.9	9.1	9.4	10.6	12.6	14.2	15.6	18.7	20.7	396	15.7	447	1	1451	1.4
TP-6-PA5-13	A-5	19.9	0.8	24.0	6.6	7.3	8.0	10.7	11.9	13.7	17.6	19.9	360	3.3	1372	3	2110	1.5
TP-6-PA5-14	A-6	20.1	0.9	24.0	6.5	7.1	7.9	10.6	12.0	13.8	17.8	20.1	362	3.9	1373	3	2137	1.5
TP-6-PA5-15	A-7	20.5	1.3	24.0	7.3	7.7	8.5	11.3	12.9	14.7	18.5	20.5	379	19.0	1391	3	2137	1.5
TP-6-PA5-16	B-5	20.8	1.1	23.9	8.8	9.4	10.5	9.4	14.2	15.6	18.8	20.8	397	15.5	4159	7	3092	1.7
TP-6-PA5-17	B-6	21.0	1.2	24.0	9.4	9.6	10.8	12.9	14.6	16.0	19.1	21.0	404	20.1	4166	7	2975	1.7
TP-6-PA5-18	B-7	21.4	1.7	24.0	9.7	9.5	10.9	13.3	15.1	16.6	19.7	21.4	416	31.7	4179	7	3016	1.7
TP-6-PA6-19	A-8	21.1	1.7	24.0	7.4	8.9	9.7	12.2	13.9	15.7	19.5	21.1	402	40.1	442	1	1673	1.5
TP-6-PA6-20	B-1	21.6	2.2	23.9	7.7	8.6	9.9	12.5	14.4	16.2	20.0	21.6	413	45.7	454	1	1773	1.4
TP-6-PA6-21	B-3	21.7	2.1	23.9	8.0	9.1	10.2	12.5	14.1	15.8	19.6	21.7	407	37.4	447	1	1605	1.4
TP-6-PA6-22	B-4	21.7	2.0	23.9	8.2	9.7	10.7	13.0	14.4	16.1	19.6	21.5	411	40.6	1422	3	2350	1.7
TP-6-PA6-23	B-5	22.1	2.4	23.7	9.8	10.8	12.0	10.8	15.5	17.1	20.2	21.8	430	57.9	1442	3	2609	1.7
TP-6-PA6-24	B-6	22.1	2.5	23.6	10.4	11.7	12.9	14.9	16.1	17.6	20.4	21.9	440	67.2	1452	3	2629	1.5
TP-6-PA6-25	B-7	22.4	2.7	23.3	11.2	11.9	13.2	15.1	16.8	18.4	21.0	22.2	453	77.4	3580	7	3538	2.0
TP-6-PA6-26	B-8	22.3	2.7	23.4	11.9	12.4	13.7	15.4	17.1	18.6	21.1	22.3	458	82.4	3585	7	3412	1.8
TP-6-PA6-27	A-1	20.8	2.0	23.9	7.3	8.1	9.3	11.9	13.7	15.4	19.1	20.8	394	41.8	4098	7	3052	1.7

Note: Shading of table rows is for ease of reading.

Table B.7 Thermal Profile Raw Data: Series 7

Specimen ID	Channel ID	T_{max} (°C)	ΔT (°C)	t_{max} (hr)	Profile Temperature (°C) at Time Indicated (hr)								A_s (°C-hr)	$A_{\Delta T}$ (°C-hr)	*TTF* (°C-hr)	$t_{\sigma max}$ (day)	σ_{max} (kPa)	ε_{max} (%)
					0.1	1	2	4	6	8	16	24						
TP-7-PA4-01	A-3	29.3	3.9	2.4	27.7	28.7	29.2	29.0	28.5	28.0	26.2	24.5	648	70.9	723	1	1305	1.3
TP-7-PA4-02	A-4	28.9	3.6	2.5	27.2	28.4	28.8	28.7	28.2	27.7	25.8	24.3	640	63.0	715	1	1345	1.3
TP-7-PA4-03	A-5	29.1	3.8	2.6	27.6	28.5	28.9	28.9	28.4	27.8	25.8	24.2	642	65.9	717	1	1256	1.3
TP-7-PA4-04	A-1	31.2	3.9	2.2	29.8	30.7	31.0	30.3	29.5	28.7	26.6	25.1	668	58.7	1837	3	1609	1.4
TP-7-PA4-05	A-3	30.7	3.5	2.1	29.3	30.2	30.6	30.2	29.6	29.0	27.1	25.6	674	65.3	1843	3	1654	1.4
TP-7-PA4-06	A-4	30.7	3.4	1.9	28.9	30.2	30.6	30.3	29.7	29.1	27.1	25.6	675	66.6	1844	3	1548	1.4
TP-7-PA4-07	A-6	29.6	4.3	2.4	28.0	29.0	29.5	29.2	28.7	28.0	25.9	24.3	647	70.9	4204	7	1872	1.4
TP-7-PA4-08	A-7	29.0	3.7	2.3	27.6	28.6	29.0	28.7	28.1	27.4	25.2	23.7	632	56.3	4213	7	1886	1.3
TP-7-PA4-09	A-8	29.0	3.8	2.6	27.7	28.5	28.9	28.7	28.0	27.3	25.1	23.5	629	54.1	4185	7	1759	1.3
TP-7-PA5-10	B-1	29.7	4.9	2.9	27.8	29.3	29.5	29.5	28.8	28.1	25.8	24.1	647	79.8	697	1	1825	1.5
TP-7-PA5-11	B-3	30.0	5.2	3.2	28.3	29.2	29.6	29.9	29.5	29.0	27.0	25.1	668	100.3	717	1	1825	1.4
TP-7-PA5-12	B-4	30.1	5.4	3.3	28.6	29.5	29.8	30.0	29.5	28.9	26.6	24.8	664	97.3	714	1	1779	1.5
TP-7-PA5-13	A-5	31.4	4.5	2.9	29.7	30.7	31.1	31.2	30.6	30.1	28.2	26.3	697	89.4	1866	3	2219	1.7
TP-7-PA5-14	A-6	30.8	4.0	3.1	28.8	30.1	30.5	30.7	30.3	29.9	28.1	26.3	692	85.4	1861	3	2276	1.5
TP-7-PA5-15	A-7	30.8	4.1	3.3	29.5	30.3	30.6	30.7	30.1	29.6	27.7	25.9	685	79.1	1878	3	2076	1.5
TP-7-PA5-16	B-5	30.5	5.8	3.0	28.6	29.8	30.2	29.8	29.8	29.2	27.0	25.1	672	105.5	4228	7	2691	1.7
TP-7-PA5-17	B-6	30.1	5.4	3.1	28.3	29.4	29.8	29.9	29.3	28.8	26.5	24.7	661	95.5	4217	7	2730	1.7
TP-7-PA5-18	B-7	29.8	5.2	3.3	28.1	29.5	29.7	29.7	29.0	28.3	25.9	24.0	649	83.7	4204	7	2491	1.5
TP-7-PA6-19	A-8	31.3	4.7	3.5	29.5	30.6	30.8	31.3	30.8	30.3	28.1	26.0	696	90.9	744	1	2069	1.5
TP-7-PA6-20	B-1	31.3	4.7	3.7	29.5	30.8	30.9	31.2	30.7	30.2	27.8	25.7	692	84.5	740	1	2210	1.5
TP-7-PA6-21	B-3	32.3	5.7	3.6	30.1	31.4	31.7	32.3	31.9	31.5	29.3	27.0	722	115.2	770	1	2223	1.5
TP-7-PA6-22	B-4	31.8	5.3	3.8	29.4	31.0	31.3	31.8	31.5	31.0	28.8	26.6	711	105.1	1881	3	2760	1.7
TP-7-PA6-23	B-5	32.8	6.3	3.7	30.3	31.8	32.2	31.8	32.4	32.0	29.6	27.3	731	125.9	1901	3	2524	1.7
TP-7-PA6-24	B-6	32.3	5.9	4.0	30.2	31.3	31.7	32.3	32.0	31.6	29.4	27.1	725	120.2	1895	3	2599	1.5
TP-7-PA6-25	B-7	32.6	6.2	3.9	30.1	31.9	32.1	32.5	32.0	31.4	28.9	26.6	719	114.6	4267	7	3039	1.7
TP-7-PA6-26	B-8	32.2	5.8	3.7	30.2	31.4	31.7	32.2	31.7	31.2	28.8	26.6	714	110.3	4263	7	2980	1.7
TP-7-PA6-27	A-1	29.9	4.5	3.3	28.8	29.7	29.7	29.7	28.8	28.0	25.1	22.9	637	79.5	4267	7	3292	1.8

Note: Shading of table rows is for ease of reading.

Table B.8 Thermal Profile Raw Data: Series 8a

Specimen ID	Channel ID	T_{max} (°C)	ΔT (°C)	t_{max} (hr)	Profile Temperature (°C) at Time Indicated (hr) 0.1	1	2	4	6	8	16	24	A_s (°C-hr)	$A_{\Delta T}$ (°C-hr)	TTF (°C-hr)	$t_{\sigma max}$ (day)	σ_{max} (kPa)	ε_{max} (%)
TP-8-PB5-01	A-4	27.7	5.8	3.0	25.3	27.0	27.6	27.7	27.4	26.9	25.3	24.0	624	95.2	4179	7	2704	1.5
TP-8-PB5-02	A-5	27.7	5.7	3.6	25.3	26.8	27.4	27.7	27.5	27.1	25.7	24.4	629	100.7	4209	7	2666	1.5
TP-8-PB5-03	A-6	28.1	6.1	3.7	25.5	27.3	27.8	28.1	27.9	27.5	25.9	24.6	637	107.7	4191	7	2713	1.7
TP-8-PB5-04	A-7	27.7	5.7	3.2	25.6	27.0	27.5	27.7	27.4	27.0	25.4	24.2	625	96.4	4180	7	2731	1.7
TP-8-PB5-05	A-8	28.1	6.2	3.1	25.7	27.4	28.0	28.0	27.6	27.2	25.4	24.1	628	99.4	4183	7	2579	1.5
TP-8-PB5-06	B-1	27.5	5.6	3.2	25.6	26.9	27.4	27.4	27.0	26.5	24.8	23.6	614	85.2	4169	7	2777	1.7
TP-8-PB5-07	B-3	27.9	5.9	3.4	25.5	27.1	27.7	27.9	27.6	27.2	25.5	24.1	628	99.1	4183	7	2739	1.5
TP-8-PB5-08	B-4	27.2	5.1	3.7	25.2	26.5	27.0	27.2	26.8	26.5	24.9	23.7	614	84.7	4168	7	2742	1.5
TP-8-PB5-09	B-5	27.6	5.6	3.5	25.1	26.8	27.4	27.6	27.3	27.0	25.3	24.0	623	93.9	4177	7	2624	1.5
TP-8-PB5-10	B-6	27.6	5.5	3.7	25.5	26.8	27.4	27.6	27.4	27.0	25.5	24.2	627	97.2	4181	7	2856	1.5
TP-8-PB5-11	B-7	27.9	5.9	3.3	25.5	27.2	27.8	27.8	27.4	27.0	25.1	23.8	623	93.7	4177	7	2857	1.7
TP-8-PB5-12	B-8	27.7	5.6	3.4	25.5	27.0	27.6	27.6	27.3	26.9	25.1	23.9	621	92.0	4176	7	2656	1.7
TP-8-PB5-13	A-1	26.6	5.3	2.9	24.2	26.0	26.5	26.4	26.3	26.0	24.4	23.0	600	74.1	4081	7	2236	1.4
TP-8-PB5-14	A-3	26.3	4.7	4.7	24.0	25.5	26.0	26.3	26.2	26.1	24.9	23.5	605	79.3	4087	7	2608	1.5
TP-8-PB5-15	A-4	27.0	5.6	3.1	24.6	26.3	26.8	26.9	26.7	26.4	24.8	23.4	609	83.3	4091	7	2190	1.5
TP-8-PB5-16	A-5	26.8	5.3	4.1	24.3	25.9	26.5	25.9	26.7	26.5	25.2	23.8	614	87.5	4095	7	2180	1.5
TP-8-PB5-17	A-6	27.5	6.0	3.8	24.7	26.6	27.2	27.4	27.3	27.0	25.5	24.0	624	97.9	4106	7	2163	1.5
TP-8-PB5-18	A-7	27.0	5.5	3.7	24.7	26.3	26.9	27.0	26.9	26.6	25.1	23.7	614	87.9	4096	7	2153	1.4
TP-8-PB5-19	A-8	27.6	6.1	3.3	25.2	27.0	27.5	27.6	27.3	26.9	25.1	23.7	620	93.6	4101	7	2107	1.4
TP-8-PB5-20	B-1	26.8	5.6	2.1	24.7	26.3	26.8	26.8	26.4	26.1	24.4	23.1	601	77.2	4083	7	2410	1.5
TP-8-PB5-21	B-3	27.0	5.5	3.7	24.5	26.2	26.8	27.0	26.8	26.5	24.9	23.4	611	86.5	4092	7	2219	1.5
TP-8-PB5-22	B-4	26.1	4.7	3.2	23.4	25.4	25.9	26.1	25.9	25.6	24.2	22.9	593	68.1	4098	7	2259	2.0
TP-8-PB5-23	B-5	26.8	5.4	3.3	24.2	26.0	26.6	26.0	26.6	26.3	24.7	23.2	606	81.4	4087	7	2366	1.5
TP-8-PB5-24	B-6	26.9	5.3	3.8	24.5	26.1	26.6	26.9	26.7	26.4	24.9	23.6	611	86.3	4092	7	2318	1.5
TP-8-PB5-25	B-7	27.2	5.8	2.9	24.6	26.6	27.0	27.2	26.9	26.4	24.6	23.2	609	84.1	4090	7	2348	1.5
TP-8-PB5-26	B-8	27.0	5.5	3.4	24.6	26.3	26.7	27.0	26.8	26.4	24.7	23.4	609	84.2	4090	7	2379	1.5
TP-8-PB5-27	A-1	26.9	5.4	2.8	24.5	26.3	26.8	26.8	26.5	26.1	24.7	23.3	607	76.8	4123	7	2187	1.5
TP-8-PB5-28	A-3	26.6	5.0	3.4	24.2	25.7	26.3	26.5	26.5	26.3	25.1	23.9	611	80.9	4127	7	2539	1.5
TP-8-PB5-29	A-4	26.9	5.3	3.0	24.6	26.3	26.8	26.9	26.6	26.3	24.9	23.7	611	80.7	4127	7	2174	1.5
TP-8-PB5-30	A-5	26.8	5.1	4.0	24.7	26.1	26.6	26.8	26.6	26.5	25.2	24.1	615	84.6	4131	7	2217	1.4

Note: Shading of table rows is for ease of reading.

Table B.9 Thermal Profile Raw Data: Series 8b

Specimen ID	Channel ID	T_{max} (°C)	ΔT (°C)	t_{max} (hr)	Profile Temperature (°C) at Time Indicated (hr)								A_s (°C-hr)	$A_{\Delta T}$ (°C-hr)	*TTF* (°C-hr)	$t_{\sigma max}$ (day)	σ_{max} (kPa)	ε_{max} (%)
					0.1	1	2	4	6	8	16	24						
TP-8-PB5-31	B-5	27.1	5.7	4.0	24.6	26.3	26.8	27.0	26.9	26.6	25.2	23.8	616	98.6	4179	7	2701	1.5
TP-8-PB5-32	B-6	26.5	5.1	4.3	24.1	25.6	26.2	26.5	26.4	26.2	24.9	23.7	608	90.4	4171	7	2904	1.7
TP-8-PB5-33	B-7	26.8	5.5	3.1	24.6	26.3	26.7	26.8	26.5	26.2	24.5	23.3	605	87.5	4168	7	2812	1.7
TP-8-PB5-34	B-8	26.4	5.1	3.0	24.5	25.9	26.3	26.4	26.2	25.8	24.4	23.2	599	81.3	4162	7	2968	1.7
TP-8-PB5-35	A-1	25.7	5.0	2.9	23.5	25.0	25.5	25.6	25.4	25.1	23.8	22.7	584	74.5	4027	7	2382	1.5
TP-8-PB5-36	A-3	25.4	4.4	5.0	23.2	24.4	25.0	25.3	25.3	25.2	24.3	23.2	588	78.9	4031	7	2532	1.5
TP-8-PB5-37	A-4	26.1	5.4	2.9	23.8	25.4	26.0	26.1	25.9	25.6	24.3	23.1	596	86.0	4014	7	2247	1.4
TP-8-PB5-38	A-5	25.8	4.8	4.5	23.5	24.9	25.4	25.8	25.7	25.6	24.5	23.3	596	85.7	4014	7	2395	1.4
TP-8-PB5-39	A-6	26.6	5.7	4.3	24.2	25.8	26.4	26.6	26.5	26.2	24.8	23.5	607	97.0	4025	7	2524	1.4
TP-8-PB5-40	A-7	25.7	4.8	4.0	23.8	25.0	25.5	25.7	25.6	25.4	24.1	23.0	590	79.4	4008	7	2243	1.5
TP-8-PB5-41	A-8	26.4	5.5	2.8	24.1	25.7	26.2	26.3	26.1	25.8	24.3	23.0	597	86.2	4012	7	2291	1.4
TP-8-PB5-42	B-1	25.6	4.9	2.7	23.6	25.0	25.5	25.5	25.3	25.0	23.7	22.5	581	72.9	3996	7	2295	1.5
TP-8-PB5-43	B-3	26.6	5.8	3.5	24.3	26.0	26.4	26.6	26.4	26.1	24.7	23.3	605	96.2	4020	7	2493	1.5
TP-8-PB5-44	B-4	25.7	4.9	3.7	23.8	25.1	25.5	25.7	25.6	25.4	24.2	23.0	590	81.2	4005	7	2412	1.4
TP-8-PB5-45	B-5	26.7	5.8	3.6	24.4	25.9	26.4	26.6	26.5	26.2	24.8	23.5	607	98.0	4022	7	2535	1.4
TP-8-PB5-46	B-6	26.1	5.1	4.4	24.1	25.2	25.8	25.2	26.0	25.8	24.6	23.4	598	89.7	4035	7	2537	1.5
TP-8-PB5-47	A-1	26.0	5.0	3.1	23.6	25.2	25.7	25.9	25.8	25.5	24.3	23.2	594	75.9	4058	7	2876	1.7
TP-8-PB5-48	A-3	25.7	4.3	5.5	23.4	24.7	25.2	25.6	25.6	25.4	24.5	23.6	595	76.8	4059	7	2839	1.7
TP-8-PB5-49	B-1	25.0	4.4	3.9	22.1	24.1	24.7	24.9	24.7	24.5	23.5	22.5	572	67.8	3663	7	2895	1.7
TP-8-PB5-50	B-3	24.7	4.0	5.2	21.9	23.5	24.1	24.6	24.7	24.6	23.9	23.0	576	72.4	3668	7	2931	1.8
TP-8-PB5-51	B-4	25.1	4.6	3.6	22.3	24.1	24.7	25.1	25.0	24.8	23.9	22.9	579	75.3	3671	7	2904	1.7
TP-8-PB5-52	B-5	24.9	4.3	4.8	22.2	23.7	24.4	24.9	24.9	24.8	24.0	23.1	580	75.5	3671	7	2710	1.7
TP-8-PB5-53	B-6	25.4	4.8	3.6	22.5	24.3	25.0	24.3	25.2	25.0	24.1	23.1	585	80.5	3676	7	2858	1.7
TP-8-PB5-54	B-7	24.7	4.2	3.3	22.2	23.8	24.4	24.7	24.6	24.4	23.5	22.6	571	66.8	3663	7	2968	1.8
TP-8-PB5-55	B-1	25.2	3.9	3.3	22.7	24.6	25.0	25.2	25.0	24.7	23.7	22.5	577	59.8	3701	7	2424	1.5
TP-8-PB5-56	B-3	25.1	3.6	6.4	22.5	24.1	24.5	25.0	25.1	25.0	24.3	23.2	585	67.9	3710	7	3014	1.8
TP-8-PB5-57	B-4	25.8	4.4	3.8	23.4	25.1	25.5	25.8	25.7	25.6	24.5	23.3	595	77.3	3719	7	2821	1.8
TP-8-PB5-58	B-5	25.4	3.9	5.9	22.8	24.3	24.8	25.3	25.3	25.3	24.4	23.3	589	71.6	3713	7	3024	1.7
TP-8-PB5-59	B-6	25.9	4.5	3.9	23.4	25.2	25.6	25.9	25.8	25.6	24.4	23.1	595	77.8	3719	7	2802	1.5
TP-8-PB5-60	B-7	25.1	3.7	3.8	22.8	24.4	24.8	25.1	25.0	24.8	23.7	22.4	576	58.9	3701	7	2821	1.7

Note: Shading of table rows is for ease of reading.

Table B.10 Thermal Profile Raw Data: Series 9

Specimen ID	Channel ID	T_{max} (°C)	ΔT (°C)	t_{max} (hr)	Profile Temperature (°C) at Time Indicated (hr) 0.1	1	2	4	6	8	16	24	A_s (°C-hr)	$A_{\Delta T}$ (°C-hr)	*TTF* (°C-hr)	$t_{\sigma max}$ (day)	σ_{max} (kPa)	ε_{max} (%)
TP-9-PB5-01	B-3	26.9	5.6	3.4	24.3	25.9	26.5	26.9	26.7	26.4	25.0	23.6	612	90.4	3948	7	2750	1.7
TP-9-PB5-02	B-4	26.3	5.0	3.6	23.9	25.3	26.0	26.3	26.2	25.9	24.6	23.4	601	79.6	3937	7	2737	1.5
TP-9-PB5-03	B-5	26.9	5.6	3.7	24.2	25.8	26.5	26.9	26.8	26.5	25.2	23.9	615	93.1	3951	7	2771	1.5
TP-9-PB5-04	B-6	26.5	5.1	4.3	23.9	25.3	26.0	26.4	26.4	26.2	25.0	23.8	609	86.6	3945	7	2797	1.7
TP-9-PB5-05	B-7	26.9	5.5	3.3	24.3	26.0	26.6	26.8	26.6	26.3	24.6	23.4	607	84.5	3943	7	2700	1.7
TP-9-PB5-06	B-8	26.4	5.0	3.5	24.0	25.4	26.1	26.3	26.2	25.9	24.5	23.3	600	78.1	3959	7	2562	1.5
TP-9-PB5-07	A-1	24.6	4.4	4.1	22.2	23.7	24.2	24.6	24.5	24.4	23.5	22.6	569	70.9	4055	7	2442	1.5
TP-9-PB5-08	A-3	24.5	4.0	6.5	21.9	23.2	23.8	24.4	24.5	24.5	24.0	23.1	574	75.2	4060	7	2584	1.5
TP-9-PB5-09	A-4	25.0	4.7	4.3	22.3	23.9	24.5	24.9	24.9	24.8	24.0	23.0	579	80.2	4065	7	2569	1.5
TP-9-PB5-10	A-5	24.7	4.1	6.8	21.9	23.3	23.9	24.5	24.7	24.7	24.1	23.2	577	78.1	4063	7	2625	1.7
TP-9-PB5-11	A-6	25.3	4.8	5.7	22.4	24.1	24.7	25.2	25.2	25.1	24.3	23.3	586	87.1	4074	7	2767	1.5
TP-9-PB5-12	A-7	24.4	3.9	5.9	22.0	23.2	23.8	24.3	24.4	24.4	23.7	22.7	569	70.2	4057	7	2923	1.8
TP-9-PB5-13	A-8	25.1	4.7	4.4	22.4	24.0	24.6	25.0	25.0	24.8	23.9	22.7	578	78.2	4065	7	2681	1.5
TP-9-PB5-14	B-1	24.4	4.2	4.6	22.1	23.5	24.0	24.4	24.4	24.2	23.3	22.3	564	68.4	4052	7	2636	1.5
TP-9-PB5-15	B-3	25.5	5.2	4.5	22.6	24.3	25.0	25.4	25.4	25.2	24.2	23.1	587	90.8	4074	7	2665	1.7
TP-9-PB5-16	B-4	24.9	4.6	5.0	22.2	23.7	24.4	23.7	24.9	24.7	23.8	22.8	576	79.8	4064	7	2833	1.7
TP-9-PB5-17	B-5	25.6	5.3	4.9	22.8	24.5	25.1	25.5	25.6	25.4	24.4	23.3	591	94.6	4080	7	2845	1.7
TP-9-PB5-18	B-6	25.2	4.7	6.1	22.6	23.9	24.5	25.1	25.2	25.0	24.2	23.2	585	87.9	4074	7	2824	1.7
TP-9-PB5-19	B-7	25.4	5.2	3.9	22.7	24.4	25.0	25.4	25.3	25.1	23.9	22.8	582	85.6	4071	7	2740	1.7
TP-9-PB5-20	B-8	25.1	4.7	4.4	22.4	24.0	24.6	25.0	25.0	24.8	23.8	22.7	577	80.5	4066	7	2798	1.7
TP-9-PB5-21	A-1	26.5	5.1	3.9	24.1	25.7	26.2	26.5	26.2	25.8	24.4	23.3	600	79.9	4163	7	3086	1.7
TP-9-PB5-22	A-3	26.4	5.0	4.7	23.9	25.3	25.9	26.4	26.4	26.2	25.1	23.9	610	89.2	4172	7	2998	1.7
TP-9-PB5-23	A-4	27.0	5.6	3.3	24.4	26.0	26.6	26.0	26.8	26.5	25.1	23.8	614	93.9	4153	7	3068	1.7
TP-9-PB5-24	A-5	26.5	5.1	4.4	23.9	25.3	26.0	26.5	26.5	26.3	25.2	24.0	612	91.1	4174	7	3118	1.7
TP-9-PB5-25	A-6	27.0	5.6	4.2	24.4	26.0	26.6	27.0	26.9	26.7	25.3	24.0	619	97.9	4181	7	3186	1.8
TP-9-PB5-26	A-7	26.3	4.8	3.8	24.2	25.4	25.9	26.3	26.1	25.9	24.6	23.4	601	79.8	4163	7	3100	1.7
TP-9-PB5-27	A-8	26.7	5.3	3.1	24.3	25.8	26.4	26.6	26.4	26.1	24.5	23.4	604	82.9	4166	7	3086	1.8
TP-9-PB5-28	B-1	26.2	4.9	2.8	24.0	25.4	26.0	26.1	25.8	25.5	24.1	23.0	592	75.0	4155	7	3089	1.7
TP-9-PB5-29	B-3	27.2	5.8	3.8	24.7	26.2	26.8	27.2	27.0	26.8	25.3	23.9	619	101.2	4181	7	3057	1.7
TP-9-PB5-30	B-4	26.6	5.2	4.1	24.3	25.6	26.2	26.5	26.4	26.2	24.9	23.7	608	90.3	4170	7	2885	1.5

Note: Shading of table rows is for ease of reading.

Table B.11 Thermal Profile Raw Data: Series 10

Specimen	Channel	T_{max}	ΔT	t_{max}	Profile Temperature (°C) at Time Indicated (hr)								A_s	$A_{\Delta T}$	*TTF*	$t_{\sigma max}$	σ_{max}	ε_{max}
ID	ID	(°C)	(°C)	(hr)	0.1	1	2	4	6	8	16	24	(°C-hr)	(°C-hr)	(°C-hr)	(day)	(kPa)	(%)
TP-10-PB4-01	A-7	26.3	5.1	3.5	24.6	26.0	26.2	26.3	26.1	25.8	24.4	23.3	600	80.9	4164	7	2125	1.4
TP-10-PB4-02	A-8	25.8	4.5	4.3	24.3	25.4	25.6	25.8	25.7	25.4	24.1	23.1	592	72.5	4155	7	2224	1.4
TP-10-PB4-03	B-1	26.2	5.3	1.9	24.6	26.0	26.2	26.1	25.8	25.4	24.0	22.9	592	74.5	4156	7	2085	1.4
TP-10-PB4-04	B-3	26.1	4.9	4.2	24.5	25.6	25.9	26.1	26.0	25.8	24.7	23.5	602	84.6	1817	3	2081	1.4
TP-10-PB4-05	B-4	26.5	5.4	3.6	24.8	26.3	26.4	26.5	26.3	26.0	24.6	23.5	605	87.1	1820	3	2101	1.4
TP-10-PB4-06	B-5	26.3	5.1	4.1	25.4	25.9	26.1	26.3	26.2	26.0	24.8	23.7	606	87.3	1820	3	2029	1.4
TP-10-PB4-07	B-6	26.8	5.6	4.1	24.8	26.4	26.6	26.8	26.7	26.4	25.0	23.8	613	94.7	662	1	1600	1.3
TP-10-PB4-08	B-7	26.2	4.9	4.0	24.7	25.8	26.0	26.2	26.0	25.7	24.3	23.3	598	79.3	647	1	1676	1.3
TP-10-PB4-09	B-8	26.8	5.5	3.3	24.7	26.4	26.6	26.7	26.4	26.1	24.5	23.4	605	85.9	629	1	1600	1.3
TP-10-PB5-10	A-1	26.7	5.5	3.4	24.2	26.0	26.4	26.6	26.3	26.0	24.6	23.4	604	82.0	1830	3	2644	1.5
TP-10-PB5-11	A-3	26.6	5.3	4.4	24.2	25.7	26.2	26.6	26.5	26.3	25.2	24.0	613	90.1	1838	3	2527	1.5
TP-10-PB5-12	A-4	27.0	5.8	3.6	24.5	26.3	26.8	27.0	26.8	26.4	25.1	23.9	615	92.1	1816	3	2508	1.5
TP-10-PB5-13	A-5	26.8	5.5	4.1	24.1	25.8	26.4	26.8	26.7	26.5	25.3	24.1	616	93.0	4177	7	2754	1.7
TP-10-PB5-14	A-6	27.3	6.0	3.6	24.6	26.4	27.0	27.3	27.1	26.9	25.4	24.1	622	99.2	4184	7	2692	1.7
TP-10-PB5-15	A-7	26.6	5.4	3.5	24.6	25.9	26.4	26.6	26.4	26.1	24.8	23.5	607	83.3	4168	7	2694	1.5
TP-10-PB5-16	A-8	27.1	5.8	3.3	24.6	26.4	26.9	26.4	26.7	26.4	24.8	23.5	611	86.9	685	1	2119	1.5
TP-10-PB5-17	B-1	26.6	5.5	3.0	24.4	26.0	26.5	26.6	26.3	25.9	24.4	23.2	601	78.7	676	1	2058	1.5
TP-10-PB5-18	B-3	27.6	6.3	3.2	24.7	26.7	27.3	27.5	27.3	27.1	25.6	24.2	626	103.6	676	1	1863	1.4
TP-10-PB6-19	B-4	27.9	6.7	3.0	24.9	27.0	27.7	27.8	27.5	27.3	25.7	24.2	630	107.5	1830	3	2783	1.5
TP-10-PB6-20	B-5	27.6	6.3	4.1	24.8	26.6	27.3	27.6	27.5	27.3	25.9	24.6	632	109.3	1832	3	2914	1.7
TP-10-PB6-21	B-6	28.4	7.2	2.9	25.5	27.5	28.2	28.4	28.2	27.9	26.2	24.7	644	120.2	693	1	2432	1.4
TP-10-PB6-22	B-7	27.6	6.3	2.8	24.8	26.8	27.4	27.5	27.3	27.0	25.4	24.0	624	100.1	673	1	2453	1.5
TP-10-PB6-23	B-8	28.2	7.0	2.7	24.8	27.2	28.1	27.2	27.8	27.3	25.5	24.0	630	106.2	679	1	2042	1.4
TP-10-PB6-24	A-1	26.5	5.9	2.8	23.8	25.7	26.4	26.5	26.2	25.8	24.4	23.2	600	87.7	1807	3	2777	1.7
TP-10-PB6-25	A-3	26.3	5.3	4.8	23.5	25.2	25.9	26.2	26.2	26.0	24.9	23.8	606	93.5	4042	7	3235	1.7
TP-10-PB6-26	A-4	26.8	6.1	3.0	24.0	26.0	26.6	26.8	26.5	26.2	24.8	23.6	609	96.5	4045	7	3047	1.7
TP-10-PB6-27	A-5	26.4	5.5	4.3	23.8	25.5	26.1	26.4	26.2	26.0	24.8	23.7	606	93.2	4042	7	3274	1.7

Note: Shading of table rows is for ease of reading.

Table B.12 Thermal Profile Raw Data: Series 11

Specimen ID	Chan. ID	T_{max} (°C)	ΔT (°C)	t_{max} (hr)	Profile Temperature (°C) at Time Indicated (hr) 0.1	1	2	4	6	8	16	24	A_s (°C-hr)	$A_{\Delta T}$ (°C-hr)	*TTF* (°C-hr)	$t_{\sigma max}$ (day)	$P_{\gamma d}$ (%)	σ_{max} (kPa)	ε_{max} (%)
TP-11-PD7-01	A-1	25.8	4.2	12.1	22.1	22.9	23.5	24.3	25.3	25.6	25.7	24.7	602	88.9	3973	7	96.1	1144	1.3
TP-11-PD7-02	A-3	26.6	4.9	13.9	22.1	22.9	23.4	24.3	25.5	26.0	26.5	25.8	615	102.2	3986	7	96.9	1275	1.3
TP-11-PD7-03	A-4	26.3	4.6	13.3	21.9	22.8	23.3	24.3	25.4	25.9	26.2	25.5	611	97.7	3982	7	96.7	1291	1.3
TP-11-PD7-04	A-5	26.9	5.2	14.8	21.9	22.7	23.3	24.4	25.6	26.2	26.9	26.1	621	107.7	4015	7	98.8	1384	1.4
TP-11-PD7-05	A-6	27.0	5.3	14.6	22.0	23.0	23.7	24.6	25.8	26.3	27.0	26.1	625	110.7	4019	7	98.6	1457	1.3
TP-11-PD7-06	A-7	26.6	4.8	13.9	22.0	22.9	23.5	24.4	25.5	26.0	26.5	25.6	615	101.3	4009	7	99.1	1450	1.3
TP-11-PD7-07	A-8	26.5	4.9	12.5	22.0	23.0	23.5	24.4	25.6	26.1	26.4	25.4	615	100.5	3986	7	100.2	1394	1.3
TP-11-PD7-08	B-1	25.8	4.0	12.2	21.9	22.8	23.3	24.0	25.0	25.5	25.7	24.9	601	84.0	3972	7	100.7	1504	1.4
TP-11-PD7-09	B-3	26.9	5.0	14.5	22.2	23.1	23.6	24.7	25.9	26.4	26.9	26.1	624	106.7	3995	7	101.0	1535	1.1
TP-11-PD7-10	B-4	26.5	4.7	13.0	22.0	22.9	23.6	24.6	25.7	26.1	26.4	25.8	616	99.2	3987	7	101.5	1543	1.3
TP-11-PD7-11	B-5	27.2	5.2	14.2	22.1	23.1	23.7	24.8	26.0	26.5	27.1	26.3	628	110.9	3999	7	101.2	1569	1.4
TP-11-PD7-12	B-6	27.1	5.2	14.7	22.1	22.9	23.6	24.7	25.9	26.4	27.1	26.2	626	109.1	3998	7	101.6	1642	1.4
TP-11-PD7-13	B-7	26.8	4.9	13.6	22.1	23.1	23.7	24.7	25.9	26.4	26.7	25.6	620	102.8	3992	7	102.5	1587	1.3
TP-11-PD7-14	B-8	26.7	4.8	13.5	22.2	23.1	23.8	24.7	25.8	26.3	26.6	25.6	618	100.6	3989	7	102.6	1614	1.3
TP-11-PD7-15	A-1	26.0	4.1	13.1	22.3	23.2	23.7	24.5	25.4	25.8	25.9	25.1	607	88.5	4083	7	100.5	1560	1.4
TP-11-PD7-16	A-3	27.0	5.0	14.0	22.3	23.2	23.9	23.2	26.0	26.5	26.9	26.1	626	107.3	4102	7	101.7	1456	1.4
TP-11-PD7-17	A-4	26.8	4.8	13.6	22.3	23.4	24.1	25.0	26.1	26.4	26.7	25.7	624	104.2	4076	7	102.4	1453	1.4
TP-11-PD7-18	A-5	26.8	4.8	13.9	22.3	23.1	23.6	24.5	25.7	26.2	26.7	26.0	620	101.0	4073	7	96.7	1253	1.3
TP-11-PD7-19	A-6	26.8	4.8	13.3	22.3	23.2	23.8	24.7	25.9	26.3	26.6	25.8	621	101.0	4073	7	86.8	531	1.1
TP-11-PD7-20	A-7	26.2	4.3	12.4	22.1	23.1	23.7	24.5	25.5	25.9	26.1	25.2	610	90.4	4063	7	86.9	615	1.3
TP-11-PD7-21	A-8	26.3	4.3	12.4	22.2	23.3	23.8	24.6	25.7	26.0	26.1	25.1	611	90.8	4087	7	89.6	673	1.3
TP-11-PD7-22	B-1	25.7	4.3	9.4	22.3	23.2	23.7	24.4	25.3	25.5	25.2	24.3	597	85.4	4073	7	93.3	952	1.4

Note: Shading of table rows is for ease of reading.

Table B.13 Thermal Profile Raw Data: Series 12

Specimen	Channel	T_{max}	ΔT	t_{max}	Profile Temperature (°C) at Time Indicated (hr)								A_s	$A_{\Delta T}$	*TTF*	$t_{\sigma max}$	σ_{max}	ε_{max}
ID	**ID**	(°C)	(°C)	(hr)	**0.1**	**1**	**2**	**4**	**6**	**8**	**16**	**24**	(°C-hr)	(°C-hr)	(°C-hr)	(day)	(kPa)	(%)
TP-12-HA4.5-01	A-1	21.7	2.3	23.9	6.9	7.6	8.7	10.9	12.7	14.3	19.5	21.7	390	26.2	4034	7	1223	2.5
TP-12-HA4.5-02	A-3	21.5	2.1	24.0	6.7	6.8	7.7	9.6	11.3	12.9	18.6	21.5	366	0.8	4010	7	1242	2.0
TP-12-HA4.5-03	A-4	21.3	1.9	23.8	7.7	7.1	7.8	9.7	11.5	13.0	18.5	21.3	367	0.0	4010	7	1177	2.0
TP-12-HA5.5-04	A-5	22.0	2.5	24.0	6.7	7.5	8.2	10.0	11.6	13.2	19.0	22.0	376	6.1	4020	7	1568	3.1
TP-12-HA5.5-05	A-6	21.9	2.4	24.0	7.0	6.5	7.6	9.5	11.3	12.9	18.8	21.9	370	0.0	4013	7	1364	1.7
TP-12-HA5.5-06	A-7	22.3	2.8	24.0	6.1	6.4	7.7	10.0	12.0	13.7	19.7	22.3	385	12.3	4003	7	1500	1.8
TP-12-HA6.5-07	A-8	23.0	3.4	23.9	6.3	6.9	8.3	10.5	12.5	14.4	20.6	23.0	402	27.0	4043	7	2249	2.1
TP-12-HA6.5-08	B-1	23.1	3.4	23.8	6.8	6.9	8.4	10.7	12.8	14.8	21.0	23.1	409	28.8	4050	7	2087	2.1
TP-12-HA6.5-09	B-3	23.1	3.3	23.9	6.3	6.9	8.3	10.6	12.7	14.6	20.9	23.1	406	23.8	4048	7	2009	2.1

Note: Shading of table rows is for ease of reading.

Table B.14 Thermal Profile Raw Data: Series 13

Specimen	Channel	T_{max}	ΔT	t_{max}	Profile Temperature (°C) at Time Indicated (hr)								A_s	$A_{\Delta T}$	*TTF*	$t_{\sigma max}$	σ_{max}	ε_{max}
ID	ID	(°C)	(°C)	(hr)	0.1	1	2	4	6	8	16	24	(°C-hr)	(°C-hr)	(°C-hr)	(day)	(kPa)	(%)
TP-13-PC4-01	A-1	26.0	4.6	2.7	23.9	25.0	25.9	26.0	25.8	25.3	24.0	23.0	590	60.8	4113	7	3218	1.8
TP-13-PC4-02	A-3	25.9	4.3	3.4	23.5	24.7	25.6	25.9	25.8	25.5	24.4	23.4	595	65.3	4118	7	3371	2.5
TP-13-PC4-03	A-4	26.2	4.5	3.4	23.6	25.0	25.9	26.0	25.7	25.4	24.1	23.0	591	61.2	4114	7	3130	2.5
TP-13-PC4-04	A-5	25.9	4.3	3.3	23.5	24.6	25.6	25.8	25.6	25.4	24.1	23.1	590	60.6	4113	7	3477	3.0
TP-13-PC4-05	A-6	26.3	4.6	3.9	23.7	25.1	26.0	26.3	26.1	25.8	24.4	23.3	598	68.5	4121	7	3307	1.1
TP-13-PC4-06	A-7	26.0	4.3	3.8	23.7	24.9	25.8	26.0	25.7	25.4	24.0	23.0	590	59.5	4113	7	3308	2.8
TP-13-PC4-07	A-8	26.4	4.6	3.6	24.0	25.3	26.3	26.3	26.0	25.7	24.1	23.1	595	64.3	4118	7	3265	3.1
TP-13-PC4-08	B-1	26.3	4.7	2.4	24.1	25.4	26.2	26.2	25.8	25.4	23.8	22.9	589	59.3	4112	7	3303	3.0
TP-13-PC4-09	B-3	26.9	5.1	3.3	24.5	25.8	26.8	26.9	26.6	26.3	24.8	23.6	609	78.8	4132	7	3093	2.8
TP-13-PC4-10	B-4	26.5	4.7	3.2	24.2	25.5	26.3	26.4	26.1	25.8	24.5	23.4	600	70.1	4123	7	3033	2.8
TP-13-PC4-11	B-5	27.1	5.3	3.0	24.6	25.9	26.8	27.1	26.7	26.4	24.9	23.8	613	82.6	4136	7	3478	3.0
TP-13-PC4-12	B-6	26.8	4.8	4.0	24.4	25.6	26.5	26.7	26.4	26.2	24.8	23.7	608	77.4	4131	7	3195	2.8
TP-13-PC4-13	B-7	26.9	5.0	2.8	24.2	25.8	26.7	26.8	26.3	25.9	24.3	23.3	601	70.9	4125	7	3282	3.1
TP-13-PC4-14	B-8	26.6	4.7	3.2	24.3	25.6	26.4	26.5	26.2	25.8	24.3	23.3	599	68.1	4122	7	3158	2.8
TP-13-PC4-29	A-1	26.7	5.0	2.5	24.4	25.8	26.6	26.6	26.2	25.8	24.4	23.2	600	65.3	4155	7	2992	1.8
TP-13-PC4-30	A-3	26.5	4.6	3.4	24.3	25.4	26.2	25.4	26.2	26.0	24.7	23.5	604	68.9	4159	7	3157	1.5
TP-13-PC4-31	A-4	26.5	4.7	2.8	23.9	25.4	26.3	26.3	26.0	25.7	24.3	23.2	597	61.7	4152	7	2958	1.7
TP-13-PC4-32	A-5	26.2	4.4	3.0	23.9	25.1	26.0	26.2	25.9	25.7	24.4	23.2	596	61.3	4152	7	3019	1.5
TP-13-PC4-33	A-6	26.7	4.9	2.8	24.2	25.5	26.5	26.6	26.4	26.1	24.7	23.5	606	70.4	4161	7	3075	1.5
TP-13-PC4-34	A-7	26.3	4.5	2.7	24.1	25.3	26.1	26.2	25.9	25.7	24.2	23.1	594	58.8	4149	7	3298	1.5
TP-13-PC4-35	A-8	26.7	4.8	2.7	24.5	25.8	26.6	26.5	26.1	25.9	24.3	23.1	599	63.5	4154	7	3194	1.7
TP-13-PC4-36	B-1	26.6	4.8	2.4	24.7	25.8	26.5	26.4	25.9	25.7	24.1	22.9	595	60.1	4150	7	3232	1.7
TP-13-PC4-37	B-3	27.2	5.4	2.8	24.9	26.2	27.1	26.2	26.9	26.6	25.1	23.8	615	80.7	4170	7	3323	1.7
TP-13-PC4-38	B-4	26.7	4.8	2.4	24.5	25.8	26.6	26.6	26.4	26.0	24.6	23.5	605	69.8	4160	7	3449	1.7
TP-13-PC4-39	B-5	27.5	5.6	2.6	25.2	26.5	27.4	27.4	27.2	26.8	25.3	24.0	621	85.9	4176	7	3197	1.5
TP-13-PC4-40	B-6	27.1	5.2	2.9	25.0	26.1	27.0	27.0	26.8	26.6	25.1	23.9	616	81.0	4171	7	3117	1.7
TP-13-PC4-41	B-7	27.3	5.4	2.5	25.0	26.3	27.2	27.1	26.8	26.4	24.8	23.6	611	76.0	4166	7	2957	1.5
TP-13-PC4-42	B-8	26.9	5.0	2.7	24.6	26.0	26.8	26.8	26.5	26.3	24.7	23.5	607	71.9	4162	7	3281	1.7
TP-13-PC4-43	A-1	26.7	5.1	2.6	24.6	25.8	26.6	26.7	26.3	25.8	24.3	23.2	599	73.1	4154	7	2781	1.5
TP-13-PC4-44	A-3	26.8	5.0	3.2	24.6	25.7	26.5	26.7	26.6	26.3	24.9	23.8	610	84.1	4165	7	2777	1.5

Note: Shading of table rows is for ease of reading.

Table B.15 Thermal Profile Raw Data: Series 14

Specimen ID	Channel ID	T_{max} (°C)	ΔT (°C)	t_{max} (hr)	Profile Temperature (°C) at Time Indicated (hr) 0.1	1	2	4	6	8	16	24	A_s (°C-hr)	$A_{\Delta T}$ (°C-hr)	TTF (°C-hr)	$t_{\sigma max}$ (day)	σ_{max} (kPa)	ε_{max} (%)
TP-14-PC4-01	B-3	25.9	4.8	3.0	23.5	24.7	25.7	25.9	25.6	25.3	24.0	22.8	588	75.8	4068	7	2018	1.3
TP-14-PC4-02	B-4	25.3	4.2	2.8	23.1	24.1	25.1	25.3	25.0	24.7	23.5	22.4	575	63.0	4056	7	2372	1.4
TP-14-PC4-03	B-5	25.7	4.6	3.5	23.2	24.4	25.5	25.7	25.5	25.2	23.8	22.7	583	71.5	4064	7	2418	1.3
TP-14-PC4-04	B-6	25.8	4.6	3.2	23.2	24.4	25.4	25.7	25.6	25.3	24.0	22.9	587	75.5	4068	7	2659	1.4
TP-14-PC4-05	B-7	25.7	4.6	3.2	21.6	24.4	25.5	25.7	25.4	25.1	23.7	22.6	581	69.2	4062	7	2588	1.4
TP-14-PC4-06	B-8	26.3	5.1	2.8	24.2	25.2	26.2	26.2	25.8	25.4	23.9	22.8	589	77.1	4070	7	2328	1.3
TP-14-PC4-07	A-1	25.7	4.5	3.0	23.4	24.5	25.4	25.6	25.3	24.9	23.6	22.5	579	60.1	4098	7	2118	1.5
TP-14-PC4-08	A-3	25.7	4.4	3.6	23.2	24.3	25.3	25.7	25.5	25.2	24.1	22.9	587	67.8	4106	7	2489	1.4
TP-14-PC4-09	A-4	25.9	4.6	3.6	23.5	24.6	25.6	25.8	25.6	25.3	24.0	22.9	587	67.8	4106	7	2597	1.5
TP-14-PC4-10	A-5	25.9	4.6	3.7	23.3	24.5	25.5	25.9	25.7	25.5	24.3	23.2	593	73.3	4112	7	2784	1.5
TP-14-PC4-11	A-6	26.2	4.8	3.5	23.5	24.7	25.8	26.1	26.0	25.7	24.5	23.3	597	77.2	4116	7	2483	1.4
TP-14-PC4-12	A-7	25.8	4.6	3.3	23.4	24.6	25.6	25.8	25.6	25.3	24.1	23.0	589	68.9	4108	7	2739	1.5
TP-14-PC4-13	A-8	26.0	4.7	2.9	23.6	24.8	25.8	25.9	25.7	25.4	24.0	22.8	588	67.9	4107	7	2700	1.5
TP-14-PC4-14	B-1	25.7	4.6	2.5	23.5	24.7	25.6	25.6	25.4	25.0	23.5	22.5	580	63.5	4099	7	2851	1.5
TP-14-PC4-15	B-3	25.9	4.6	3.8	23.4	24.5	25.5	25.8	25.7	25.3	24.0	22.9	588	71.6	4107	7	3039	1.7
TP-14-PC4-16	B-4	25.4	4.2	3.3	23.0	24.2	25.1	24.2	25.2	24.8	23.6	22.5	577	60.8	4096	7	3050	1.7
TP-14-PC4-17	B-5	25.7	4.4	3.6	23.1	24.3	25.4	25.7	25.5	25.2	23.9	22.7	584	67.7	4103	7	2538	1.4
TP-14-PC4-18	B-6	25.9	4.6	3.6	23.4	24.5	25.5	25.8	25.7	25.4	24.1	23.0	590	73.5	4109	7	2261	1.3
TP-14-PC4-19	B-7	26.1	4.9	3.4	23.5	24.8	25.9	26.1	25.8	25.4	23.9	22.8	588	71.7	4083	7	2775	1.5
TP-14-PC4-20	B-8	26.0	4.8	3.0	23.5	24.8	25.8	26.0	25.7	25.4	24.0	22.8	588	71.7	4108	7	3098	1.5
TP-14-PC4-21	B-7	26.2	4.9	2.8	23.8	25.1	26.0	26.1	25.8	25.5	24.0	22.9	590	68.5	4002	7	2390	1.4
TP-14-PC4-22	B-8	25.7	4.3	3.3	23.6	24.6	25.5	25.7	25.5	25.2	23.9	22.8	585	63.3	3996	7	2355	1.4
TP-14-PC4-23	A-1	25.4	4.2	3.0	23.1	24.3	25.2	24.3	25.0	24.7	23.5	22.5	577	54.1	3916	7	2853	1.5
TP-14-PC4-24	A-3	25.2	3.8	4.1	22.7	23.8	24.8	25.2	25.0	24.8	23.9	23.0	581	58.6	3920	7	2714	1.5
TP-14-PC4-25	A-4	25.6	4.3	3.2	23.2	24.2	25.3	25.5	25.3	25.0	23.9	22.9	584	60.8	3921	7	2964	1.5
TP-14-PC4-26	A-5	25.3	4.0	3.9	22.8	23.9	24.9	25.3	25.2	25.0	24.1	23.1	584	61.1	3922	7	2889	1.5
TP-14-PC4-27	A-6	25.9	4.5	3.8	23.3	24.5	25.5	25.9	25.6	25.4	24.2	23.2	591	67.8	3929	7	2991	1.5
TP-14-PC4-28	A-7	25.2	3.8	3.6	23.0	23.9	24.9	25.1	25.0	24.7	23.7	22.7	577	53.5	3914	7	3073	1.5
TP-14-PC4-29	A-8	25.6	4.2	3.5	23.3	24.4	25.4	25.6	25.3	25.0	23.7	22.7	581	57.4	3918	7	2954	1.5
TP-14-PC4-30	B-1	25.5	4.3	3.2	23.4	24.4	25.3	25.4	25.0	24.8	23.6	22.6	577	56.0	3937	7	2939	1.5

Note: Shading of table rows is for ease of reading.

Table B.16 Thermal Profile Raw Data: Series 15

Specimen ID	Channel ID	T_{max} (°C)	ΔT (°C)	t_{max} (hr)	Profile Temperature (°C) at Time Indicated (hr) 0.1	1	2	4	6	8	16	24	A_s (°C-hr)	$A_{\Delta T}$ (°C-hr)	*TTF* (°C-hr)	$t_{\sigma max}$ (day)	σ_{max} (kPa)	ε_{max} (%)
TP-15-PC3-01	A-1	25.4	4.1	3.2	23.8	24.8	25.2	25.3	25.0	24.7	23.5	22.5	576	57.1	824	1	1923	1.4
TP-15-PC3-02	A-3	25.1	3.8	3.9	23.6	24.4	24.9	25.1	25.0	24.9	23.9	22.9	581	61.5	828	1	2052	1.3
TP-15-PC3-03	A-4	25.6	4.4	2.6	24.1	25.0	25.5	25.6	25.4	25.1	23.9	22.8	585	65.7	832	1	1994	1.4
TP-15-PC3-04	A-5	25.4	4.1	3.6	23.9	24.6	25.2	25.4	25.3	25.1	24.0	23.0	585	65.5	1811	3	2620	1.5
TP-15-PC3-05	A-6	26.1	4.7	3.2	24.3	25.4	25.9	26.0	25.8	25.5	24.1	23.1	593	73.4	1819	3	2371	1.4
TP-15-PC3-06	A-7	25.5	4.2	3.1	24.1	24.9	25.4	25.5	25.3	24.9	23.6	22.7	581	61.9	1808	3	2336	1.3
TP-15-PC3-07	A-8	25.9	4.6	2.8	24.4	25.2	25.8	25.8	25.5	25.1	23.7	22.7	584	64.6	4124	7	2458	1.4
TP-15-PC3-08	B-1	25.3	4.1	2.8	23.9	24.7	25.2	25.3	25.0	24.6	23.3	22.4	574	55.9	4113	7	2364	1.3
TP-15-PC3-09	B-3	25.8	4.6	3.3	24.2	25.1	25.6	25.8	25.7	25.3	24.1	23.0	590	72.1	4130	7	2306	1.4
TP-15-PC4-10	B-4	26.5	5.2	3.1	24.5	25.7	26.4	26.4	26.1	25.7	24.3	23.1	598	79.7	1824	3	2814	1.5
TP-15-PC4-11	B-5	26.3	5.0	3.2	24.2	25.3	26.1	26.2	26.1	25.7	24.5	23.4	599	81.3	1826	3	2857	1.5
TP-15-PC4-14	B-8	26.6	5.3	3.2	24.4	25.7	26.5	26.5	26.2	25.8	24.1	23.1	597	78.8	4136	7	2880	1.4
TP-15-PC4-15	A-1	25.5	4.4	3.1	23.4	24.6	25.3	25.3	25.1	24.6	23.3	22.3	574	60.8	4115	7	3165	1.5
TP-15-PC4-16	A-3	25.3	4.0	3.7	23.0	24.2	25.0	24.2	25.1	24.9	23.9	22.8	581	67.9	680	1	1981	1.5
TP-15-PC4-17	A-4	25.8	4.6	3.2	23.6	24.9	25.7	25.7	25.5	25.1	23.9	22.8	586	72.2	659	1	2137	1.4
TP-15-PC4-18	A-5	25.4	4.1	4.4	23.2	24.4	25.2	25.4	25.3	25.0	24.0	22.9	585	71.4	659	1	2215	1.4
TP-15-PC5-19	A-1	26.3	5.4	2.5	23.5	25.2	26.2	26.1	25.9	25.4	24.2	23.2	594	75.7	1807	3	3599	1.7
TP-15-PC5-20	A-3	26.2	5.2	3.3	23.5	25.0	25.9	26.2	26.0	25.7	24.7	23.7	601	82.8	1840	3	3608	1.7
TP-15-PC5-21	A-4	26.3	5.3	3.1	23.5	24.9	26.0	26.3	26.0	25.7	24.5	23.5	599	80.7	1813	3	3884	1.8
TP-15-PC5-22	B-1	25.7	4.6	2.5	23.2	24.7	25.7	25.6	25.2	24.9	23.5	22.4	579	65.4	4094	7	4011	2.0
TP-15-PC5-23	B-3	26.6	5.4	3.4	23.6	25.4	26.4	25.4	26.3	25.9	24.5	23.3	602	88.7	4117	7	3779	2.0
TP-15-PC5-24	B-4	26.0	4.8	3.3	23.4	24.9	25.8	26.0	25.7	25.4	24.1	22.9	591	77.9	4107	7	3977	2.0
TP-15-PC5-25	B-5	26.6	5.4	3.0	23.7	25.4	26.4	26.5	26.3	26.0	24.5	23.3	602	88.8	651	1	2752	1.7
TP-15-PC5-26	B-6	26.1	4.8	3.1	23.4	24.9	25.9	26.0	25.7	25.4	24.1	23.0	591	77.3	640	1	2921	1.7
TP-15-PC5-27	B-7	26.2	5.0	2.8	23.4	25.0	26.0	26.1	25.7	25.2	23.7	22.6	585	71.5	634	1	2727	1.7
TP-15-PC4-31	A-5	26.3	5.2	3.3	23.7	25.2	26.1	26.3	26.0	25.8	24.6	23.6	601	82.7	1816	3	2840	1.5
TP-15-PC4-32	A-6	25.9	4.7	3.8	23.4	24.8	25.6	25.9	25.7	25.5	24.4	23.5	595	76.7	4159	7	3140	1.5

Note: Shading of table rows is for ease of reading.

Table B.17 Thermal Profile Raw Data: Series 16

Specimen ID	Channel ID	T_{max} (°C)	ΔT (°C)	t_{max} (hr)	Profile Temperature (°C) at Time Indicated (hr) 0.1	1	2	4	6	8	16	24	A_s (°C-hr)	$A_{\Delta T}$ (°C-hr)	TTF (°C-hr)	$t_{\sigma max}$ (day)	σ_{max} (kPa)	ε_{max} (%)
TP-16-HA45-01	A-1	25.4	3.4	12.6	23.0	23.2	23.3	23.8	24.4	25.0	25.2	24.1	591	69.3	4179	7	1160	1.8
TP-16-HA45-02	A-3	26.0	4.0	13.1	23.0	23.2	23.3	23.8	24.6	25.2	25.9	24.8	601	79.5	4190	7	1258	1.5
TP-16-HA45-03	A-4	25.9	3.9	12.4	23.2	23.4	23.6	24.0	24.7	25.3	25.7	24.6	600	77.8	4188	7	1108	1.5
TP-16-HA55-04	A-5	26.7	4.6	13.9	22.9	23.1	23.4	24.0	24.9	25.7	26.6	25.3	612	89.8	4201	7	1432	1.7
TP-16-HA55-05	A-6	26.8	4.7	13.8	23.0	23.2	23.4	24.0	25.0	25.8	26.7	25.5	614	91.5	4228	7	1628	1.8
TP-16-HA55-06	A-7	26.3	4.2	13.6	23.2	23.4	23.5	24.0	24.9	25.6	26.1	24.9	607	83.8	4194	7	1462	1.8
TP-16-HA65-07	A-8	26.9	4.8	13.3	23.2	23.4	23.6	24.2	25.2	26.1	26.7	25.3	617	93.0	4204	7	1700	2.0
TP-16-HA65-08	B-1	26.5	4.7	12.8	23.1	23.2	23.4	23.9	24.9	25.7	26.3	24.8	608	90.1	4195	7	1916	1.8
TP-16-HA65-09	B-3	26.8	5.0	12.5	23.4	23.6	23.7	24.2	25.2	26.1	26.5	25.0	614	96.3	4201	7	2026	2.3

Note: Shading of table rows is for ease of reading.

Table B.18 Thermal Profile Raw Data: Series 17

Specimen ID	Channel ID	T_{max} (°C)	ΔT (°C)	t_{max} (hr)	Profile Temperature (°C) at Time Indicated (hr) 0.1	1	2	4	6	8	16	24	A_s (°C-hr)	$A_{\Delta T}$ (°C-hr)	TTF (°C-hr)	$t_{\sigma max}$ (day)	σ_{max} (kPa)	ε_{max} (%)
TP-17-HA45-01	A-1	30.5	-1.3	0.2	30.3	30.2	29.9	29.9	29.9	29.8	27.0	24.4	673	36.0	4193	7	1222	1.7
TP-17-HA45-02	A-3	30.0	2.8	8.3	29.7	29.5	29.3	29.5	29.8	29.9	27.7	25.1	680	44.2	4200	7	1364	1.7
TP-17-HA45-03	A-4	30.4	3.1	7.9	29.7	30.0	29.8	30.0	30.2	30.3	27.8	25.2	686	52.4	4206	7	1331	1.7
TP-17-HA55-04	A-5	31.2	3.9	7.7	30.4	30.4	30.2	30.6	31.0	31.2	28.4	25.5	700	68.1	4220	7	1476	2.3
TP-17-HA55-05	A-6	31.1	3.9	7.9	29.4	29.8	29.7	30.2	30.7	31.0	28.5	25.6	697	66.4	4217	7	1870	2.3
TP-17-HA55-06	A-7	30.4	3.2	7.5	30.0	30.1	29.8	30.0	30.3	30.4	27.6	24.8	682	53.7	4202	7	1624	2.0
TP-17-HA65-07	A-8	31.1	4.0	7.9	30.2	30.1	29.8	30.2	30.8	31.0	28.0	24.9	692	64.1	4211	7	2079	2.7
TP-17-HA65-08	B-1	31.1	3.2	7.7	30.2	30.4	30.1	30.5	30.9	31.1	27.8	24.6	690	47.1	4210	7	2245	1.8
TP-17-HA65-09	B-3	30.9	-2.5	0.2	30.6	30.4	30.0	30.3	30.6	30.8	27.5	24.3	685	43.3	4204	7	1903	2.0

Note: Shading of table rows is for ease of reading.

Table B.19 Thermal Profile Raw Data: Series 18

Specimen ID	Channel ID	T_{max} (°C)	ΔT (°C)	t_{max} (hr)	Profile Temperature (°C) at Time Indicated (hr) 0.1	1	2	4	6	8	16	24	A_s (°C-hr)	$A_{\Delta T}$ (°C-hr)	*TTF* (°C-hr)	$t_{\sigma max}$ (day)	σ_{max} (kPa)	ε_{max} (%)
TP-18-PA4-01	A-1	22.7	1.9	2.1	22.2	22.6	22.7	22.6	22.6	22.5	21.9	21.5	532	26.6	3975	7	1712	1.4
TP-18-PA4-02	A-3	22.7	1.9	4.3	22.2	22.6	22.7	22.7	22.7	22.6	22.2	21.7	536	31.0	3980	7	1793	1.5
TP-18-PA4-03	A-4	22.9	2.0	1.6	22.3	22.8	22.9	22.9	22.8	22.7	22.3	21.7	538	32.7	3957	7	1755	1.4
TP-18-PA4-04	A-5	22.8	1.9	4.0	22.3	22.7	22.7	22.8	22.7	22.7	22.3	21.8	538	32.4	3957	7	1839	1.4
TP-18-PA4-05	A-6	23.0	2.1	3.5	22.5	22.9	23.0	23.0	23.0	22.9	22.3	21.8	541	35.3	3960	7	1573	1.4
TP-18-PA4-06	A-7	22.7	1.8	3.8	22.3	22.6	22.7	22.7	22.7	22.6	22.0	21.6	534	28.4	3953	7	1695	1.4
TP-18-PA4-07	A-8	22.9	2.0	1.6	22.4	22.8	22.8	22.8	22.8	22.7	22.1	21.6	536	30.1	3955	7	1739	1.4
TP-18-PA4-08	B-1	22.7	1.9	1.2	22.2	22.7	22.7	22.6	22.6	22.4	21.8	21.3	530	26.0	3949	7	1754	1.5
TP-18-PA4-09	B-3	23.0	2.2	3.3	22.5	23.0	23.0	23.0	22.9	22.8	22.3	21.7	540	35.2	3959	7	1727	1.4
TP-18-PA4-10	B-4	22.9	2.0	3.3	22.4	22.8	22.8	22.8	22.7	22.7	22.2	21.6	537	32.7	3956	7	1710	1.4
TP-18-PA4-11	B-5	23.2	2.3	2.8	22.7	23.1	23.1	23.2	23.1	23.0	22.3	21.8	543	38.3	3962	7	1718	1.4
TP-18-PA4-12	B-6	23.0	2.1	4.8	22.6	22.9	23.0	23.0	23.0	22.9	22.3	21.8	541	36.2	3959	7	1769	1.5
TP-18-PA4-13	B-7	23.1	2.3	1.2	22.6	23.1	23.1	23.0	22.9	22.8	22.1	21.5	538	33.7	3957	7	1614	1.4
TP-18-PA4-14	B-8	22.9	2.0	4.6	22.4	22.9	22.9	22.8	22.9	22.7	22.1	21.5	536	31.4	3955	7	1668	1.4
TP-18-PA4-15	A-1	22.6	1.8	4.0	22.1	22.5	22.6	22.6	22.5	22.4	22.0	21.6	532	27.3	3938	7	1660	1.4
TP-18-PA4-16	A-3	22.6	1.7	4.3	21.9	22.3	22.4	22.3	22.5	22.4	22.2	21.7	534	29.0	3940	7	1758	1.4
TP-18-PA4-17	A-4	22.6	1.8	4.2	22.0	22.4	22.5	22.6	22.5	22.4	22.2	21.6	534	28.9	3938	7	1525	1.4
TP-18-PA4-18	A-5	22.6	1.7	4.1	21.9	22.3	22.4	22.6	22.5	22.5	22.2	21.7	534	29.6	3939	7	1635	1.4
TP-18-PA4-19	A-6	22.8	1.9	3.8	22.1	22.5	22.6	22.8	22.7	22.7	22.3	21.8	537	32.4	3942	7	1596	1.4
TP-18-PA4-20	A-7	22.6	1.7	3.8	22.0	22.4	22.4	22.6	22.5	22.5	22.1	21.6	533	27.7	3937	7	1619	1.4
TP-18-PA4-21	A-8	22.8	1.9	3.7	22.2	22.6	22.6	22.8	22.7	22.6	22.1	21.7	535	29.8	3939	7	1540	1.3
TP-18-PA4-22	B-1	22.7	1.8	3.2	22.1	22.6	22.5	22.6	22.5	22.4	21.9	21.6	531	26.9	3936	7	1591	1.4
TP-18-PA4-23	B-3	22.9	2.0	3.6	22.3	22.7	22.8	22.7	22.7	22.7	22.2	21.7	538	33.4	3943	7	1702	1.4
TP-18-PA4-24	B-4	22.7	1.8	3.5	22.2	22.5	22.6	22.6	22.6	22.5	22.1	21.6	534	29.4	3939	7	1696	1.4
TP-18-PA4-25	B-5	23.0	2.1	3.3	22.3	22.7	22.9	22.9	22.9	22.8	22.3	21.7	539	34.8	3942	7	1593	1.4
TP-18-PA4-26	B-6	22.8	1.9	3.9	22.2	22.5	22.7	22.8	22.8	22.7	22.2	21.7	537	32.7	3940	7	1741	1.4
TP-18-PA4-27	B-7	23.1	2.2	2.7	22.4	22.9	23.0	23.0	22.9	22.8	22.2	21.6	538	33.5	3941	7	1677	1.3
TP-18-PA4-28	B-8	22.9	2.0	3.1	22.3	22.7	22.9	22.9	22.8	22.7	22.1	21.6	537	31.9	3940	7	1759	1.4
TP-18-PA4-29	A-1	23.2	2.0	4.5	22.8	23.2	23.2	23.2	23.2	22.9	22.3	21.7	540	30.0	3909	7	1818	1.4
TP-18-PA4-30	A-3	23.2	1.9	5.4	22.6	22.9	23.0	23.1	23.2	23.0	22.6	22.0	545	34.4	3913	7	1907	1.4

Note: Shading of table rows is for ease of reading.

Table B.20 Thermal Profile Raw Data: Series 19

Specimen ID	Channel ID	T_{max} (°C)	ΔT (°C)	t_{max} (hr)	Profile Temperature (°C) at Time Indicated (hr) 0.1	1	2	4	6	8	16	24	A_s (°C-hr)	$A_{\Delta T}$ (°C-hr)	*TTF* (°C-hr)	$t_{\sigma max}$ (day)	σ_{max} (kPa)	ε_{max} (%)
TP-19-PA3-01	A-1	21.8	1.2	2.0	21.4	21.7	21.8	21.7	21.7	21.6	21.2	20.9	514	18.2	3654	7	574	1.0
TP-19-PA3-02	A-3	21.5	0.8	6.1	21.0	21.2	21.3	21.4	21.5	21.4	21.2	21.0	510	14.6	3651	7	556	1.1
TP-19-PA3-03	A-4	21.8	1.2	2.8	21.3	21.7	21.8	21.8	21.8	21.7	21.2	21.0	514	18.5	3655	7	555	1.0
TP-19-PA3-04	A-5	21.5	0.8	5.8	21.0	21.2	21.4	21.5	21.5	21.5	21.2	21.0	511	15.3	7283	14	1118	1.3
TP-19-PA3-05	A-6	21.9	1.3	2.6	21.4	21.8	21.8	21.9	21.9	21.8	21.5	21.1	518	22.2	7290	14	1229	1.4
TP-19-PA3-06	A-7	21.6	0.8	5.5	21.2	21.3	21.4	21.5	21.5	21.5	21.3	20.9	512	16.6	7308	14	1397	1.4
TP-19-PA3-07	A-1	21.4	0.9	4.6	20.8	21.2	21.3	21.3	21.3	21.3	21.2	21.0	510	14.5	1623	3	417	1.3
TP-19-PA3-08	A-3	21.4	0.7	10.5	20.7	21.0	21.1	21.2	21.3	21.3	21.4	21.2	511	15.4	1624	3	389	1.3
TP-19-PA3-09	A-4	21.5	0.9	8.6	20.9	21.2	21.3	21.5	21.5	21.5	21.5	21.3	514	19.2	1606	3	389	1.3
TP-19-PA4-10	B-3	23.6	2.3	4.3	23.1	23.4	23.5	23.6	23.5	23.4	22.9	22.3	554	39.0	1704	3	934	1.3
TP-19-PA4-11	B-4	23.3	2.0	4.2	22.8	23.2	23.2	23.3	23.2	23.0	22.5	22.0	545	29.4	1695	3	963	1.3
TP-19-PA4-12	B-5	23.4	2.2	3.5	22.9	23.2	23.3	23.4	23.3	23.1	22.5	22.0	546	31.1	1697	3	871	1.3
TP-19-PA4-13	B-4	22.3	1.6	4.4	21.7	22.0	22.1	22.2	22.1	22.1	21.7	21.2	523	27.3	3664	7	1288	1.1
TP-19-PA4-14	B-5	22.0	1.3	4.6	21.4	21.6	21.7	21.9	21.9	21.9	21.5	21.2	519	23.0	3659	7	1327	1.3
TP-19-PA4-15	B-6	22.3	1.6	4.4	21.7	22.0	22.1	22.2	22.2	22.1	21.6	21.3	523	27.5	3663	7	1356	1.3
TP-19-PA4-16	B-7	21.9	1.2	4.3	21.4	21.6	21.7	21.6	21.8	21.7	21.3	21.0	516	20.1	7292	14	2319	1.5
TP-19-PA4-17	B-8	22.0	1.3	4.1	21.3	21.7	21.7	21.9	21.9	21.8	21.4	21.0	517	21.0	7293	14	2086	1.5
TP-19-PA4-18	A-5	22.0	1.4	9.9	21.0	21.4	21.6	21.8	21.9	21.9	21.9	21.6	523	27.9	7634	14	2414	1.5
TP-19-PA5-19	B-6	23.8	2.5	3.1	23.0	23.5	23.6	23.7	23.6	23.4	22.6	22.0	551	35.6	1701	3	1141	1.4
TP-19-PA5-20	B-7	23.6	2.3	3.6	22.8	23.2	23.4	23.5	23.3	23.2	22.4	21.8	545	30.0	1696	3	1212	1.4
TP-19-PA5-21	B-8	23.8	2.5	3.1	23.0	23.4	23.6	23.7	23.5	23.3	22.4	21.8	547	31.9	1698	3	1131	1.3
TP-19-PA5-22	A-8	22.4	1.7	3.8	21.6	22.0	22.1	22.4	22.3	22.2	21.7	21.2	525	29.4	3665	7	1907	1.4
TP-19-PA5-23	B-1	22.1	1.4	5.1	21.3	21.6	21.8	21.6	22.0	21.9	21.4	21.1	518	22.4	3659	7	2064	1.5
TP-19-PA5-24	B-3	22.3	1.6	4.9	21.4	21.8	21.9	22.3	22.2	22.2	21.8	21.3	525	29.3	3666	7	1644	1.4
TP-19-PA5-25	A-6	22.1	1.5	9.6	21.1	21.6	21.8	22.1	22.1	22.1	22.0	21.6	526	30.7	7637	14	3646	2.0
TP-19-PA5-26	A-7	22.0	1.3	9.5	20.8	21.3	21.5	21.8	21.9	21.9	21.9	21.5	522	26.9	7633	14	3537	2.0
TP-19-PA5-27	A-8	22.1	1.6	3.8	21.1	21.6	21.8	22.1	22.0	22.1	21.9	21.5	525	29.1	7660	14	3231	2.0

Note: Shading of table rows is for ease of reading.

Table B.21 Thermal Profile Raw Data: Series 20

Specimen ID	Channel ID	T_{max} (°C)	ΔT (°C)	t_{max} (hr)	Profile Temperature (°C) at Time Indicated (hr) 0.1	1	2	4	6	8	16	24	A_s (°C-hr)	$A_{\Delta T}$ (°C-hr)	*TTF* (°C-hr)	$t_{\sigma max}$ (day)	σ_{max} (kPa)	ε_{max} (%)
TP-20-PA3-01	A-3	18.4	-0.5	23.9	7.9	8.3	8.8	10.4	11.7	12.9	16.4	18.4	341	0.0	4044	7	1256	1.4
TP-20-PA3-02	A-4	18.1	-0.8	24.0	7.9	7.7	8.3	9.9	11.3	12.5	16.1	18.1	332	0.0	4036	7	1266	1.3
TP-20-PA3-03	A-5	18.2	-0.8	24.0	7.8	8.1	8.6	10.2	11.5	12.7	16.2	18.2	336	0.0	4040	7	940	1.1
TP-20-PA4-04	A-6	18.5	-0.5	24.0	7.8	8.0	9.4	10.4	11.9	13.1	16.5	18.5	343	0.0	4048	7	1975	1.5
TP-20-PA4-05	A-7	19.1	0.1	24.0	7.4	7.7	9.7	10.7	12.4	13.7	17.3	19.1	357	0.0	4061	7	2130	1.5
TP-20-PA4-06	A-8	19.3	0.4	23.9	7.7	7.9	9.4	11.2	12.8	14.2	17.6	19.3	366	1.3	4071	7	1823	1.4
TP-20-PA5-07	B-1	19.6	0.6	23.9	8.9	9.5	10.5	12.5	14.1	15.3	18.2	19.6	385	16.9	4090	7	2651	1.7
TP-20-PA5-08	B-3	19.3	0.3	23.9	8.9	9.7	10.7	12.4	13.9	15.0	17.9	19.3	381	11.3	4085	7	2758	1.7
TP-20-PA5-09	B-4	19.4	0.3	24.0	10.4	11.4	12.3	13.6	14.9	15.8	18.2	19.4	396	24.2	4100	7	2163	1.5

Note: Shading of table rows is for ease of reading.

Table B.22 Thermal Profile Raw Data: Series 21

Specimen ID	Channel ID	T_{max} (°C)	ΔT (°C)	t_{max} (hr)	Profile Temperature (°C) at Time Indicated (hr) 0.1	1	2	4	6	8	16	24	A_s (°C-hr)	$A_{\Delta T}$ (°C-hr)	*TTF* (°C-hr)	$t_{\sigma max}$ (day)	σ_{max} (kPa)	ε_{max} (%)
TP-21-PA3-01	A-3	29.3	2.6	0.2	29.0	29.0	28.5	27.6	26.7	25.9	23.6	22.1	600	44.0	4253	7	1052	1.3
TP-21-PA3-02	A-4	29.0	2.3	0.2	28.6	28.6	28.1	27.1	26.2	25.5	23.3	21.9	591	35.4	4244	7	1043	1.3
TP-21-PA3-03	A-5	29.0	2.4	0.2	28.7	28.7	28.3	27.3	26.5	25.7	23.4	22.0	596	41.5	4249	7	883	1.3
TP-21-PA4-04	A-6	29.5	3.0	0.4	28.8	29.3	29.0	28.1	27.2	26.5	24.2	22.7	613	59.5	4242	7	1912	1.5
TP-21-PA4-05	A-7	29.2	2.7	0.3	28.8	29.0	28.5	27.5	26.6	25.8	23.5	22.2	599	46.4	4228	7	1874	1.4
TP-21-PA4-06	A-8	29.1	2.7	0.4	28.7	28.9	28.4	27.5	26.6	25.9	23.7	22.3	601	49.4	4230	7	1793	1.4
TP-21-PA4-10	B-4	30.9	2.9	0.4	30.3	30.6	30.4	29.7	28.8	28.0	25.3	23.5	643	31.5	3999	7	2199	1.5
TP-21-PA4-11	B-5	30.5	2.5	0.3	30.0	30.3	30.0	29.2	28.3	27.5	24.9	23.2	634	22.5	3990	7	2285	1.5
TP-21-PA4-12	B-6	30.1	2.2	0.2	29.8	30.0	29.8	28.9	27.9	27.1	24.4	22.7	623	13.1	3979	7	1894	1.5

Note: Shading of table rows is for ease of reading.

Table B.23 Thermal Profile Raw Data: Series 22

Specimen ID	Channel ID	T_{max} (°C)	ΔT (°C)	t_{max} (hr)	Profile Temperature (°C) at Time Indicated (hr)								A_s (°C-hr)	$A_{\Delta T}$ (°C-hr)	TTF (°C-hr)	$t_{\sigma max}$ (day)	σ_{max} (kPa)	ε_{max} (%)
					0.1	1	2	4	6	8	16	24						
TP-22-PA2-01	A-4	24.1	3.0	3.1	22.8	23.5	24.0	24.0	23.9	23.7	22.9	22.2	556	45.8	3925	7	1130	1.3
TP-22-PA2-02	A-5	23.9	2.7	4.5	22.7	23.3	23.7	23.9	23.9	23.8	23.5	22.9	565	53.9	3933	7	1109	1.3
TP-22-PA2-03	A-6	24.1	2.9	4.0	22.7	23.3	23.8	24.1	24.0	23.9	23.5	22.9	566	55.3	3934	7	1116	1.1
TP-22-PA4-04	A-4	25.0	3.8	4.1	22.9	23.8	24.4	25.0	24.8	24.6	24.1	23.5	582	64.0	4047	7	2162	1.4
TP-22-PA4-05	A-5	24.9	3.5	5.2	22.6	23.5	24.2	24.8	24.8	24.7	24.4	23.9	585	67.2	4050	7	2220	1.5
TP-22-PA4-06	A-6	25.1	3.8	4.5	22.6	23.7	24.4	25.0	24.9	24.8	24.4	23.9	587	68.4	4051	7	2139	1.4
TP-22-PA6-07	A-7	26.2	4.7	6.6	22.9	24.1	24.9	25.7	26.1	26.1	25.5	24.5	610	91.4	4075	7	3387	1.8
TP-22-PA6-08	A-8	25.9	4.2	8.4	22.7	23.8	24.4	25.3	25.8	25.9	25.3	24.3	603	84.8	4091	7	3733	2.0
TP-22-PA6-09	B-1	26.1	4.6	6.2	23.1	24.3	24.9	25.6	26.0	26.0	25.3	24.3	607	83.5	4071	7	3265	1.8
TP-22-PA8-10	B-3	28.2	6.4	8.8	23.5	24.6	25.3	26.6	27.9	28.2	27.6	26.0	651	126.9	4114	7	5035	2.3
TP-22-PA8-11	B-4	27.7	5.9	8.7	23.2	24.4	25.0	26.2	27.4	27.7	27.0	25.5	639	115.3	4103	7	5320	2.4
TP-22-PA8-12	B-5	27.8	6.2	7.1	23.6	24.8	25.4	26.4	27.6	27.8	26.9	25.4	640	115.6	4103	7	4712	2.3
TP-22-PA10-13	A-7	29.1	7.7	8.5	23.1	24.3	24.9	26.6	28.5	29.0	27.8	25.8	655	143.9	4023	7	5512	2.4
TP-22-PA10-14	A-8	28.7	7.4	8.2	22.8	23.8	24.5	26.2	28.1	28.7	27.5	25.6	648	136.9	4016	7	5583	2.5
TP-22-PA10-15	B-1	28.4	6.9	8.0	23.0	24.2	24.8	26.2	27.8	28.3	26.7	24.8	636	120.9	4004	7	4909	2.1

Note: Shading of table rows is for ease of reading.

Table B.24 Thermal Profile Raw Data: Series 23

Specimen ID	Channel ID	T_{max} (°C)	ΔT (°C)	t_{max} (hr)	Profile Temperature (°C) at Time Indicated (hr) 0.1	1	2	4	6	8	16	24	A_s (°C-hr)	$A_{\Delta T}$ (°C-hr)	*TTF* (°C-hr)	$t_{\sigma max}$ (day)	σ_{max} (kPa)	ε_{max} (%)
TP-23-PA2-01	A-1	29.4	2.8	1.3	28.5	29.3	29.2	28.4	27.9	27.3	25.5	24.1	636	38.2	4240	7	1053	1.3
TP-23-PA2-02	A-3	28.7	2.1	1.3	28.3	28.6	28.6	28.0	27.7	27.3	25.6	24.2	635	37.1	4239	7	1109	1.3
TP-23-PA2-03	A-4	29.0	2.7	1.9	28.0	28.8	28.9	28.4	27.9	27.3	25.5	24.1	636	38.6	4239	7	1114	1.4
TP-23-PA4-04	A-5	29.9	3.8	2.1	28.3	29.3	29.8	29.5	29.0	28.4	26.5	24.9	658	61.9	4262	7	1884	1.4
TP-23-PA4-05	A-6	29.6	3.7	2.1	28.3	29.1	29.6	29.5	29.0	28.5	26.8	25.2	662	66.2	4290	7	2014	1.5
TP-23-PA4-06	A-7	29.5	3.7	2.5	28.3	29.1	29.4	29.4	28.8	28.3	26.4	24.9	656	60.4	4259	7	1887	1.4
TP-23-PA6-07	A-8	30.5	4.8	3.7	28.7	29.7	29.9	30.5	30.1	29.7	27.6	25.6	682	87.1	4285	7	3149	1.8
TP-23-PA6-08	B-1	30.6	5.3	3.8	28.8	29.9	30.0	30.6	30.2	29.8	27.9	25.9	687	92.2	4289	7	3204	1.7
TP-23-PA6-09	B-3	31.2	5.9	4.2	29.7	30.3	30.4	31.2	31.1	30.8	29.1	26.9	710	116.7	4313	7	2990	1.7
TP-23-PA8-10	B-4	32.6	7.5	5.1	29.3	30.4	30.8	32.3	32.6	32.2	29.8	27.1	729	136.0	4332	7	4823	2.3
TP-23-PA8-11	B-5	32.8	7.6	6.1	29.1	30.2	30.6	32.2	32.8	32.6	30.6	28.1	742	149.1	4344	7	2697	2.3
TP-23-PA8-12	B-6	33.4	8.3	6.3	29.9	30.9	31.3	32.7	33.4	33.3	31.1	28.4	755	162.6	4357	7	4283	2.1
TP-23-PA10-13	B-7	34.6	9.5	6.4	29.6	30.9	31.4	33.2	34.6	34.4	31.5	28.4	767	175.3	4370	7	5903	2.5
TP-23-PA10-14	B-8	34.6	9.5	6.4	29.6	30.8	31.3	33.2	34.6	34.4	31.6	28.5	768	176.5	4371	7	5886	2.5
TP-23-PA10-15	B-5	36.1	8.2	5.1	31.7	33.0	33.4	35.8	35.9	35.4	32.1	29.2	792	169.9	4334	7	5563	2.4

Note: Shading of table rows is for ease of reading.

Table B.25 Thermal Profile Raw Data: Series 24

Specimen ID	Channel ID	T_{max} (°C)	ΔT (°C)	t_{max} (hr)	Profile Temperature (°C) at Time Indicated (hr) 0.1	1	2	4	6	8	16	24	A_s (°C-hr)	$A_{\Delta T}$ (°C-hr)	*TTF* (°C-hr)	$t_{\sigma max}$ (day)	σ_{max} (kPa)	ε_{max} (%)
TP-24-HB5-01	A-1	20.9	2.2	23.9	7.5	8.1	9.4	11.8	13.6	15.1	19.3	20.9	393	68.6	4131	7	1502	2.0
TP-24-HB5-02	A-3	20.6	1.9	24.0	7.7	8.1	9.2	11.4	13.0	14.4	18.8	20.6	382	56.0	4120	7	1809	2.1
TP-24-HB5-03	A-4	20.4	1.6	24.0	8.2	7.9	9.0	11.2	12.8	14.1	18.4	20.3	376	46.4	4088	7	1957	2.3
TP-24-HB6-04	A-5	21.2	2.4	23.9	7.9	8.3	9.3	11.5	13.2	14.6	19.5	21.2	392	60.4	4105	7	2491	2.4
TP-24-HB6-05	A-6	20.8	2.0	23.7	7.3	7.6	8.9	11.0	12.8	14.2	19.0	20.8	382	48.0	4094	7	2234	2.4
TP-24-HB6-06	A-7	21.3	2.4	23.8	7.4	8.2	9.7	11.9	13.7	15.3	19.9	21.3	402	64.7	4114	7	1875	2.1
TP-24-HB7-07	A-8	21.9	3.0	23.6	7.7	8.3	9.8	12.1	14.0	15.8	20.6	21.9	415	74.6	4127	7	2426	2.0
TP-24-HB7-08	B-1	21.6	2.6	23.2	8.1	8.6	10.1	12.5	14.3	16.0	20.6	21.6	416	61.7	4155	7	2459	2.1
TP-24-HB7-09	B-3	22.0	3.0	23.0	7.8	8.4	9.8	12.2	14.2	15.9	20.9	22.0	418	62.2	4131	7	2580	2.1

Note: Shading of table rows is for ease of reading.

Table B.26 Thermal Profile Raw Data: Series 25

Specimen ID	Channel ID	T_{max} (°C)	ΔT (°C)	t_{max} (hr)	Profile Temperature (°C) at Time Indicated (hr)								A_s (°C-hr)	$A_{\Delta T}$ (°C-hr)	TTF (°C-hr)	$t_{\sigma max}$ (day)	σ_{max} (kPa)	ε_{max} (%)
					0.1	1	2	4	6	8	16	24						
TP-25-HB5-01	A-1	24.4	3.2	9.0	21.9	22.5	23.1	23.8	24.1	24.3	23.8	23.0	569	60.4	3901	7	2043	2.3
TP-25-HB5-02	A-3	25.0	3.8	9.2	21.7	22.4	23.1	23.9	24.5	24.9	24.6	23.8	581	73.1	3914	7	1959	2.4
TP-25-HB5-03	A-4	24.8	3.6	10.6	21.7	22.3	22.9	23.7	24.2	24.6	24.4	23.6	578	69.2	3911	7	1693	2.3
TP-25-HB6-04	A-5	25.7	4.4	10.6	21.8	22.5	23.2	24.1	24.8	25.4	25.3	24.3	594	85.3	3927	7	1959	1.8
TP-25-HB6-05	A-6	25.9	4.6	10.9	21.8	22.6	23.3	24.2	25.0	25.6	25.4	24.4	598	88.9	3931	7	1887	2.4
TP-25-HB6-06	A-7	25.6	4.3	10.8	21.9	22.6	23.2	24.1	24.8	25.3	25.1	24.1	591	82.1	3924	7	2585	2.1
TP-25-HB7-07	A-8	26.4	5.1	10.0	22.1	22.9	23.6	24.6	25.5	26.1	25.6	24.4	605	95.0	3937	7	1764	2.7
TP-25-HB7-08	B-1	25.3	4.2	9.9	21.9	22.6	23.2	24.0	24.7	25.2	24.7	23.6	585	77.0	3917	7	1990	1.7
TP-25-HB7-09	B-3	25.7	4.5	9.9	22.1	22.8	23.4	24.2	25.0	25.6	25.0	23.7	591	83.0	3924	7	2432	3.0

Note: Shading of table rows is for ease of reading.

Table B.27 Thermal Profile Raw Data: Series 26

Specimen ID	Channel ID	T_{max} (°C)	ΔT (°C)	t_{max} (hr)	Profile Temperature (°C) at Time Indicated (hr)								A_s (°C-hr)	$A_{\Delta T}$ (°C-hr)	TTF (°C-hr)	$t_{\sigma max}$ (day)	σ_{max} (kPa)	ε_{max} (%)
					0.1	1	2	4	6	8	16	24						
TP-26-HB5-01	A-1	31.0	0.4	1.9	30.2	30.8	30.9	30.5	30.0	29.1	25.8	23.7	659	29.1	4015	7	1723	1.8
TP-26-HB5-02	A-3	30.9	0.3	1.8	30.1	30.6	30.9	30.9	30.6	30.0	26.9	24.5	677	48.4	4034	7	1843	2.5
TP-26-HB5-03	A-4	31.1	0.4	1.6	29.8	30.9	31.1	31.0	30.7	30.0	26.9	24.4	678	50.9	4034	7	1558	2.0
TP-26-HB6-04	A-5	31.9	3.2	4.4	30.7	31.4	31.7	31.8	31.7	31.1	27.7	24.9	697	72.1	4053	7	2042	2.4
TP-26-HB6-05	A-6	31.8	3.2	4.5	30.4	31.1	31.5	31.7	31.6	31.1	27.8	25.0	697	73.0	4054	7	1894	1.8
TP-26-HB6-06	A-7	31.2	2.3	3.7	29.9	31.1	31.2	31.2	30.9	30.2	26.8	24.2	678	56.0	4035	7	1587	2.0
TP-26-HB7-07	A-8	32.3	3.7	4.1	31.0	32.0	32.1	32.2	32.0	31.2	27.2	24.4	694	73.1	4050	7	2326	2.3
TP-26-HB7-08	B-1	31.8	3.7	4.0	30.3	31.4	31.5	31.8	31.6	30.8	27.0	24.4	686	71.7	4043	7	2265	2.0
TP-26-HB7-09	B-3	31.8	4.1	4.5	30.4	31.2	31.4	31.8	31.7	31.1	27.4	24.6	693	80.3	4050	7	1621	3.0

Note: Shading of table rows is for ease of reading.

Table B.28 Thermal Profile Raw Data: Series 27

Specimen ID	Chan. ID	Sensor Type	T_{max} (°C)	ΔT (°C)	t_{max} (hr)	Profile Temperature (°C) at Time Indicated (hr) 0.1	1	2	4	6	8	16	24	A_s (°C-hr)	$A_{\Delta T}$ (°C-hr)	*TTF* (°C-hr)	$t_{\sigma max}$ (day)	σ_{max} (kPa)	ε_{max} (%)
TP-27-PC4-01	C-1	*TC*	24.3	4.1	2.8	22.5	23.4	24.2	24.3	24.1	23.8	22.8	22.0	557	54.7	3958	7	3107	1.7
TP-27-PC4-02	C-3	*TC*	24.2	3.5	5.2	22.3	23.1	23.8	24.1	24.1	24.0	23.3	22.5	563	60.8	3964	7	3254	1.7
TP-27-PC4-03	C-4	*TC*	24.5	4.2	3.4	22.7	23.6	24.3	24.5	24.3	24.2	23.4	22.6	568	64.9	3968	7	2978	1.5
TP-27-PC4-04	C-5	*TC*	24.2	3.5	4.8	22.1	23.0	23.8	24.1	24.1	24.0	23.4	22.6	565	61.6	3965	7	3270	1.5
TP-27-PC4-05	C-6	*TC*	24.6	4.0	4.7	22.5	23.4	24.3	24.5	24.5	24.4	23.6	22.7	571	68.0	3972	7	3403	1.7
TP-27-PC4-06	C-7	*TC*	24.1	3.5	4.6	22.1	23.0	23.9	24.1	23.9	23.8	22.9	22.1	557	53.3	3957	7	3382	1.7
TP-27-PC4-07	C-8	*TC*	24.4	3.7	4.4	22.2	23.1	24.0	24.3	24.2	24.1	23.0	22.2	560	56.7	3959	7	3349	1.7
TP-27-PC4-08	C-1	*TC*	24.8	4.2	2.7	23.1	24.0	24.7	24.7	24.4	24.1	23.1	22.4	566	54.8	4137	7	2081*	1.4
TP-27-PC4-09	C-3	*TC*	24.6	3.9	3.4	22.7	23.7	24.4	24.6	24.5	24.4	23.7	23.0	573	61.9	4145	7	3457	1.8
TP-27-PC4-10	C-4	*TC*	25.1	4.4	3.0	23.2	24.2	25.0	25.0	24.9	24.6	23.8	23.0	579	67.0	4125	7	2668*	1.7
TP-27-PC4-11	C-5	*TC*	24.9	4.1	3.2	22.8	23.9	24.7	24.8	24.7	24.6	23.8	23.0	577	65.3	4123	7	3073	1.8
TP-27-PC4-12	C-6	*TC*	25.2	4.5	3.0	23.1	24.2	25.0	25.2	25.1	24.9	24.0	23.2	583	71.2	4129	7	3103	1.7
TP-27-PC4-13	C-7	*TC*	24.8	4.1	2.6	23.2	24.1	24.7	24.7	24.5	24.4	23.3	22.6	570	57.1	4115	7	3307	1.7
TP-27-PC4-14	C-8	*TC*	25.0	4.2	3.0	23.0	23.9	24.8	24.9	24.8	24.6	23.5	22.7	573	60.6	4119	7	2951	1.7
TP-27-PC4-15	C-1	*TC*	25.4	4.6	2.6	23.6	24.6	25.4	25.3	25.0	24.5	23.4	22.5	574	58.2	4166	7	3276	2.0
TP-27-PC4-16	C-3	*TC*	25.2	4.1	3.8	23.4	24.3	25.1	24.3	25.1	24.9	24.0	23.1	583	67.0	4175	7	3374	1.8
TP-27-PC4-17	C-4	*TC*	25.6	4.6	2.7	23.5	24.7	25.4	25.5	25.3	25.0	24.0	23.2	586	69.8	4178	7	3268	1.8
TP-27-PC4-18	C-5	*TC*	25.3	4.1	4.4	23.3	24.3	25.2	25.3	25.1	24.9	24.0	23.2	585	68.4	4177	7	3054	1.8
TP-27-PC4-19	C-6	*TC*	25.8	4.7	3.3	23.7	24.8	25.6	25.7	25.6	25.3	24.3	23.4	592	75.2	4184	7	3075	1.7
TP-27-PC4-20	C-7	*TC*	25.3	4.3	2.8	23.4	24.5	25.2	25.3	25.0	24.7	23.6	22.7	577	60.6	4169	7	3236	1.7
TP-27-PC4-21	C-8	*TC*	25.6	4.5	2.9	23.5	24.5	25.3	25.5	25.3	24.9	23.7	22.8	581	64.6	4173	7	3064	1.7
TP-27-PC4-22	C-1	*TC*	24.5	4.2	2.6	22.7	23.6	24.4	24.5	24.2	23.9	22.8	22.2	559	55.9	4242	7	3277	1.7
TP-27-PC4-23	C-3	*TC*	24.5	3.9	4.2	22.6	23.4	24.2	23.4	24.4	24.2	23.4	22.7	568	64.2	4250	7	3318	1.7
TP-27-PC4-24	C-4	*TC*	24.9	4.4	3.3	22.9	23.8	24.7	24.8	24.6	24.4	23.4	22.8	571	67.6	4254	7	2910	1.7
TP-27-PC4-25	C-5	*TC*	24.6	4.0	3.9	22.7	23.6	24.3	24.6	24.5	24.4	23.5	22.9	571	67.5	4254	7	3374	1.7
TP-27-PC4-26	C-6	*TC*	25.1	4.5	3.6	23.1	24.1	24.9	25.1	24.9	24.8	23.7	23.0	579	74.3	4261	7	3242	1.8
TP-27-PC4-27	C-7	*TC*	24.7	4.1	3.6	22.8	23.7	24.5	24.6	24.3	24.2	23.1	22.4	565	60.3	4247	7	3409	1.8
TP-27-PC4-28	C-8	*TC*	24.8	4.2	3.6	22.8	23.6	24.5	24.7	24.5	24.3	23.2	22.5	567	62.6	4249	7	3106	1.8
TP-27-PC4-29	C-1	*TC*	25.0	4.0	2.1	23.2	24.2	25.0	24.8	24.6	24.1	22.8	22.0	563	55.3	3892	7	3079	1.7
TP-27-PC4-30	C-3	*TC*	24.3	3.3*	3.1	22.4	23.5	24.2	24.3	24.1	23.9	22.9	22.1	559	51.4	3888	7	3316	1.7

Notes: Shading of table rows is for ease of reading; Chan. = Channel; and asterisked values indicate an outlier that was removed from the respective analysis.

Table B.28 (continued)

Specimen ID	Chan. ID	Sensor Type	T_{max} (°C)	ΔT (°C)	t_{max} (hr)	Profile Temperature (°C) at Time Indicated (hr) 0.1	1	2	4	6	8	16	24	A_s (°C-hr)	$A_{\Delta T}$ (°C-hr)	*TTF* (°C-hr)	$t_{\sigma max}$ (day)	σ_{max} (kPa)	ε_{max} (%)
TP-27-PC4-01	C-1	*TM*	23.9	3.9	2.9	21.9	23.0	23.7	23.8	23.7	23.4	22.4	21.8	548	51.1	3948	7	3107	1.7
TP-27-PC4-02	C-3	*TM*	23.9	3.7	3.5	21.9	22.8	23.6	23.9	23.8	23.7	23.0	22.4	557	60.1	3958	7	3254	1.7
TP-27-PC4-03	C-4	*TM*	24.3	4.2	3.2	22.2	23.2	24.1	24.2	24.1	24.0	23.1	22.4	562	64.4	3962	7	2978	1.5
TP-27-PC4-04	C-5	*TM*	24.0	3.6	5.0*	21.7	22.8	23.6	24.0	24.0	23.9	23.3	22.7	562	64.7	3962	7	3270	1.5
TP-27-PC4-05	C-6	*TM*	24.2	3.9	3.8	21.9	23.0	23.9	24.2	24.1	24.0	23.2	22.5	563	65.0	3963	7	3403	1.7
TP-27-PC4-06	C-7	*TM*	23.6	3.5	3.3	21.4	22.6	23.4	23.6	23.5	23.4	22.5	21.8	547	49.6	3948	7	3382	1.7
TP-27-PC4-07	C-8	*TM*	24.0	3.8	3.4	21.7	22.8	23.6	24.0	23.9	23.7	22.8	22.0	554	55.8	3953	7	3349	1.7
TP-27-PC4-08	C-1	*TM*	24.3	4.0	2.7	22.5	23.5	24.2	24.2	24.0	23.7	22.7	22.0	556	51.1	4127	7	2081*	1.4
TP-27-PC4-09	C-3	*TM*	24.3	3.8	3.5	22.3	23.4	24.1	24.3	24.2	24.1	23.3	22.7	566	60.9	4137	7	3457	1.8
TP-27-PC4-10	C-4	*TM*	24.7	4.3	2.6	22.7	23.8	24.6	24.7	24.5	24.3	23.4	22.7	571	65.7	4116	7	2668*	1.7
TP-27-PC4-11	C-5	*TM*	24.4	3.9	3.4	22.3	23.5	24.2	24.4	24.3	24.2	23.4	22.8	568	63.2	4114	7	3073	1.8
TP-27-PC4-12	C-6	*TM*	24.7	4.2	3.4	22.4	23.7	24.5	24.7	24.6	24.5	23.6	22.8	573	67.8	4119	7	3103	1.7
TP-27-PC4-13	C-7	*TM*	24.2	3.8	2.6	22.7	23.6	24.1	24.2	24.0	23.9	22.9	22.2	559	53.4	4105	7	3307	1.7
TP-27-PC4-14	C-8	*TM*	24.6	4.0	3.1	22.4	23.5	24.3	24.5	24.4	24.2	23.2	22.4	565	59.3	4111	7	2951	1.7
TP-27-PC4-15	C-1	*TM*	24.8	4.3	2.3	22.9	24.1	24.8	24.8	24.4	24.1	22.9	22.1	563	54.4	4155	7	3276	2.0
TP-27-PC4-16	C-3	*TM*	24.8	4.2	3.1	22.9	23.9	24.7	23.9	24.7	24.5	23.6	22.8	574	65.7	4166	7	3374	1.8
TP-27-PC4-17	C-4	*TM*	25.2	4.5	3.0	22.8	24.2	25.0	25.2	24.9	24.7	23.7	22.8	578	69.0	4170	7	3268	1.8
TP-27-PC4-18	C-5	*TM*	24.8	4.1	3.5	22.7	23.9	24.7	24.8	24.7	24.5	23.7	22.9	575	66.3	4167	7	3054	1.8
TP-27-PC4-19	C-6	*TM*	25.3	4.4	3.6	22.9	24.2	25.0	25.2	25.1	24.8	23.9	23.0	581	72.1	4173	7	3075	1.7
TP-27-PC4-20	C-7	*TM*	24.7	4.0	2.6	22.7	23.9	24.6	24.7	24.4	24.1	23.1	22.3	565	55.7	4157	7	3236	1.7
TP-27-PC4-21	C-8	*TM*	25.1	4.3	3.2	22.9	24.0	24.9	25.1	24.8	24.5	23.4	22.6	572	63.0	4164	7	3064	1.7
TP-27-PC4-22	C-1	*TM*	24.1	4.0	2.8	22.3	23.2	24.0	24.1	23.8	23.5	22.5	21.9	552	52.7	4234	7	3277	1.7
TP-27-PC4-23	C-3	*TM*	24.2	3.9	3.5	22.2	23.1	23.9	23.1	24.1	24.0	23.2	22.5	562	63.3	4245	7	3318	1.7
TP-27-PC4-24	C-4	*TM*	24.5	4.3	3.0	22.5	23.5	24.3	24.5	24.3	24.1	23.2	22.6	565	66.2	4248	7	2910	1.7
TP-27-PC4-25	C-5	*TM*	24.2	3.9	3.7	22.3	23.2	23.9	24.2	24.1	24.0	23.2	22.6	563	63.9	4246	7	3374	1.7
TP-27-PC4-26	C-6	*TM*	24.7	4.3	3.5	22.5	23.6	24.4	24.7	24.5	24.3	23.4	22.7	569	69.7	4252	7	3242	1.8
TP-27-PC4-27	C-7	*TM*	24.1	3.9	2.8	22.3	23.2	24.0	24.1	23.9	23.7	22.7	22.2	555	54.9	4237	7	3409	1.8
TP-27-PC4-28	C-8	*TM*	24.5	4.1	3.3	22.3	23.3	24.1	24.5	24.2	24.0	23.0	22.3	561	60.7	4243	7	3106	1.8
TP-27-PC4-29	C-1	*TM*	24.4	3.8	2.7	22.4	23.6	24.3	24.3	24.0	23.6	22.4	21.6	551	52.4	3881	7	3079	1.7
TP-27-PC4-30	C-3	*TM*	23.9	3.2*	2.8	21.9	23.0	23.7	23.8	23.7	23.4	22.5	21.8	549	49.7	3878	7	3316	1.7

Notes: Shading of table rows is for ease of reading; Chan. = Channel; and asterisked values indicate an outlier that was removed from the respective analysis.

Table B.29 Thermal Profile Raw Data: Series 28

Specimen ID	Chan. ID	T_{max} (°C)	ΔT (°C)	t_{max} (hr)	Profile Temperature (°C) at Time Indicated (hr) 0.1	1	2	4	6	8	16	24	A_s (°C-hr)	$A_{\Delta T}$ (°C-hr)	*TTF* (°C-hr)	$t_{\sigma max}$ (day)	$P_{\gamma d}$ (%)	σ_{max} (kPa)	ε_{max} (%)
TP-28-PD7-01	A-1	26.3	4.5	10.4	22.2	23.2	23.7	24.6	25.9	26.2	25.9	24.8	609	90.4	4026	7	91.5	680	1.1
TP-28-PD7-02	A-3	27.0	5.2	10.8	22.3	23.4	24.0	25.0	26.4	26.8	26.8	25.9	626	107.7	4043	7	93.2	942	1.3
TP-28-PD7-03	A-4	26.9	5.1	10.1	22.6	23.5	24.1	25.1	26.4	26.7	26.6	25.6	624	104.4	4041	7	93.8	940	1.4
TP-28-PD7-04	A-5	27.4	5.5	11.8	22.3	23.1	23.8	24.9	26.5	27.0	27.2	26.2	632	112.5	4049	7	95.9	1377	1.5
TP-28-PD7-05	A-6	27.3	5.4	11.3	22.3	23.4	24.0	25.0	26.5	27.0	27.1	26.1	631	111.6	4049	7	96.3	1365	1.3
TP-28-PD7-06	A-7	26.9	5.2	10.3	22.3	23.3	23.8	24.8	26.3	26.8	26.7	25.6	623	103.4	4040	7	97.3	1632	1.4
TP-28-PD7-07	A-8	27.1	5.4	9.4	22.5	23.5	24.1	25.1	26.6	27.0	26.7	25.5	626	106.0	4043	7	99.1	1555	1.3
TP-28-PD7-08	B-1	26.5	4.7	9.8	22.3	23.3	23.8	24.7	26.1	26.5	26.1	25.1	614	91.4	4031	7	98.0	1556	1.3
TP-28-PD7-09	B-3	27.4	5.4	11.0	22.4	23.7	24.4	25.4	26.9	27.2	27.2	26.2	636	112.7	4053	7	98.8	1704	1.4
TP-28-PD7-10	B-4	27.2	5.3	10.5	22.4	23.5	24.1	25.2	26.7	27.0	26.9	25.9	630	106.9	4047	7	100.1	1617	1.5
TP-28-PD7-11	B-5	27.7	5.6	12.6	22.5	23.7	24.4	25.4	27.0	27.4	27.6	26.5	642	117.8	4059	7	101.2	1702	2.0
TP-28-PD7-12	B-6	27.7	5.6	12.2	22.4	23.6	24.4	25.5	27.0	27.5	27.5	26.4	641	117.4	4058	7	101.2	1670	1.7
TP-28-PD7-13	B-7	27.4	5.4	10.4	22.4	23.6	24.3	25.4	27.0	27.3	27.0	25.8	633	108.3	4050	7	101.7	1655	1.7
TP-28-PD7-14	B-8	27.2	5.2	10.8	22.4	23.5	24.2	25.3	26.8	27.1	26.9	25.8	630	105.5	4047	7	101.9	1833	1.7
TP-28-PD7-15	A-1	26.7	5.0	8.4	23.7	24.3	24.7	25.6	26.6	26.7	26.1	25.0	621	97.8	4054	7	100.7	1748	1.5
TP-28-PD7-16	A-3	27.6	5.7	11.4	23.5	24.2	24.8	24.2	27.2	27.4	27.3	26.2	641	118.4	4075	7	102.4	1816	1.5
TP-28-PD7-17	A-4	27.4	5.5	10.5	23.4	24.2	24.9	25.8	27.0	27.2	27.0	25.9	636	112.8	4070	7	100.7	1783	1.5
TP-28-PD7-18	A-5	27.6	5.6	11.6	23.1	23.9	24.6	25.6	27.0	27.4	27.4	26.4	641	117.7	4075	7	101.5	1826	1.7

Notes: Shading of table rows is for ease of reading; and Chan. = Channel.

Table B.30 Thermal Profile Raw Data: Series 29

Specimen	Chan.	T_{max}	ΔT	t_{max}	Profile Temperature (°C) at Time Indicated (hr)								A_s	$A_{\Delta T}$	*TTF*	$t_{\sigma max}$	$P_{\gamma d}$	σ_{max}	ε_{max}
ID	ID	(°C)	(°C)	(hr)	0.1	1	2	4	6	8	16	24	(°C-hr)	(°C-hr)	(°C-hr)	(day)	(%)	(kPa)	(%)
TP-29-PE7-01	B-1	25.6	4.7	6.4	22.3	23.0	23.5	24.1	25.5	25.4	24.1	23.3	581	74.2	4049	7	86.8	567	0.7
TP-29-PE7-02	B-3	26.0	5.1	6.8	22.3	22.9	23.4	24.3	25.9	26.0	25.0	24.1	596	88.8	4064	7	87.7	595	0.7
TP-29-PE7-03	B-4	25.6	4.7	6.3	22.4	23.0	23.5	24.2	25.6	25.5	24.4	23.6	586	78.1	4053	7	86.3	726	0.8
TP-29-PE7-04	A-5	27.1	5.3	8.1	22.5	23.2	23.8	25.0	26.8	27.1	26.7	25.7	626	99.3	4240	7	95.6	1101	1.3
TP-29-PE7-05	A-6	27.4	5.5	8.1	22.6	23.4	23.9	25.1	27.0	27.3	26.7	25.7	628	101.6	4242	7	95.6	1211	1.4
TP-29-PE7-06	A-7	27.1	5.2	8.0	22.7	23.3	23.8	24.9	26.7	27.1	26.3	25.3	621	94.1	4235	7	95.8	1181	1.3
TP-29-PE7-07	A-8	27.3	5.4	7.8	22.8	23.6	24.3	25.3	27.1	27.3	26.3	25.3	624	97.1	4238	7	98.0	1637	1.4
TP-29-PE7-08	B-1	26.6	4.8	7.8	22.5	23.2	23.7	24.6	26.4	26.6	25.8	24.8	611	80.7	4225	7	98.1	1722	1.7
TP-29-PE7-09	B-3	27.2	5.1	9.2	22.6	23.4	24.0	25.1	26.9	27.1	26.7	25.7	628	97.6	4242	7	98.0	1350	1.4
TP-29-PE7-10	B-4	26.8	4.7	9.0	22.5	23.2	23.7	24.7	26.5	26.8	26.4	25.5	620	89.5	4234	7	101.4	1770	1.4
TP-29-PE7-11	B-5	27.2	5.2	8.1	22.7	23.5	24.1	25.1	27.0	27.2	26.8	25.9	630	99.2	4244	7	101.2	1935	1.5
TP-29-PE7-12	B-6	27.5	5.6	7.4	22.8	23.5	24.1	25.4	27.2	27.4	26.9	26.0	634	102.9	4248	7	100.9	1803	1.7
TP-29-PE7-13	B-7	27.5	5.6	7.2	22.9	23.7	24.3	25.5	27.3	27.5	26.6	25.5	630	98.3	4243	7	102.3	1879	1.5
TP-29-PE7-14	B-8	27.2	5.4	7.1	22.9	23.5	24.1	25.1	27.0	27.2	26.5	25.4	625	93.6	4239	7	102.0	1747	1.5
TP-29-PE7-15	A-1	26.8	5.4	6.7	22.8	23.5	24.2	25.2	26.8	26.8	25.7	24.6	614	92.2	4216	7	103.0	2425	1.8
TP-29-PE7-16	A-3	27.1	5.6	7.0	23.0	23.6	24.2	23.6	27.0	27.1	26.5	25.5	626	105.1	4229	7	104.7	2234	1.5
TP-29-PE7-17	A-4	27.1	5.5	6.8	23.0	23.7	24.3	25.3	27.0	27.0	26.3	25.3	623	101.2	4225	7	104.7	2351	1.5
TP-29-PE7-18	A-5	27.1	5.4	8.0	22.7	23.4	23.9	25.0	26.9	27.0	26.6	25.7	626	104.7	4229	7	104.7	2417	1.7

Notes: Shading of table rows is for ease of reading; and Chan. = Channel.

Table B.31 Thermal Profile Raw Data: Series 30

Specimen ID	Chan. ID	T_{max} (°C)	ΔT (°C)	t_{max} (hr)	Profile Temperature (°C) at Time Indicated (hr) 0.1	1	2	4	6	8	16	24	A_s (°C-hr)	$A_{\Delta T}$ (°C-hr)	*TTF* (°C-hr)	$t_{\sigma max}$ (day)	$P_{\gamma d}$ (%)	σ_{max} (kPa)	ε_{max} (%)
TP-30-PE7-01	A-1	26.2	4.8	8.1	22.5	23.2	23.8	24.6	25.7	26.1	25.4	24.4	602	84.2	4209	7	85.0	440	1.3
TP-30-PE7-02	A-3	27.0	5.4	9.4	22.3	23.0	23.7	24.8	26.2	26.8	26.7	25.6	622	104.2	4229	7	89.6	1169	1.4
TP-30-PE7-03	A-4	27.0	5.4	9.1	22.4	23.1	23.8	24.9	26.2	26.9	26.5	25.4	621	102.2	4227	7	91.2	1112	1.3
TP-30-PE7-04	A-5	27.4	5.5	11.7	22.4	23.1	23.8	24.9	26.4	27.1	27.1	26.1	631	112.1	4237	7	97.1	1819	1.4
TP-30-PE7-05	A-6	27.6	5.9	9.4	22.7	23.4	24.2	25.3	26.8	27.4	27.2	26.1	635	116.2	4242	7	96.4	1574	1.3
TP-30-PE7-06	A-7	27.0	5.3	9.4	22.5	23.2	23.8	24.8	26.3	26.9	26.5	25.4	621	102.1	4228	7	97.5	1981	1.4
TP-30-PE7-07	A-8	27.1	5.4	8.6	22.5	23.2	23.9	25.0	26.4	27.0	26.4	25.4	622	102.6	4229	7	97.9	2001	1.5
TP-30-PE7-08	B-1	26.7	5.1	8.3	22.3	23.0	23.7	24.8	26.1	26.7	25.9	24.9	612	93.3	4219	7	99.0	2092	1.5
TP-30-PE7-09	A-6	27.5	5.6	10.1	22.7	23.4	24.1	25.2	26.8	27.4	27.1	26.0	634	111.8	4236	7	99.5	1912	1.5
TP-30-PE7-10	A-7	27.1	5.3	10.1	22.5	23.2	23.9	25.0	26.5	27.0	26.6	25.4	624	102.1	4226	7	101.1	2336	1.7
TP-30-PE7-11	A-8	27.3	5.5	9.2	22.7	23.5	24.3	25.4	26.9	27.3	26.7	25.4	628	105.7	4230	7	101.2	2022	1.5
TP-30-PE7-12	B-1	26.9	5.1	9.0	22.6	23.3	24.0	25.1	26.5	26.9	26.2	25.0	618	93.7	4220	7	102.8	2474	1.7
TP-30-PE7-13	B-3	27.6	5.6	9.7	22.8	23.5	24.3	25.3	27.0	27.4	27.2	26.0	636	110.7	4238	7	101.9	2678	1.7
TP-30-PE7-14	B-4	27.3	5.4	9.6	22.6	23.2	23.9	25.0	26.6	27.2	27.0	25.9	630	105.1	4232	7	104.2	2733	1.8
TP-30-PE7-15	B-5	27.7	5.7	9.4	22.7	23.5	24.2	25.3	26.9	27.5	27.3	26.2	637	111.9	4239	7	103.0	2601	1.7
TP-30-PE7-16	B-6	27.7	5.6	11.6	22.6	23.4	24.1	23.4	26.9	27.5	27.4	26.3	639	113.0	4240	7	104.7	2559	1.8
TP-30-PE7-17	B-7	27.3	5.4	8.8	22.8	23.6	24.3	25.3	26.9	27.2	26.7	25.4	628	102.4	4230	7	104.5	2563	1.7
TP-30-PE7-18	B-8	27.4	5.4	9.1	22.6	23.4	24.1	25.2	26.7	27.2	26.8	25.6	629	102.7	4230	7	104.8	2731	1.8

Notes: Shading of table rows is for ease of reading; Chan. = Channel.

Table B.32 Thermal Profile Raw Data: Series 31

Specimen	Chan.	t_d	T_{max}	ΔT	t_{max}	Profile Temperature (°C) at Time Indicated (hr)								A_s	$A_{\Delta T}$	TTF	$t_{\sigma max}$	σ_{max}	ε_{max}
ID	ID	(min)	(°C)	(°C)	(hr)	0.1	1	2	4	6	8	16	24	(°C-hr)	(°C-hr)	(°C-hr)	(day)	(kPa)	(%)
TP-31-PD7-01	B-5	7	27.2	5.2	14.2	22.1	23.1	23.7	24.8	26.0	26.5	27.1	26.3	628	110.9	3999	7	1569	1.4
TP-31-PD7-02	B-6	11	27.1	5.2	14.7	22.1	22.9	23.6	24.7	25.9	26.4	27.1	26.2	626	109.1	3998	7	1642	1.4
TP-31-PD7-03	A-6	17	27.4	5.3	12.9	22.7	23.7	24.3	25.3	26.5	27.0	27.4	26.4	636	111.4	4070	7	1633	1.5
TP-31-PD7-04	A-7	21	26.9	4.8	12.1	22.7	23.5	24.1	25.1	26.2	26.6	26.8	25.8	625	100.3	4059	7	1519	1.3
TP-31-PD7-05	B-1	32	25.7	4.3	8.9	22.6	23.5	24.0	24.7	25.5	25.6	25.4	24.5	601	86.2	4064	7	1642	1.3
TP-31-PD7-06	B-3	35	26.2	4.6	12.2	22.3	23.0	23.6	24.5	25.6	25.9	26.1	25.2	610	94.7	4072	7	1683	1.4
TP-31-PD7-07	B-4	47	25.7	4.2	10.6	22.6	23.3	23.7	24.5	25.4	25.6	25.5	24.6	602	86.5	4064	7	1635	1.4
TP-31-PD7-08	B-5	50	25.4	3.9	11.2	22.2	22.9	23.3	24.1	25.0	25.3	25.3	24.4	594	79.0	4057	7	1681	1.3
TP-31-PD7-09	B-5	63	26.4	4.4	11.7	22.5	23.4	23.9	24.9	25.8	26.0	26.3	25.4	615	92.2	4049	7	1738	1.4
TP-31-PD7-10	B-6	68	26.2	4.2	12.5	22.2	22.9	23.4	24.5	25.4	25.8	26.1	25.2	610	86.4	4043	7	1591	1.4

Notes: Shading of table rows is for ease of reading; Chan. = Channel; TP-31-PD7-01 is also TP-11-PD7-11; and TP-31-PD7-02 is also TP-11-PD7-12.

Table B.33 Thermal Profile Raw Data: Series 32

Specimen	Chan.	t_d	T_{max}	ΔT	t_{max}	Profile Temperature (°C) at Time Indicated (hr)								A_s	$A_{\Delta T}$	TTF	$t_{\sigma max}$	σ_{max}	ε_{max}
ID	ID	(min)	(°C)	(°C)	(hr)	0.1	1	2	4	6	8	16	24	(°C-hr)	(°C-hr)	(°C-hr)	(day)	(kPa)	(%)
TP-32-PD7-01	A-1	11	33.2	4.0	4.4	32.1	32.6	32.7	33.2	33.0	32.6	29.6	27.1	739	89.0	4245	7	1535	1.4
TP-32-PD7-02	A-3	16	33.5	4.8	5.6	30.8	32.0	32.4	33.3	33.5	33.3	30.9	28.3	758	108.9	4264	7	1582	1.5
TP-32-PD7-03	A-4	19	33.4	4.8	5.4	30.9	32.0	32.3	33.2	33.4	33.2	30.7	28.2	754	109.2	4259	7	1587	1.4
TP-32-PD7-04	A-5	24	33.7	5.5	6.2	30.6	31.9	32.4	33.5	33.7	33.6	31.3	28.6	764	120.0	4270	7	1734	1.4
TP-32-PD7-05	A-6	33	33.5	5.2	5.7	30.9	32.0	32.4	33.4	33.5	33.4	31.0	28.4	761	118.5	4266	7	1761	1.4
TP-32-PD7-06	A-7	35	33.3	4.4	4.1	31.4	32.3	32.6	33.3	33.2	32.9	30.2	27.6	747	105.6	4253	7	1818	1.4
TP-32-PD7-07	A-8	48	33.2	4.1	3.1	31.5	32.5	32.8	33.2	33.0	32.6	29.7	27.2	740	101.9	4246	7	1563	1.4
TP-32-PD7-08	B-1	51	32.9	3.4	3.1	30.9	32.4	32.6	32.8	32.5	32.1	29.1	26.7	728	80.0	4234	7	1428	1.1
TP-32-PD7-09	B-3	60	33.4	4.2	3.5	31.9	32.6	32.8	33.3	33.1	32.7	29.6	27.1	739	93.8	4245	7	1673	1.4
TP-32-PD7-10	B-4	63	33.0	3.9	3.5	31.2	32.3	32.5	33.0	32.7	32.3	29.2	26.7	731	85.5	4236	7	1645	1.5

Notes: Shading of table rows is for ease of reading; Chan. = Channel.

Table B.34 Thermal Profile Raw Data: Series 33

Specimen ID	Chan. ID	t_d (min)	T_{max} (°C)	ΔT (°C)	t_{max} (hr)	Profile Temperature (°C) at Time Indicated (hr) 0.1	1	2	4	6	8	16	24	A_s (°C-hr)	$A_{\Delta T}$ (°C-hr)	TTF (°C-hr)	$t_{\sigma max}$ (day)	σ_{max} (kPa)	ε_{max} (%)
TP-33-PE7-01	B-3	8	26.9	5.4	7.6	22.6	23.4	24.0	25.1	26.7	26.9	26.2	25.4	620	100.6	4227	7	1855	1.3
TP-33-PE7-02	B-4	13	26.7	5.2	7.6	22.4	23.1	23.8	24.8	26.5	26.7	25.9	25.1	614	94.0	4221	7	2078	1.5
TP-33-PE7-03	B-5	9	27.2	5.7	7.2	22.7	23.4	24.1	25.3	27.0	27.2	26.4	25.6	626	105.2	4232	7	1792	1.7
TP-33-PE7-04	B-5	18	26.0	5.0	6.6	22.4	23.0	23.5	24.4	25.9	25.8	24.9	24.0	595	87.1	4062	7	1974	1.4
TP-33-PE7-05	B-7	45	26.5	5.2	6.4	22.8	23.5	24.1	25.1	26.5	26.5	25.5	24.7	610	90.1	4217	7	1864	1.4
TP-33-PE7-06	B-8	48	26.5	5.0	7.3	22.5	23.2	23.8	24.9	26.4	26.4	25.5	24.8	609	88.7	4216	7	1955	1.5
TP-33-PE7-07	A-1	46	26.0	4.8	7.4	22.2	22.7	23.2	24.2	25.8	25.9	25.1	24.2	596	84.4	4200	7	2013	1.4
TP-33-PE7-08	A-3	49	26.4	5.2	7.9	22.1	22.6	23.2	24.4	26.2	26.4	25.8	24.9	609	97.0	4213	7	2150	1.7
TP-33-PE7-09	A-4	56	25.9	4.9	6.3	22.2	22.8	23.3	24.4	25.8	25.8	25.1	24.3	597	85.4	4201	7	2034	1.5
TP-33-PE7-10	A-4	59	25.8	4.9	5.9	22.1	22.7	23.2	24.3	25.7	25.7	25.0	24.2	594	82.2	4198	7	2028	1.5

Notes: Shading of table rows is for ease of reading; Chan. = Channel.

Table B.35 Thermal Profile Raw Data: Series 34

Specimen ID	Chan. ID	t_d (min)	T_{max} (°C)	ΔT (°C)	t_{max} (hr)	Profile Temperature (°C) at Time Indicated (hr) 0.1	1	2	4	6	8	16	24	A_s (°C-hr)	$A_{\Delta T}$ (°C-hr)	TTF (°C-hr)	$t_{\sigma max}$ (day)	σ_{max} (kPa)	ε_{max} (%)
TP-34-PE7-01	A-1	7	34.0	5.5	4.3	31.9	32.6	32.9	34.0	33.5	32.9	30.3	28.1	751	114.6	4293	7	2089	1.5
TP-34-PE7-02	A-3	11	34.3	5.9	4.6	31.6	32.3	32.7	34.2	34.0	33.6	31.5	29.2	770	133.9	4312	7	2112	1.5
TP-34-PE7-03	A-4	19	34.6	6.3	4.0	31.2	32.5	33.0	34.6	34.3	33.9	31.4	29.1	773	141.5	4315	7	2103	1.8
TP-34-PE7-04	A-5	23	34.4	6.4	4.6	31.5	32.2	32.7	34.4	34.2	33.9	31.7	29.5	775	143.4	4317	7	2110	1.5
TP-34-PE7-05	A-6	32	34.7	6.7	3.9	31.8	32.7	33.2	34.7	34.3	33.9	31.6	29.3	776	148.9	4317	7	2107	1.5
TP-34-PE7-06	A-7	35	34.3	6.3	3.9	31.7	32.6	33.0	34.3	33.8	33.3	30.8	28.6	761	134.4	4302	7	2160	1.5
TP-34-PE7-07	A-8	49	33.6	5.6	3.6	31.4	31.9	32.3	33.6	33.1	32.6	30.3	28.3	748	123.3	4289	7	2171	1.5
TP-34-PE7-08	B-1	51	33.7	3.8	3.6	30.8	32.0	32.4	33.6	33.1	32.6	30.1	28.0	745	87.7	4286	7	2156	1.8
TP-34-PE7-09	B-3	62	33.6	4.3	3.9	30.7	31.8	32.2	33.5	33.3	33.0	31.0	28.9	758	116.7	4301	7	2187	1.7
TP-34-PE7-10	B-4	65	33.3	3.7	3.4	30.8	31.6	32.0	33.2	32.8	32.4	30.2	28.2	744	100.3	4286	7	2188	1.5

Notes: Shading of table rows is for ease of reading; Chan. = Channel.

Table B.36 Field Thermal Profile Raw Data: Series 35, 37, and 39

Specimen ID	Chan. ID	L	P	t_d (min)	T_{max} (°C)	ΔT (°C)	t_{max} (hr)	Profile Temperature (°C) at Time Indicated (hr) 0.1	1	2	4	6	8	16	24	A_s (°C-hr)	$A_{\Delta T}$ (°C-hr)	TTF (°C-hr)	$P_{\gamma d}$ (%)	σ_{max} (kPa)	ε_{max} (%)
FW-35-PD7-01	A-1	1	C	6	33.6	4.0	8.1	25.4	26.3	27.5	29.2	31.8	33.6	31.3	25.7	726	75.4	4087	101.5	2166	1.4
FW-35-PD7-02	A-3	1	C	8	33.3	3.8	11.1	24.7	25.0	26.1	28.4	30.9	32.7	31.8	26.9	726	75.6	4087	100.7	2213	1.5
FW-35-PD7-03	A-4	1	1	33	31.1	1.9	12.0	23.7	24.1	25.4	27.5	28.8	30.2	30.2	26.0	688	37.7	4049	97.7	1199	1.5
FW-35-PD7-04	A-5	1	1	35	31.1	2.0	12.4	23.3	24.1	25.2	27.2	28.5	30.0	30.2	26.0	685	34.9	4046	97.8	1122	1.3
FW-35-PD7-05	A-6	1	3	39	30.7	1.6	12.5	23.2	24.2	25.3	27.0	28.4	29.7	29.7	25.4	678	27.8	4062	97.0	1041	1.0
FW-35-PD7-06	A-7	1	3	42	30.6	1.2	10.7	23.2	24.5	25.6	27.3	29.0	30.1	29.0	23.9	671	20.5	4055	97.0	873	1.3
FW-35-PD7-07	A-8	1	2	46	30.5	1.1	10.4	22.6	24.7	25.9	27.6	29.0	29.9	28.7	23.5	666	16.0	4050	96.9	1198	1.4
FW-37-PD7-01	B-7	2	C	4	37.3	6.2	5.7	32.2	33.6	34.7	36.7	37.1	36.9	30.8	26.1	783	125.2	4143	100.7	2165	1.5
FW-37-PD7-02	B-8	2	C	7	37.3	6.3	5.7	32.7	33.4	34.4	36.3	36.9	36.6	30.6	26.0	778	120.1	4138	101.2	2093	1.5
FW-37-PD7-03	B-1	2	1	18	34.5	2.9	3.5	31.7	32.3	33.6	34.4	33.8	32.8	27.0	22.9	703	40.8	4063	98.8	752	1.0
FW-37-PD7-04	B-3	2	1	20	34.7	3.0	3.5	31.2	32.0	33.4	34.5	34.1	33.7	28.6	24.2	727	65.8	4088	98.1	751	1.0
FW-37-PD7-05	B-4	2	3	24	37.3	5.8	3.9	32.1	33.5	34.8	37.2	37.2	36.9	30.7	25.3	779	118.4	4140	97.2	1682	1.4
FW-37-PD7-06	B-5	2	3	27	37.1	6.2	6.6	32.0	32.8	34.1	36.7	37.0	37.0	31.3	26.2	786	125.2	4146	96.2	1373	1.1
FW-37-PD7-07	B-6	2	2	29	34.4	2.8	3.1	31.7	32.4	33.5	34.1	34.2	34.0	29.2	25.2	738	80.1	4098	99.2	795	1.1
FW-39-PD7-01	A-1	3	C	6	20.8	4.1	10.9	12.6	13.3	14.2	16.1	18.1	20.2	20.1	17.1	444	87.5	3843	97.6	1975	2.0
FW-39-PD7-02	A-3	3	C	8	20.6	3.8	11.9	12.5	13.1	14.0	15.8	17.8	19.6	20.3	17.9	444	88.1	3844	97.3	2186	1.8
FW-39-PD7-03	A-4	3	1	15	19.2	2.5	10.8	14.2	14.3	15.1	16.4	17.8	18.8	18.5	16.0	421	64.5	3821	92.6	614	1.4
FW-39-PD7-04	A-5	3	1	17	19.1	2.3	11.5	12.9	13.6	14.5	15.7	17.5	18.5	18.6	16.1	417	60.2	3840	91.9	520	1.0
FW-39-PD7-05	A-6	3	2	27	20.1	3.4	10.1	14.3	15.1	16.0	17.4	19.0	19.9	19.2	16.4	441	82.9	3863	92.1	942	1.0
FW-39-PD7-06	A-7	3	3	38	23.1	6.3	10.3	14.3	15.4	16.5	18.2	20.3	22.3	21.6	17.4	483	124.9	3906	93.6	2320	1.4
FW-39-PD7-07	A-8	3	3	40	23.0	6.3	10.3	13.4	14.7	15.9	18.0	20.0	22.2	21.4	17.1	477	118.4	3900	93.6	2761	1.7

Notes: Shading of table rows is for ease of reading; Chan. = Channel; L = Location; P = Position; and $t_{\sigma max}$ = 7 days.

Table B.37 Field Thermal Profile Moisture Contents: Series 35, 37, and 39

Series	Position C	Position 1	Position 2	Position 3
35	10.8 %	10.5 %	9.8 %	9.0 %
37	10.5 %	8.8 %	8.2 %	8.5 %
39	17.1 %	15.4 %	14.9 %	13.9 %

Table B.38 Field Thermal Profile Raw Data: Series 41, 43, and 45

Specimen ID	Chan. ID	L	P	t_d (min)	T_{max} (°C)	ΔT (°C)	t_{max} (hr)	Profile Temperature (°C) at Time Indicated (hr) 0.1	1	2	4	6	8	16	24	A_s (°C-hr)	$A_{\Delta T}$ (°C-hr)	TTF (°C-hr)	$P_{\gamma d}$ (%)	σ_{max} (kPa)	ε_{max} (%)
FW-41-PE7-01	A-1	1	C	5	36.0	5.8	6.2	28.5	29.9	31.0	33.7	35.6	34.3	29.5	25.2	740	75.2	4310	92.4	1169	1.1
FW-41-PE7-02	A-3	1	C	8	36.3	6.2	6.1	28.0	30.1	31.4	33.9	36.2	35.7	31.3	26.9	769	104.4	4339	92.9	1271	1.1
FW-41-PE7-03	A-4	1	1	52	34.8	4.9	9.3	27.7	30.0	31.4	32.6	34.2	34.4	32.4	28.6	774	109.0	4344	101.0	2525	1.7
FW-41-PE7-04	A-5	1	1	54	35.0	5.1	9.2	27.9	29.9	31.3	32.6	34.2	34.6	32.4	28.6	774	109.6	4345	99.9	2457	1.5
FW-41-PE7-05	A-6	1	3	58	33.2	3.4	9.1	27.7	29.4	30.3	31.4	32.9	33.0	30.9	27.8	743	77.9	4313	100.4	893	1.1
FW-41-PE7-06	A-7	1	3	63	32.4	2.5	9.1	27.8	29.3	30.1	31.2	32.3	32.1	29.6	26.3	720	56.0	4291	100.5	1180	1.4
FW-41-PE7-07	A-8	1	2	65	34.2	4.1	5.9	28.5	30.8	31.9	33.1	34.1	33.7	30.8	27.0	753	88.7	4323	102.4	2244	1.7
FW-43-PE7-01	B-1	2	C	4	38.1	4.9	3.5	36.4	36.5	37.3	38.0	37.8	36.3	29.6	25.4	780	72.1	4353	97.1	1762	1.3
FW-43-PE7-02	B-3	2	C	6	38.7	5.6	5.3	35.5	35.9	37.1	38.5	38.5	37.5	31.7	27.3	812	105.3	4385	97.3	1850	1.3
FW-43-PE7-03	B-4	2	3	48	36.4	3.3	5.2	34.5	35.3	35.8	36.1	36.3	35.7	31.5	27.7	791	85.4	4364	99.3	1572	1.4
FW-43-PE7-04	B-5	2	3	51	36.2	3.1	5.1	34.6	34.8	35.4	35.8	36.0	35.4	31.3	27.7	786	80.5	4359	98.6	1472	1.4
FW-43-PE7-05	B-6	2	2	55	36.5	3.5	5.1	34.7	35.2	35.8	36.1	36.4	35.8	31.6	28.0	795	89.8	4368	99.6	1433	1.4
FW-43-PE7-06	B-7	2	1	58	35.7	2.6	5.0	33.4	34.6	35.2	35.3	35.5	34.6	30.2	27.0	767	62.2	4340	99.4	1274	1.1
FW-43-PE7-07	B-8	2	1	59	35.8	2.7	5.3	34.2	34.9	35.4	35.3	35.6	34.6	29.9	26.6	763	59.4	4336	101.3	1489	1.4
FW-45-PE7-01	A-1	3	C	5	36.4	6.6	4.9	30.5	33.6	35.2	35.5	36.0	35.1	31.2	27.9	782	116.6	4370	102.6	2243	1.4
FW-45-PE7-02	A-3	3	C	6	36.5	6.4	5.0	30.8	33.4	35.0	35.8	36.3	35.6	32.2	28.8	796	131.9	4385	102.0	2133	1.4
FW-45-PE7-03	A-4	3	3	41	34.1	4.0	4.9	31.1	32.4	33.1	33.5	34.0	33.4	30.4	27.6	753	89.2	4342	100.8	1259	1.3
FW-45-PE7-04	A-5	3	3	44	34.5	4.5	4.9	30.9	32.3	33.2	34.0	34.1	33.4	30.3	27.4	753	89.5	4342	101.6	1115	1.1
FW-45-PE7-05	A-6	3	1	50	33.7	3.6	4.8	30.7	31.5	32.4	33.1	33.4	33.0	30.1	27.3	743	79.8	4332	95.7	790	1.1
FW-45-PE7-06	A-7	3	1	52	33.9	3.8	4.7	30.7	31.8	32.8	33.5	33.4	32.6	29.0	26.2	729	65.1	4317	94.0	710	1.0
FW-45-PE7-07	A-8	3	2	54	34.9	4.9	4.6	31.2	33.0	34.1	34.4	34.4	33.6	29.9	27.0	752	88.4	4341	98.8	1308	1.3

Notes: Shading of table rows is for ease of reading; Chan. = Channel; L = Location; P = Position; and $t_{\sigma max}$ = 7 days.

Table B.39 Field Thermal Profile Moisture Contents: Series 41, 43, and 45

Series	Position C	Position 1	Position 2	Position 3
41	8.2 %	14.1 %	14.7 %	15.7 %
43	8.2 %	14.2 %	14.8 %	13.9 %
45	11.1 %	13.9 %	13.3 %	12.6 %

Table B.40 Field *UC* Strength Raw Data: Series 35, 36, 37, 38, 39, and 40

Specimen ID	Type	L	P	t_d (min)	*h/d* Ratio	Density (kg/m^3)	ω (%)	$P_{\gamma d}$ (%)	*TTF* (°C-hr)	$t_{\sigma max}$ (day)	σ_{max} (kPa)	ε_{max} (%)
FW-35-PD7-08	Mold	1	2	52	1.97	1898	9.8	96.3	2942	7	903	1.1
FW-35-PD7-09	Mold	1	2	55	1.97	1881	9.8	95.4	2948	7	1219	1.3
FW-35-PD7-10	Mold	1	4	59	1.97	1883	8.4	96.7	2953	7	1261	1.3
FW-35-PD7-11	Mold	1	4	61	1.97	1896	8.4	97.4	2957	7	1545	1.4
FW-35-PD7-12	Mold	1	5	64	1.98	1921	10.8	96.5	2962	7	1645	1.7
FW-35-PD7-13	Mold	1	5	66	1.97	1905	10.8	95.8	2966	7	1556	1.5
FW-36-PD7-01	Core	1	3	--	2.01	1861	9.0	95.1	2945	7	798	1.5
FW-36-PD7-02	Core	1	3	--	2.02	1788	9.0	91.4	2950	7	544	1.5
FW-36-PD7-03	Core	1	3	--	1.99	1852	9.0	94.6	2956	7	896	2.0
FW-36-PD7-04	Core	1	3	--	2.03	1854	9.0	94.7	2960	7	598	1.5
FW-36-PD7-05	Core	1	3	--	2.02	1849	9.0	94.5	2963	7	801	1.3
FW-36-PD7-06	Core	1	3	--	2.02	1833	9.0	93.7	2968	7	420	1.5
FW-37-PD7-08	Mold	2	2	33	1.97	1865	8.2	96.0	2934	7	856	1.5
FW-37-PD7-09	Mold	2	4	35	1.97	1969	9.2	100.4	2937	7	2450	1.5
FW-37-PD7-10	Mold	2	4	37	1.97	1965	9.2	100.2	2940	7	2677	1.8
FW-37-PD7-11	Mold	2	5	41	1.97	1957	10.2	98.9	2944	7	760	0.8
FW-37-PD7-12	Mold	2	5	43	1.97	1912	10.2	96.6	2949	7	1553	1.4
FW-37-PD7-13	Mold	2	3	46	1.97	1892	8.5	97.1	2953	7	2062	1.5
FW-38-PD7-01	Core	2	3	--	1.99	1948	8.5	99.9	2935	7	1023	1.6
FW-38-PD7-02	Core	2	3	--	2.00	1901	8.5	97.5	2938	7	756	2.0
FW-38-PD7-03	Core	2	3	--	2.02	1937	8.5	99.4	2938	7	985	1.7
FW-38-PD7-04	Core	2	3	--	1.98	1871	8.5	96.0	2947	7	734	1.3
FW-38-PD7-05	Core	2	3	--	2.00	1902	8.5	97.6	2952	7	900	1.3
FW-38-PD7-06	Core	2	3	--	2.00	1904	8.5	97.7	2953	7	900	1.3
FW-39-PD7-08	Mold	3	5	27	1.97	2053	14.9	92.1	3569	7	1975	2.0
FW-39-PD7-09	Mold	3	5	30	1.97	2047	14.9	92.1	3569	7	2186	1.8
FW-39-PD7-10	Mold	3	2	35	1.97	1920	14.9	92.1	3582	7	614	1.4
FW-39-PD7-11	Mold	3	4	39	1.97	1904	14.3	92.3	3582	7	520	1.0
FW-39-PD7-12	Mold	3	4	41	1.97	1899	14.3	92.5	3582	7	942	1.0
FW-39-PD7-13	Mold	3	3	48	1.97	1914	13.9	93.0	3582	7	2320	1.4
FW-40-PD7-01	Core	3	3	--	2.00	1827	13.9	89.4	3593	7	1044	1.5
FW-40-PD7-02	Core	3	3	--	2.01	1863	13.9	91.1	3593	7	1438	1.9
FW-40-PD7-03	Core	3	3	--	2.00	1903	13.9	93.1	3593	7	1514	2.1
FW-40-PD7-04	Core	3	3	--	2.01	1890	13.9	92.4	3604	7	1462	1.7
FW-40-PD7-05	Core	3	3	--	2.03	1868	13.9	91.4	3604	7	1368	1.9
FW-40-PD7-06	Core	3	3	--	1.99	1855	13.9	90.7	3604	7	1387	1.9

Notes: Shading of table rows is for ease of reading; L = Location; and P = Position.

Table B.41 Field *UC* Strength Raw Data: Series 41, 42, 43, 44, 45, and 46

Specimen ID	Type	L	P	t_d (min)	h/d Ratio	Density (kg/m^3)	ω (%)	$P_{\gamma d}$ (%)	*TTF* (°C-hr)	$t_{\sigma max}$ (day)	σ_{max} (kPa)	ε_{max} (%)
FW-41-PE7-08	Mold	1	2	65	1.97	2013.8	14.7	101.1	5340	7	2610	1.8
FW-41-PE7-09	Mold	1	4	68	1.97	1943.3	15.7	96.8	5340	7	1970	1.4
FW-41-PE7-10	Mold	1	4	70	1.97	1938.3	15.7	96.5	5352	7	1925	1.5
FW-41-PE7-11	Mold	1	5	72	1.97	1952.0	15.7	97.2	5352	7	2313	1.5
FW-41-PE7-12	Mold	1	5	75	1.96	1947.5	15.7	97.0	5352	7	2098	1.4
FW-41-PE7-13	Mold	1	3	77	1.97	1978.1	15.7	98.5	5352	7	2054	1.5
FW-42-PE7-01	Core	1	3	--	2.01	1932.8	15.7	96.2	5352	7	1996	1.8
FW-42-PE7-02	Core	1	3	--	1.99	1931.5	15.7	96.2	5352	7	1600	2.1
FW-42-PE7-03	Core	1	3	--	2.01	1949.2	15.7	97.0	5352	7	1152	1.8
FW-42-PE7-04*	Core	1	3	--	2.01	1935.9	15.7	96.4	5390	7	1569	2.1
FW-42-PE7-05	Core	1	3	--	1.98	1953.9	15.7	97.3	5390	7	1513	3.2
FW-42-PE7-06	Core	1	3	--	2.00	1961.8	15.7	97.7	5390	7	1856	2.0
FW-43-PE7-08	Mold	2	5	44	1.96	1878.4	13.9	94.9	5181	7	2568	1.7
FW-43-PE7-09	Mold	2	5	46	1.96	1957.2	13.9	98.9	5181	7	2658	1.5
FW-43-PE7-10	Mold	2	3	53	1.97	1996.9	13.9	101.0	5181	7	3248	1.8
FW-43-PE7-11	Mold	2	2	61	1.97	1861.8	14.8	93.4	5181	7	1544	1.3
FW-43-PE7-12	Mold	2	4	63	1.97	1878.3	13.7	95.1	5181	7	1606	1.4
FW-43-PE7-13	Mold	2	4	65	1.97	1884.5	13.7	95.4	5181	7	2511	1.5
FW-44-PE7-01	Core	2	3	--	2.00	1867.6	13.9	94.5	5218	7	1021	2.0
FW-44-PE7-02	Core	2	3	--	1.98	1883.2	13.9	95.3	5218	7	929	1.3
FW-44-PE7-03*	Core	2	3	--	1.99	1869.7	13.9	94.6	5218	7	956	1.4
FW-44-PE7-04*	Core	2	3	--	2.02	1866.0	13.9	94.4	5231	7	1104	1.5
FW-44-PE7-05*	Core	2	3	--	1.97	1855.1	13.9	93.8	5231	7	1103	1.7
FW-44-PE7-06*	Core	2	3	--	2.02	1851.8	13.9	93.7	5231	7	1164	1.8
FW-45-PE7-08	Mold	3	4	46	1.97	1928.6	12.8	98.5	5243	7	2178	1.7
FW-45-PE7-09	Mold	3	4	47	1.97	1912.3	12.8	97.7	5243	7	1979	1.5
FW-45-PE7-10	Mold	3	2	55	1.99	1938.7	13.3	98.5	5243	7	1322	1.3
FW-45-PE7-11	Mold	3	5	57	1.98	1896.9	12.6	97.0	5255	7	2208	1.5
FW-45-PE7-12	Mold	3	5	59	1.98	1927.6	12.6	98.6	5255	7	2231	1.3
FW-45-PE7-13	Mold	3	3	61	1.97	1913.9	12.6	97.9	5255	7	1525	1.3
FW-46-PE7-01*	Core	3	3	--	1.93	1968.9	12.6	100.7	5291	7	1197	1.4
FW-46-PE7-02*	Core	3	3	--	1.89	1931.6	12.6	98.8	5291	7	1203	1.5
FW-46-PE7-03	Core	3	3	--	1.93	1906.6	12.6	97.5	5291	7	961	1.5
FW-46-PE7-04*	Core	3	3	--	1.95	1888.3	12.6	96.6	5291	7	928	1.5
FW-46-PE7-05*	Core	3	3	--	1.96	1911.9	12.6	97.8	5291	7	1036	1.4
FW-46-PE7-06*	Core	3	3	--	1.98	1926.5	12.6	98.5	5291	7	1178	1.5

Notes: Shading of table rows is for ease of reading; L = Location; P = Position; and Asterisked specimens were capped with Plaster of Paris before compressive strength testing.

Table B.42 Thermal Profile Raw Data: Series 47

Specimen ID	Channel ID	T_{max} (°C)	ΔT (°C)	t_{max} (hr)	Profile Temperature (°C) at Time Indicated (hr)								A_s (°C-hr)	$A_{\Delta T}$ (°C-hr)	*TTF* (°C-hr)	$t_{\sigma max}$ (day)	σ_{max} (kPa)	ε_{max} (%)
					0.1	1	2	4	6	8	16	24						
TP-47-PD4-01	A-1	25.9	0.9	3.7	24.1	25.0	25.5	25.9	25.6	25.3	24.2	23.6	592	24.9	4069	7	633	1.0
TP-47-PD4-02	A-3	25.8	1.1	4.9	23.8	24.6	25.1	25.7	25.7	25.5	25.0	24.4	602	35.4	4079	7	695	1.1
TP-47-PD6-03	A-4	27.2	3.4	8.6	24.2	25.6	26.0	26.7	27.2	27.2	26.6	25.5	636	70.1	4113	7	1256	1.1
TP-47-PD6-04	A-5	27.3	3.9	10.9	24.1	25.0	25.6	26.4	27.0	27.2	27.0	26.0	640	74.0	4117	7	1289	1.3
TP-47-PD8-05	A-6	28.9	5.4	9.9	24.3	25.6	26.1	27.0	28.4	28.8	28.3	26.8	667	102.6	4144	7	2191	1.5
TP-47-PD8-06	A-7	28.2	4.6	9.8	24.0	25.0	25.4	26.3	27.6	28.0	27.6	26.2	650	85.5	4127	7	2232	1.5

Note: Shading of table rows is for ease of reading.

Table B.43 Thermal Profile Raw Data: Series 48

Specimen ID	Channel ID	T_{max} (°C)	ΔT (°C)	t_{max} (hr)	Profile Temperature (°C) at Time Indicated (hr)								A_s (°C-hr)	$A_{\Delta T}$ (°C-hr)	*TTF* (°C-hr)	$t_{\sigma max}$ (day)	σ_{max} (kPa)	ε_{max} (%)
					0.1	1	2	4	6	8	16	24						
TP-48-PE4-01	A-8	26.5	1.8	4.2	24.3	25.3	25.8	26.4	26.1	25.8	24.7	24.1	603	39.5	4080	7	639	1.0
TP-48-PE4-02	B-1	26.0	1.2	4.1	24.0	24.9	25.3	26.0	25.8	25.3	24.1	23.5	591	22.8	4068	7	772	1.1
TP-48-PE6-03	B-3	27.3	3.0	6.0	24.0	25.0	25.6	26.4	27.3	27.1	25.9	24.8	625	57.7	4102	7	1394	1.4
TP-48-PE6-04	B-4	27.1	2.8	6.2	23.8	24.6	25.2	26.0	27.1	27.0	25.8	24.8	621	53.9	4098	7	1358	1.3
TP-48-PE8-05	B-5	28.7	4.4	6.0	24.3	25.2	25.8	26.7	28.7	28.5	26.8	25.4	646	79.5	4123	7	2405	1.5
TP-48-PE8-06	B-6	28.5	4.3	6.7	24.1	24.6	25.1	26.3	28.4	28.3	26.8	25.4	641	75.6	4118	7	2594	1.5

Note: Shading of table rows is for ease of reading.

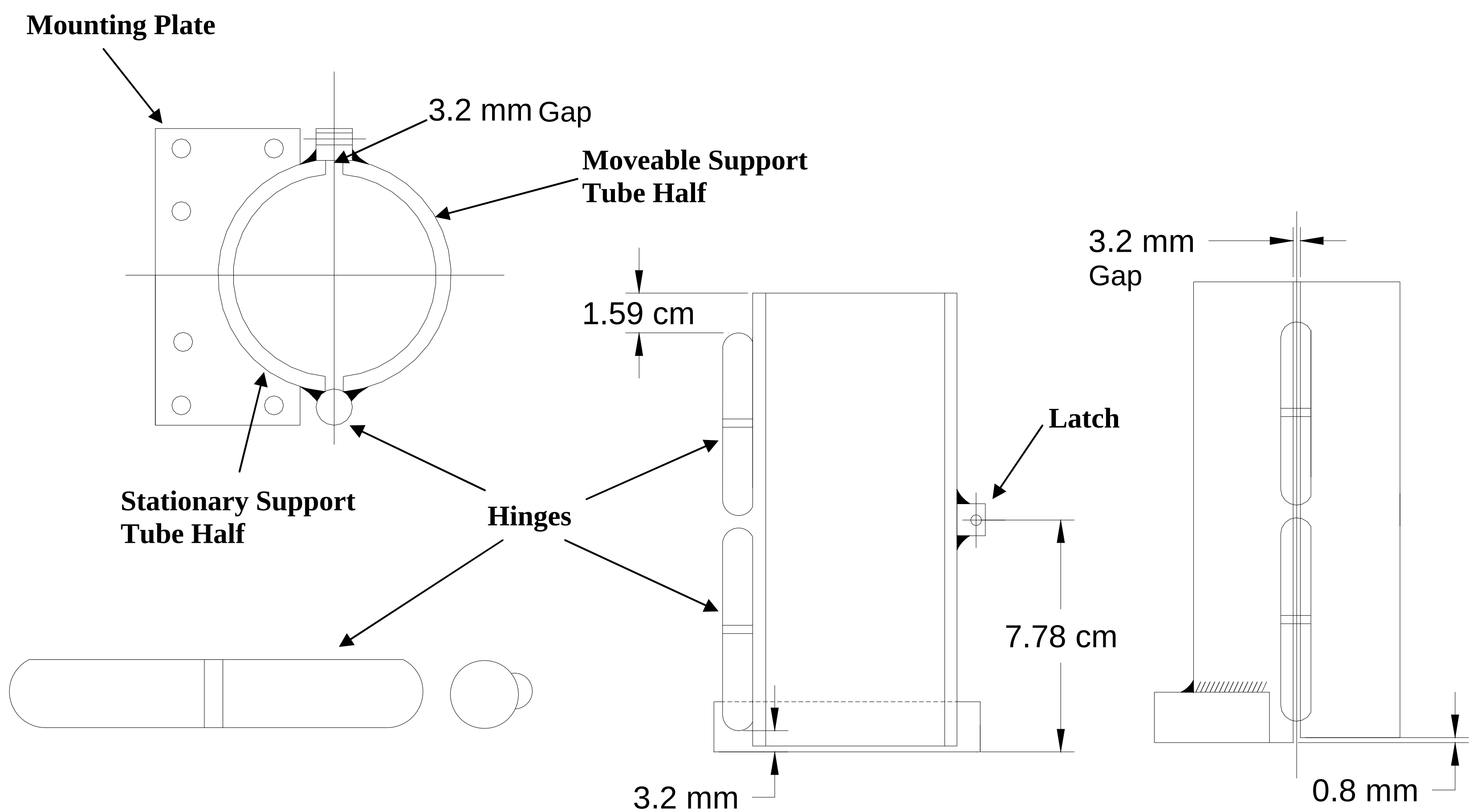
Table B.44 Thermal Profile Raw Data: Series 49

Specimen ID	Chan. ID	T_{BL} (°C)	T_{max} (°C)	ΔT (°C)	t_{max} (hr)	Profile Temperature (°C) at Time Indicated (hr) 0.1	1	2	4	6	8	16	24	A_s (°C-hr)	$A_{\Delta T}$ (°C-hr)	TTF (°C-hr)	$t_{\sigma max}$ (day)	σ_{max} (kPa)	ε_{max} (%)
TP-49-PA5-01	A-1	32	36.5	3.1	11.8	32.8	34.2	35.2	36.0	36.3	36.4	36.0	35.6	861	66.3	886	1	1908	1.7
TP-49-PA5-02	A-3	32	36.8	3.4	11.8	32.4	33.7	34.8	35.9	36.2	36.5	36.6	36.2	867	71.8	892	1	1969	1.7
TP-49-PA5-03	A-4	32	37.0	3.8	11.0	32.8	34.2	35.2	36.4	36.7	36.9	36.7	36.3	873	77.4	898	1	1849	1.5
TP-49-PA5-04	A-5	32	37.5	4.1	11.4	33.3	34.8	35.9	36.9	37.1	37.3	37.1	36.5	884	87.5	2064	3	1944	1.4
TP-49-PA5-05	A-6	32	37.6	4.2	11.5	33.2	34.7	35.8	36.8	37.2	37.4	37.1	36.6	885	89.0	2066	3	1819	1.4
TP-49-PA5-06	A-7	32	37.3	4.2	7.9	33.4	34.9	35.8	36.9	37.1	37.2	36.7	36.1	879	82.0	2059	3	1709	1.4
TP-49-PA5-07	A-8	32	37.5	4.4	7.7	33.8	35.4	36.3	37.2	37.3	37.4	36.7	36.2	883	85.5	4366	7	2159	1.5
TP-49-PA5-08	B-1	32	36.9	3.8	7.6	33.3	35.0	35.9	36.8	36.8	36.9	36.3	35.7	871	74.6	4354	7	2155	1.5
TP-49-PA5-09	B-3	32	37.1	4.1	6.6	33.5	35.0	36.0	37.0	37.0	37.0	36.3	35.8	873	76.5	4357	7	2073	1.5
TP-49-PA5-10	A-1	32	36.1	3.1	1.1	33.2	36.0	35.6	34.3	33.0	31.8	27.6	24.7	717	73.0	813	1	1664	1.4
TP-49-PA5-11	A-3	32	36.8	5.0	2.2	34.2	36.5	36.7	36.0	35.1	34.1	30.5	27.5	774	130.3	870	1	1733	1.4
TP-49-PA5-12	A-4	32	37.2	5.6	2.2	34.8	36.8	37.1	36.5	35.4	34.4	30.7	27.6	780	137.8	876	1	1663	1.4
TP-49-PA5-13	A-5	32	36.3	4.9	2.2	34.1	36.1	36.3	35.8	34.9	34.0	30.4	27.4	771	129.3	1440	2	1659	1.4
TP-49-PA5-14	A-6	32	36.6	5.3	2.2	34.6	36.5	36.6	36.0	35.1	34.1	30.4	27.3	773	132.0	1441	2	1719	1.5
TP-49-PA5-15	A-7	32	35.5	2.5	0.6	33.5	35.3	35.1	34.2	33.0	31.9	28.0	25.2	722	82.6	1391	2	1658	1.5
TP-49-PA5-16	A-8	32	35.6	2.6	0.5	33.7	35.3	35.2	35.3	32.8	31.6	27.6	24.7	715	76.4	4212	7	2178	1.5
TP-49-PA5-17	B-1	32	34.2	1.9	0.4	32.7	34.0	33.7	32.6	31.2	29.9	25.7	22.9	674	72.4	4171	7	2262	1.5
TP-49-PA5-18	B-3	32	34.5	3.6	1.4	33.9	34.5	34.4	33.6	32.2	30.9	26.7	23.9	697	97.1	4194	7	2128	1.5

Notes: Shading of table rows is for ease of reading; Chan. = Channel; After specimen preparation, the devices containing specimens 10 through 18 were placed in ambient air conditions near 21 °C.

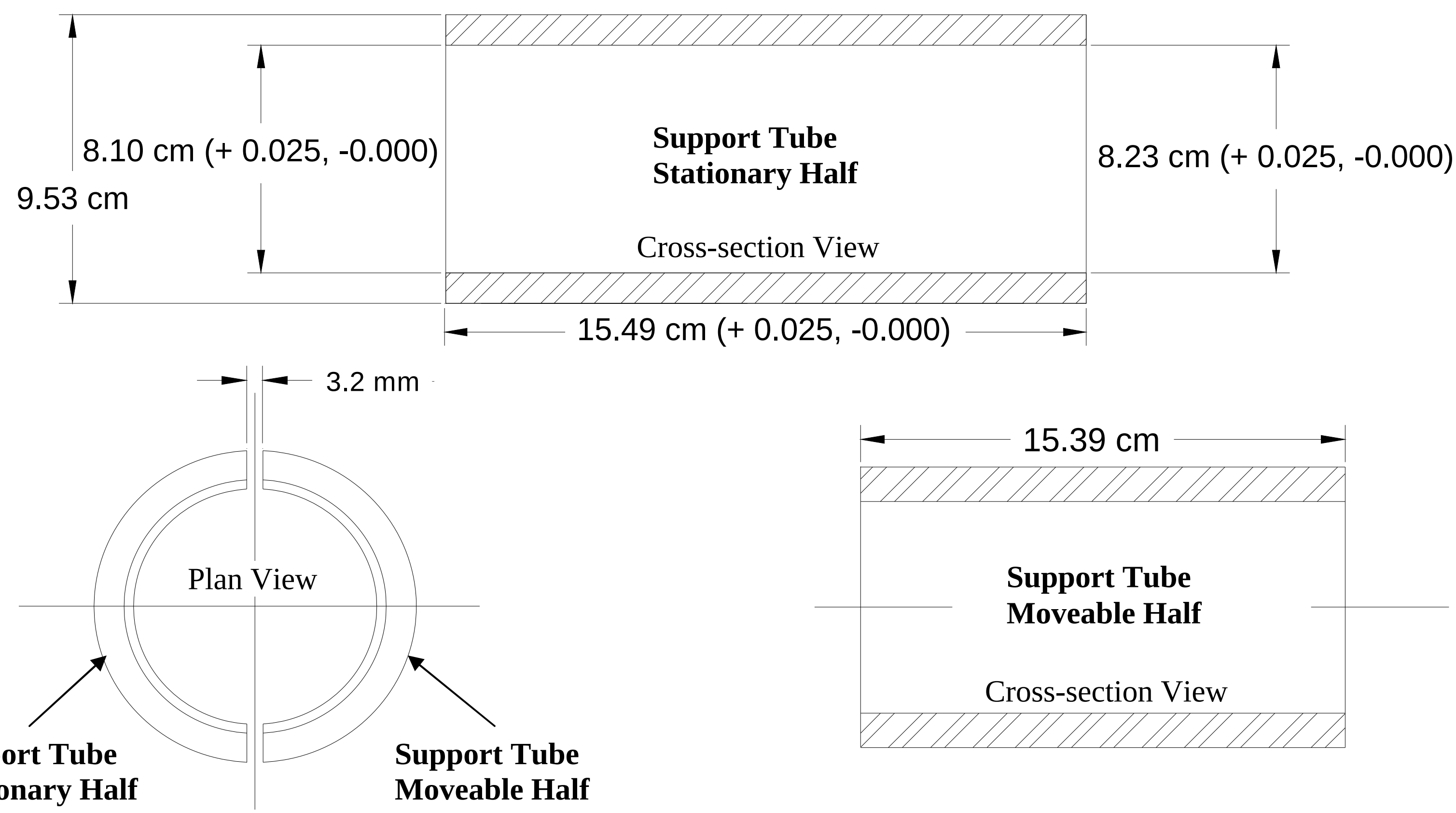
APPENDIX C

MISSISSIPPI STATE UNIVERSITY COMPACTOR DRAWINGS



Notes:
1) Hinges, Latches, and Stationary Support Tube Half are welded as shown
2) Hinges (2 req'd) are McMaster part number 1071A22 and are welded to Support Tube Halves

Figure C.1 *PM* Mold Assembly: Overall View



Notes:
1) Support Tube Halves made from steel tubing 9.53 cm O.D. and 7.62 cm I.D.
2) Cut tubing into two pieces along 15.49 cm length
3) Support Tube Stationary Half is welded to *PM* mounting plate.
4) Support Tube Moveable Half is shorten by 0.1 cm from 8.10 cm I.D. end

Figure C.2 *PM* Mold Assembly: Support Tube

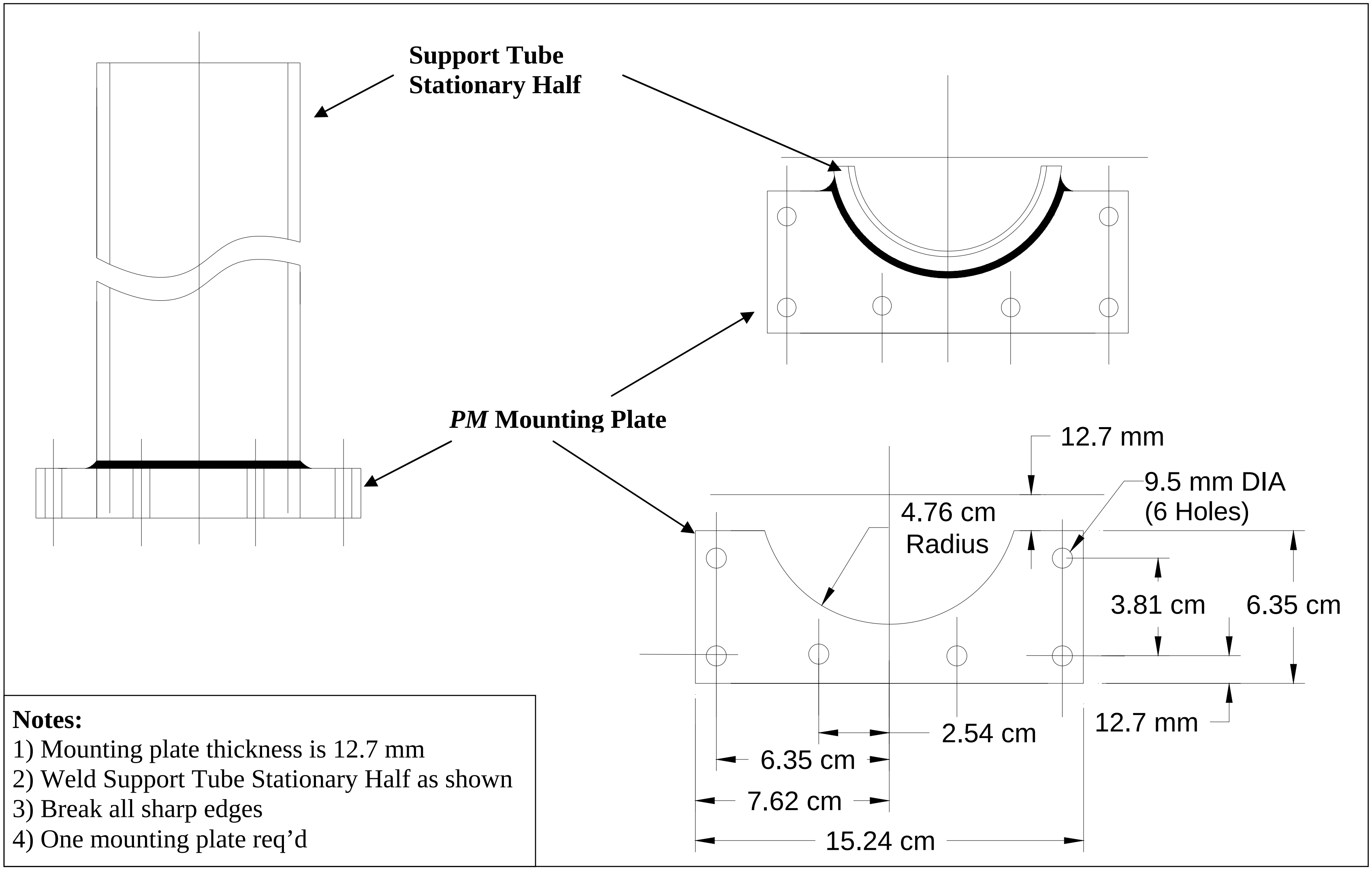


Figure C.3 *PM* Mold Assembly: Mounting Plate and Support Tube Stationary Half

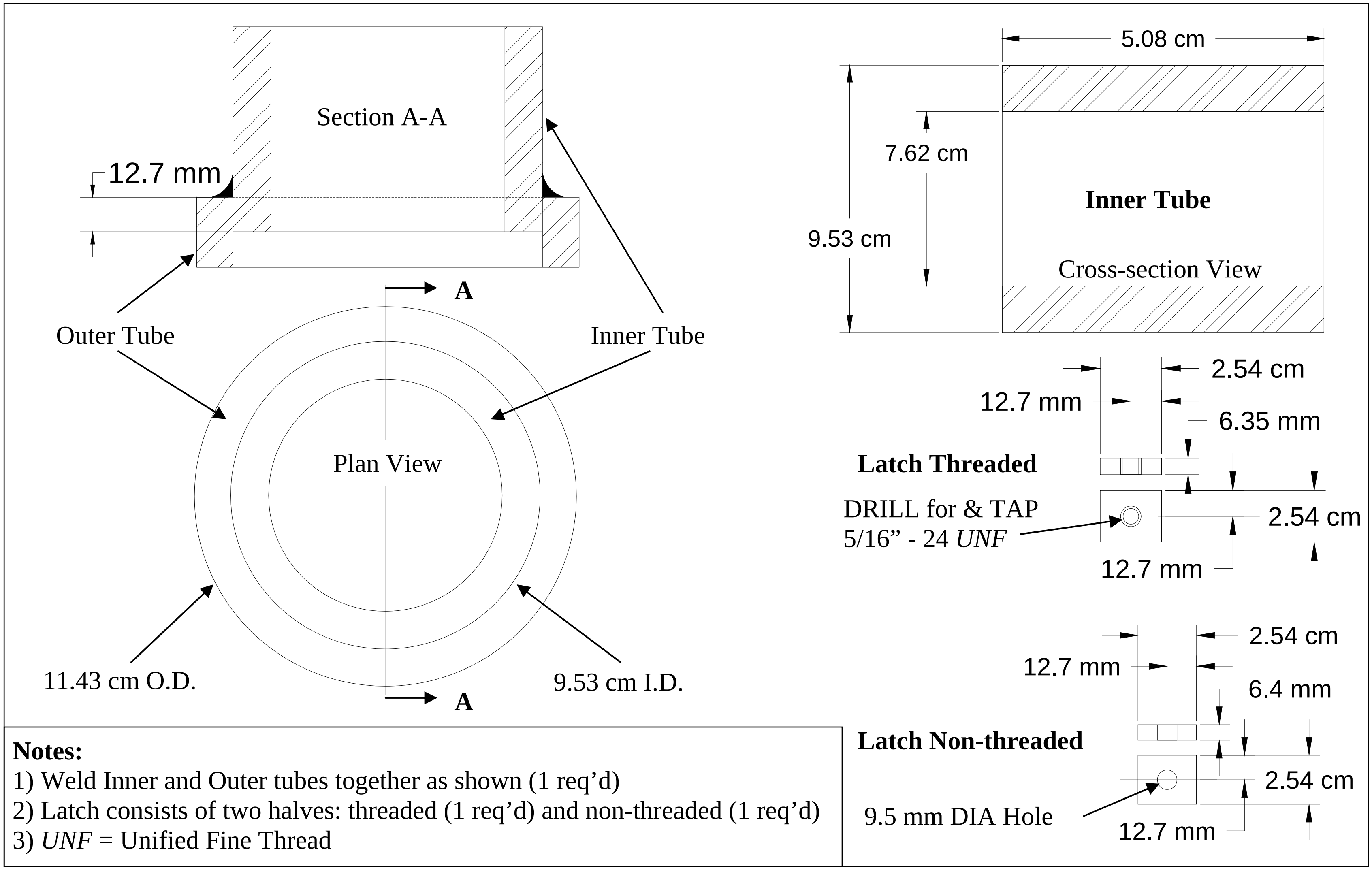
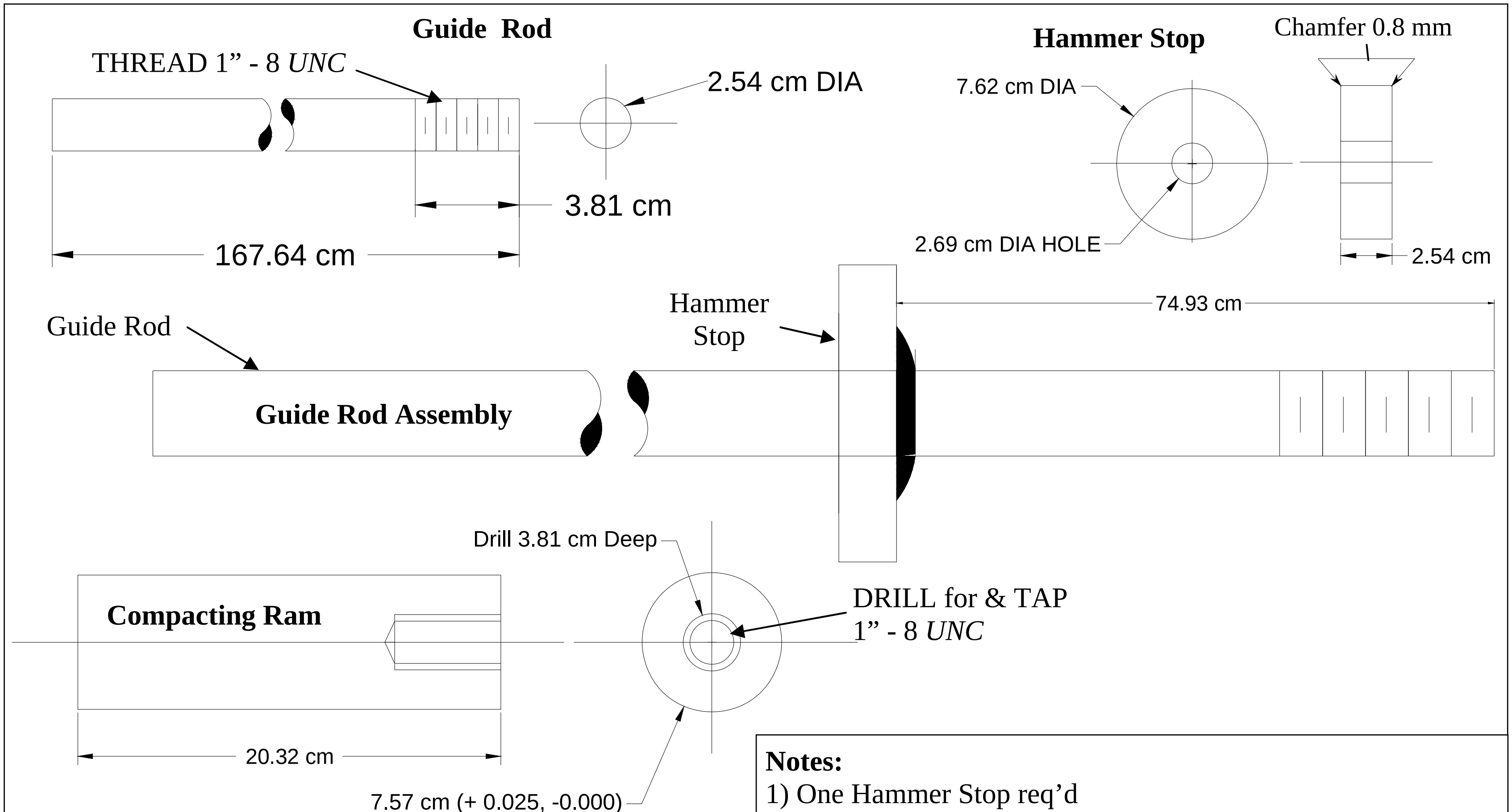
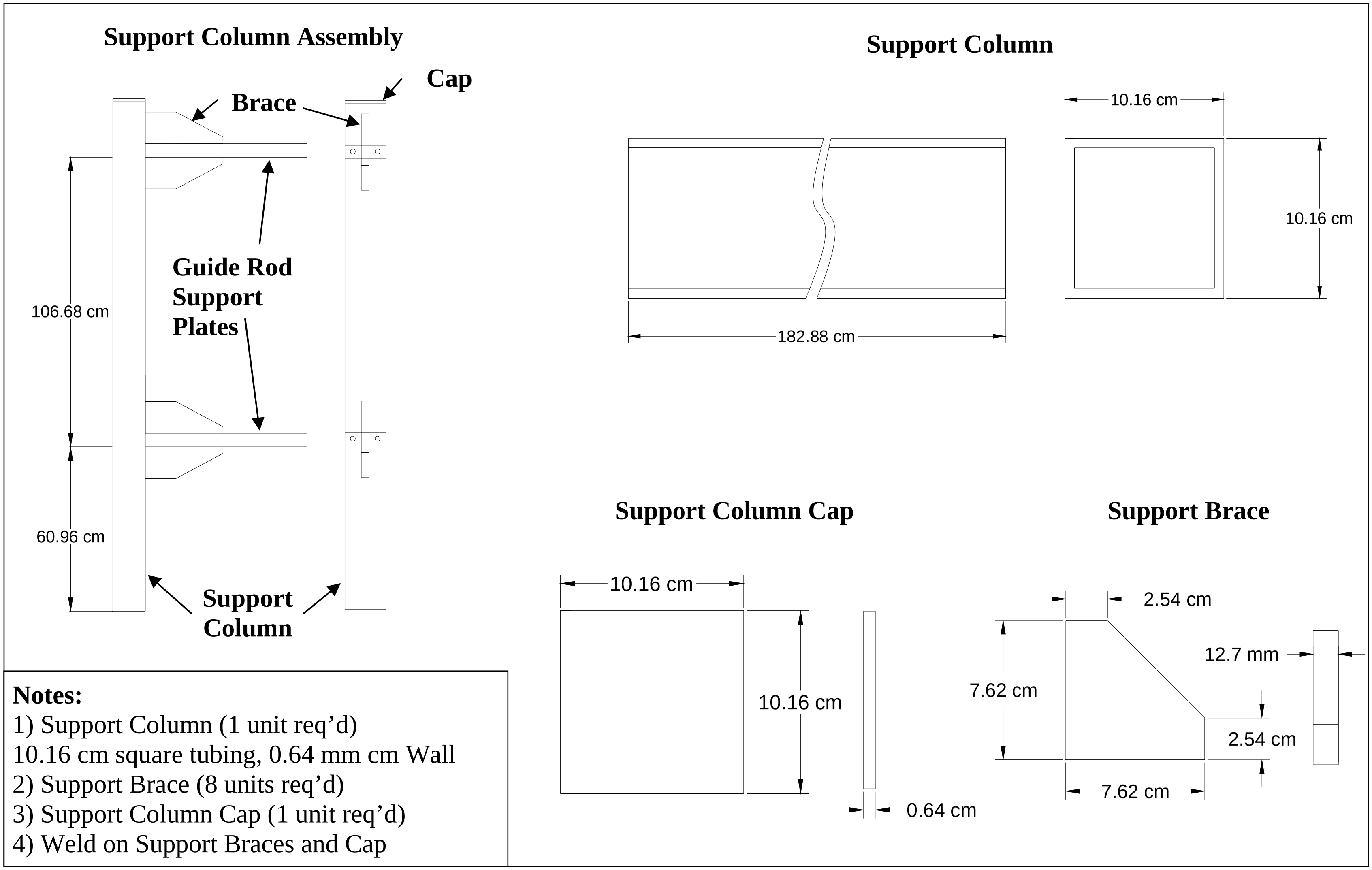


Figure C.4 *PM* Mold Assembly: Guide Collar and Latch



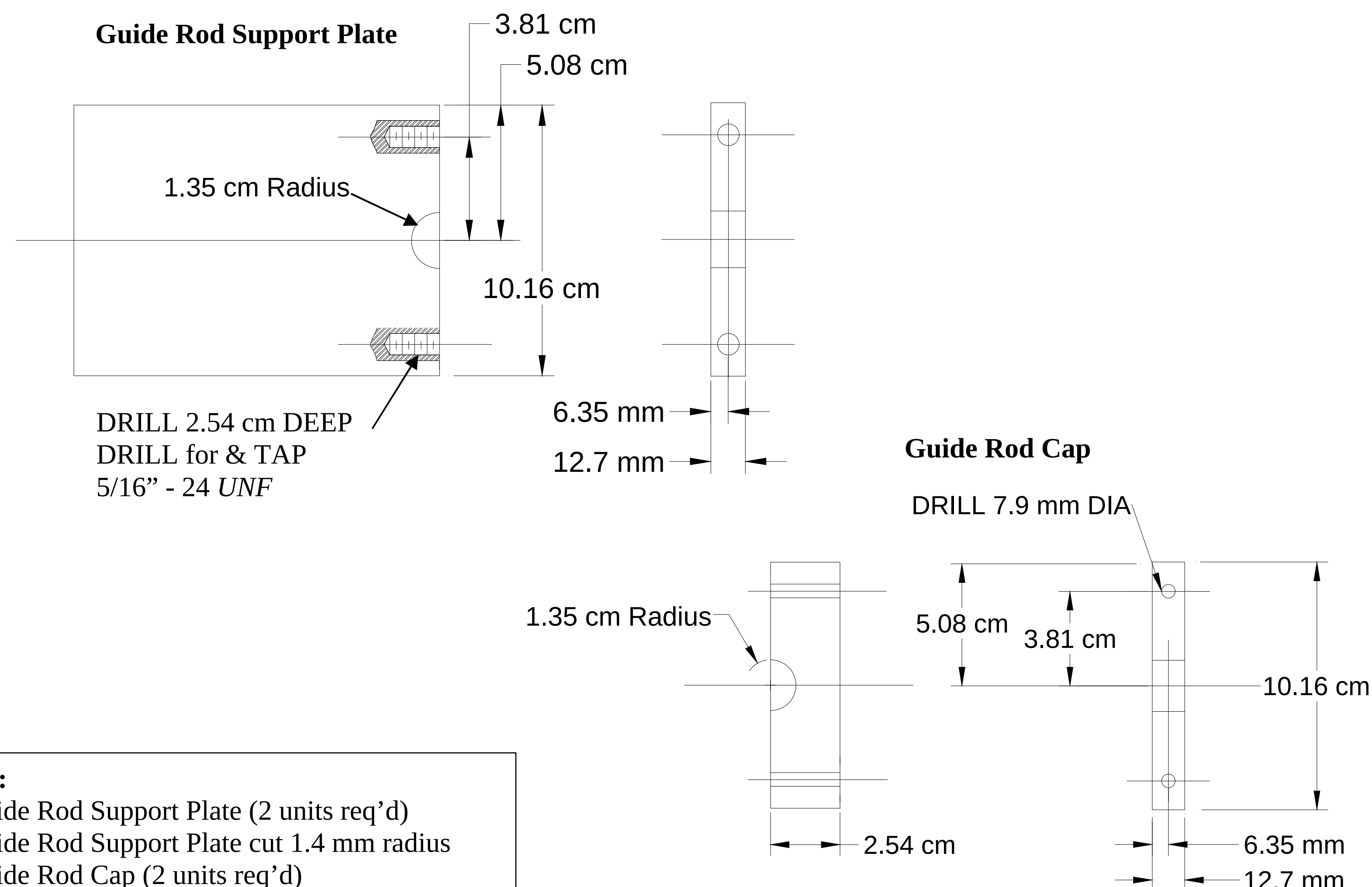
Notes:
1) One Hammer Stop req’d
2) Chamfer both ends of the Guide Rod 0.8 mm x 45°
3) Weld Hammer Stop as shown (Robust Weld)
4) One Guide Rod Assembly and one Compacting Ram req’d
5) *UNC* = Unified Coarse Thread

Figure C.5 *CF* Guide Rod Assembly



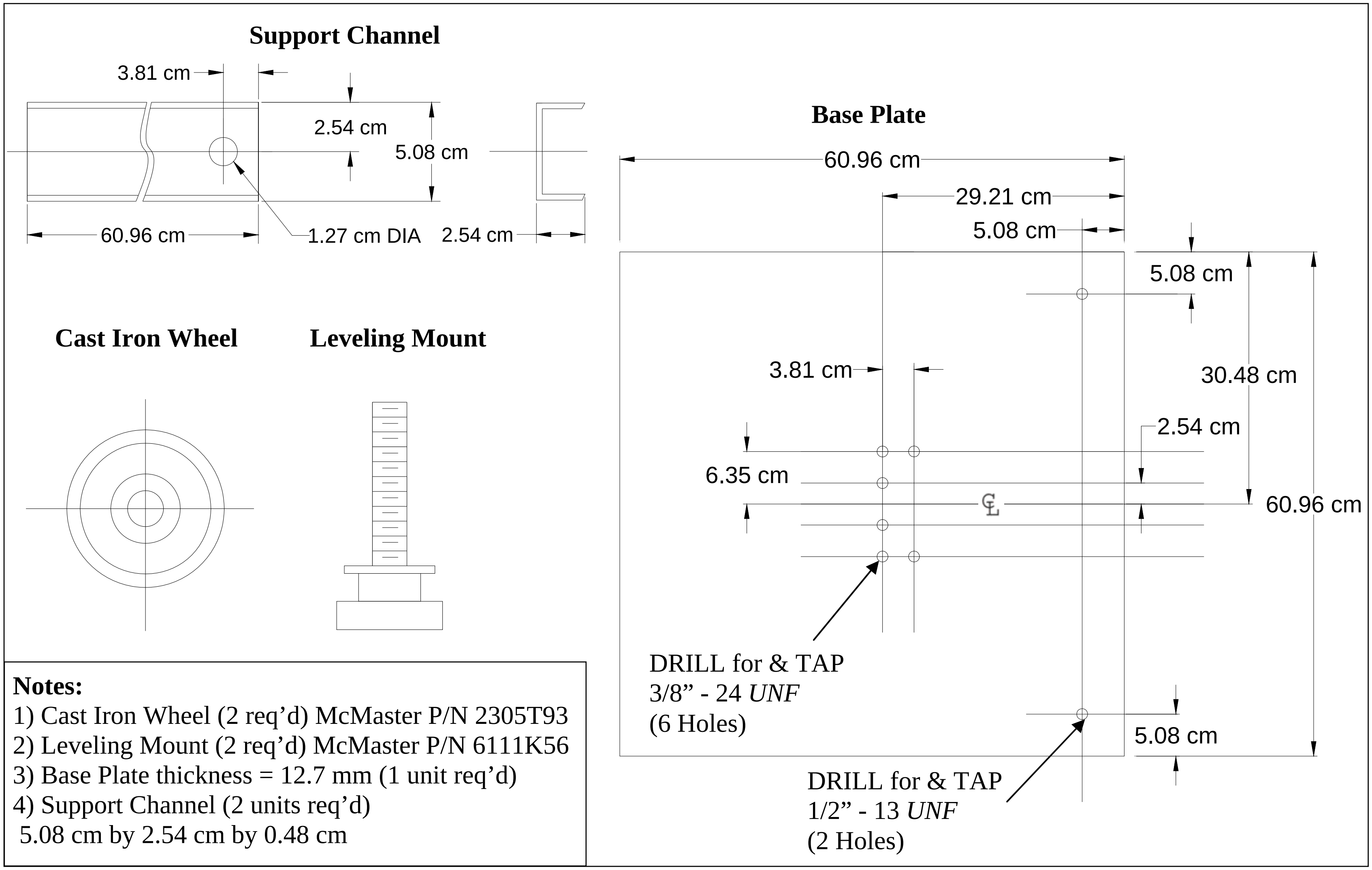
Notes:
1) Support Column (1 unit req'd)
10.16 cm square tubing, 0.64 mm cm Wall
2) Support Brace (8 units req'd)
3) Support Column Cap (1 unit req'd)
4) Weld on Support Braces and Cap

Figure C.6 *CF* Support Column Assembly (1 of 2)



Notes:
1) Guide Rod Support Plate (2 units req'd)
2) Guide Rod Support Plate cut 1.4 mm radius
3) Guide Rod Cap (2 units req'd)

Figure C.7 *CF* Column Support Assembly (2 of 2)



Notes:
1) Cast Iron Wheel (2 req'd) McMaster P/N 2305T93
2) Leveling Mount (2 req'd) McMaster P/N 6111K56
3) Base Plate thickness = 12.7 mm (1 unit req'd)
4) Support Channel (2 units req'd)
5.08 cm by 2.54 cm by 0.48 cm

Figure C.8 *CF* Base Assembly (1 of 2)

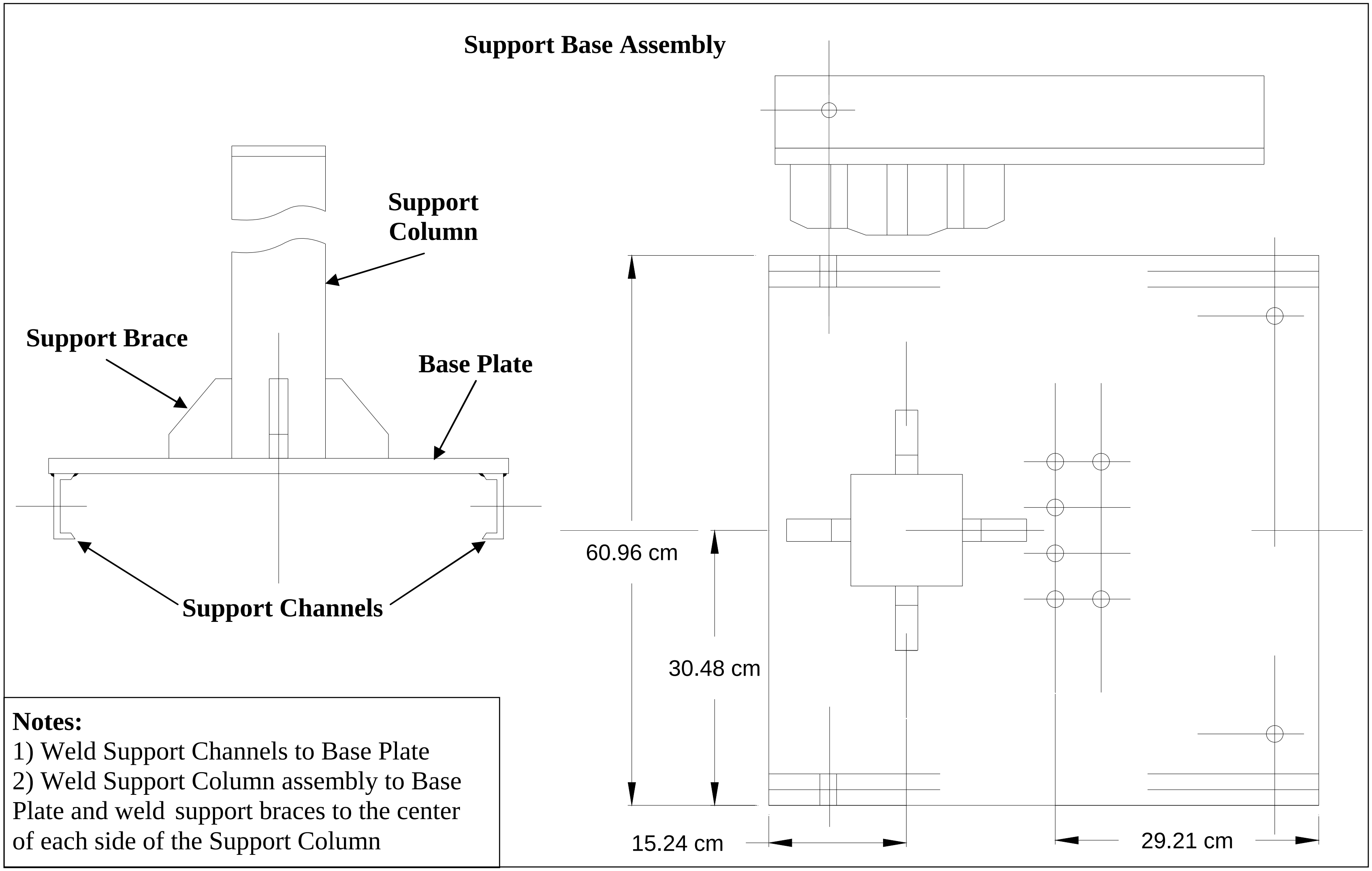


Figure C.9 *CF* Base Assembly (2 of 2)

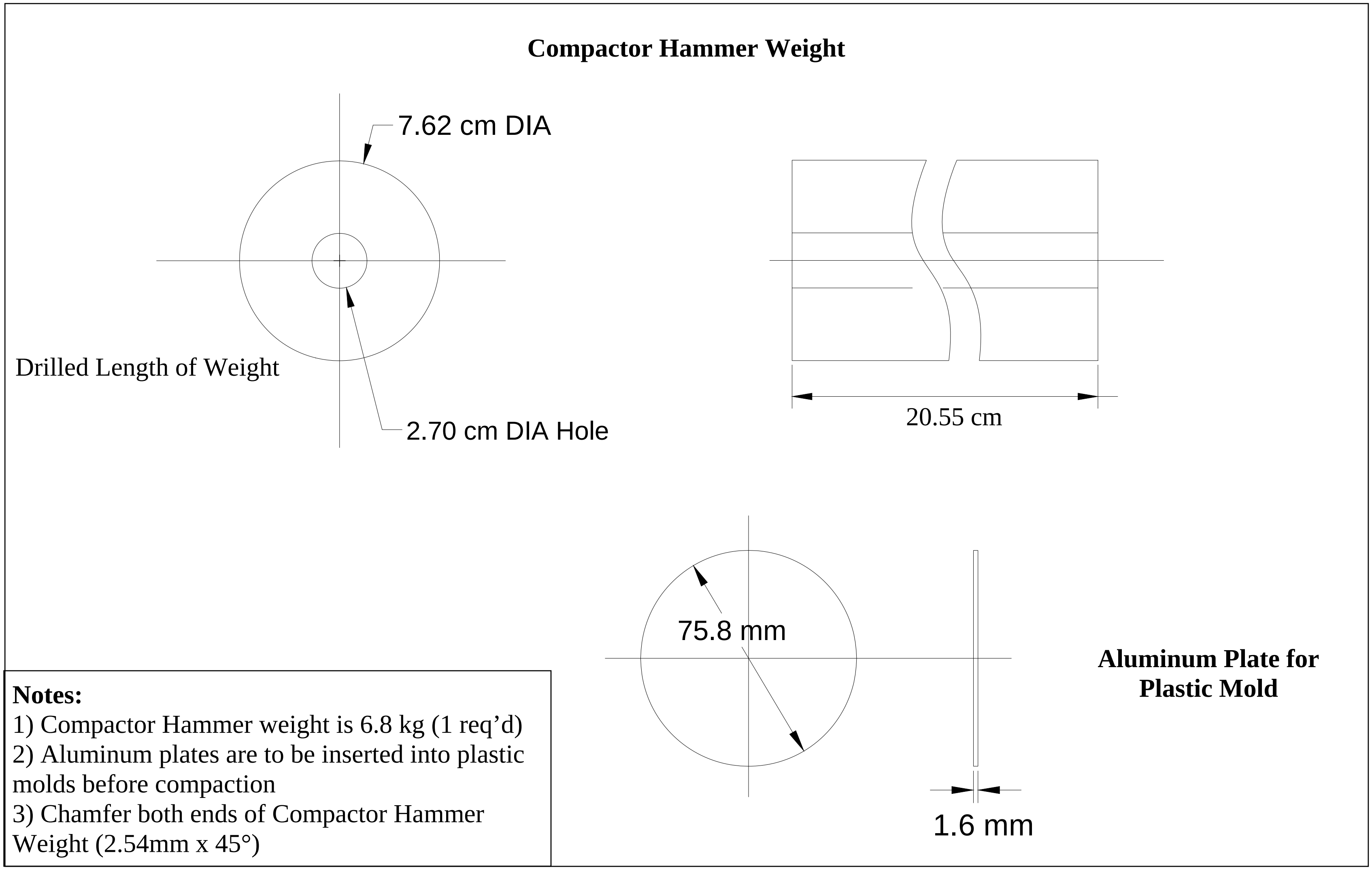


Figure C.10 *CF* Compactor Hammer Weight and Aluminum Plates

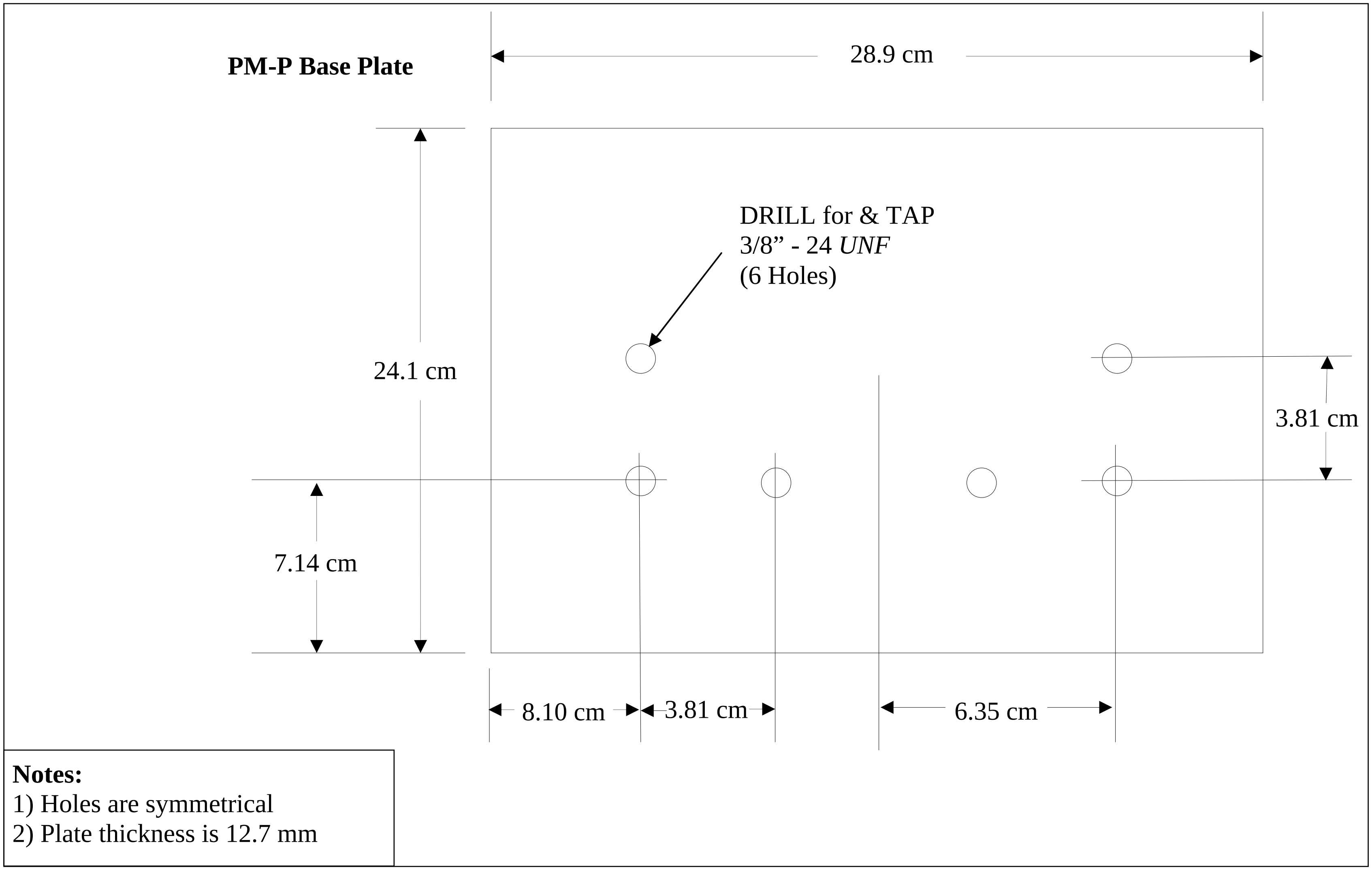


Figure C.11 *PM-P* Compaction Plate