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Evaluation of laboratory and field techniques to improve portland cement concrete performance

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Evaluation of laboratory and field techniques to improve portland cement concrete performance

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ABSTRACT

This dissertation is presented as a compilation of five papers, four submitted, or to be submitted, to scholarly journals, and one submitted to a peer reviewed conference. Each paper is presented as a chapter in the dissertation and includes a short literature review, research data, significant findings, and references. A general conclusion section follows the main body of the dissertation and summarizes the significant research findings from each paper and includes recommendations for further research.

The first paper presents a paste and concrete laboratory study investigating the two-stage mixing process and its effects on portland cement concrete mix consistency and concrete performance. In the paste study, mixing energy was varied to determine the effects on rheological and compressive strength properties. The concrete study investigated the two-stage mixing process and its effects on fresh and hardened concrete properties.

The second paper details a new characterization procedure for portland cement using the heat signature. The first fifteen minutes of the heat generation curve are of particular interest. A Type I/II portland cement was used to determine the effects of initial water and initial cement temperature on the heat signature of the paste. Several other portland cements, including blended cements, were also investigated to show the differences in cement chemistry when comparing the heat generation curves.

The third paper investigates the effects of differing air entraining agent (AEA), water reducing agents, and supplementary cementitious materials (SCM) on the air void structure of fresh mortar samples. This study was conduced as part of a larger study investigating ternary mix designs. The air void analyzer (AVA) was used to document the air void structure and identify anomalies or incompatible material combinations. Cubes were cast for compressive strength testing at seven days to show incompatible combinations in terms of retarded strength gain.

The fourth paper uses AVA data from a sixteen state pooled fund study to evaluate the AVA usage and sampling locations. Samples were obtained from the slip formed concrete surface behind the paver on vibrators and between vibrators from sixteen states.

AVA samples were obtained before the paver on three states. Statistical analysis (t-test) was conducted at an alpha level of 0.05 to determine significance.

The fifth paper presents data on the heat signature of ternary mixes. Fresh mortar samples were prepared and placed into 4 inch by 8 inch cylinder with a thermocouple wire and then placed into a curing chamber at 70°F for 24 hours. The heat signatures were characterized and the results were modeled using slope 1 and slope 2, maximum temperature, time to maximum temperature, area under the heat signature curve, initial set, and final set.

CHAPTER 1. GENERAL INTRODUCTION

Overview

Concrete is the worlds' most used and versatile construction material and is composed of: (1) coarse aggregate, (2) fine aggregate, (3) cementitious materials, (4) water, and (5) admixtures. Concrete is generally produced by mixing the coarse and fine aggregate with an admixture such as air entraining agent and water and then adding the portland cement and further mixing for about 60 – 90 seconds. Many variations on the specific batching sequence exist when comparing between a dry batch, wet batch, central plant, and ready mix concrete production plants.

Lime based hydraulic cements were used for concretes as early as 7,000 BC (Brown 1996). John Smeaton invented the concept of "natural hydraulic cements in 1756 (Mindess, Young, and Darwin 2002). Invention of the process of making portland cement is generally credited to Joseph Aspdin in 1824, in which he named the material after the Isle of Portland (Aspdin 1824). Natural hydraulic cements have been used construction of the Erie Canal in 1818 (Snell and Snell 2000) and the US throughout most of the early 19th century. The US imported its first barrels of portland cement in 1868, and David Saylor was producing portland cement by 1875. By 1885 the US was producing all of its own portland cement (Harakal 2007). Natural pozzolans such as calcined clays and shale have been in use for thousands of years and excellent historical summaries are readily available in the literature (Abdun-Nur 1961; Mielenz 1983; Helmuth 1987; Lea 1971; Massazza 1998).

With the current global demand for portland cement on the rise, and the need for long-life pavements and structures, engineers have looked to alternative binders such as fly ash, silica fume, ground granulated blast furnace slag (GGBFS), metakaolin and rice husk ash to increase pavement durability while lowering life-cycle cost. The rise in demand for portland cement has also created a demand for longer-lasting, more cost effective, durable concrete pavements and structures. Advances have been made in obtaining said durable concrete, including incorporation of supplementary cementitious materials (SCMs), improved mix designs and construction techniques, and improved testing methods.

Supplementary cementitious materials, such as fly ash, ground granulated blast-furnace slag, and silica fume, have become common parts of modern concrete practice (PCA 2002; Transportation Research Board 1990). The blending of two or three cementitious materials to optimize durability, strength, or economics provides owners, engineers, materials suppliers, and contractors with substantial advantages over mixtures containing only portland cement. However, these advances in concrete technology and engineering have not been adequately captured in the specification of concrete. Use of SCMs is often curtailed because of prescriptive concerns or historical comparisons about how such materials should perform. In addition, supplementary cementitious materials can exhibit significant variation in chemical and physical properties, both within a given source and, more commonly, between sources. Hence, current literature contains contradictory reports concerning the "optimal use" of supplementary cementitious materials. Attributes to using SCMs may include: improved workability, decreased chloride permeability, decrease in heat generation, and increased long-term strength.

Currently, advances are being made in other areas of concrete pertaining to mixing procedures, mix design, and testing on both the fresh and hardened concrete. Mixing procedures are being evaluated to determine optimum mixing time and batching sequences. Reduced mixing time will lead to increased production rates, lowering the initial cost of concrete construction. Mix design advancements include incorporating SCMs in ternary and quaternary mixes to provide a cost effective and more durable concrete. Other mix design advancements include adjusting the aggregate gradations to provide more durable and workable concrete mixes. Fresh concrete testing advances include the Air Void Analyzer (AVA) for testing the air void structure on fresh, or plastic concrete, and several new calorimeters to measure heat generation. Advances in hardened concrete testing include more rapid methods in the determination of the hardened concrete air void structure.

Other advances in concrete pavement construction and concrete materials usage include investigation of two-lift pavement construction where the lower lift, bottom 6 – 8 inches, utilizes lower quality materials, such as recycled concrete aggregate, and premium quality materials, virgin aggregate, are used in the upper lift of 2 – 4 inches. This construction procedure makes the best use of the ever decreasing supply of exceptional quality materials. Another advance in concrete materials includes the incorporation of engineered nano-materials. Nanotechnology has the potential to greatly enhance the durability of concrete pavement and concrete structures as well as drastically change the intrinsic properties. Nano-fibers have the potential to prevent cracking of concrete on the micro or nano level. Nano-capsules have the potential to "heal" concrete when cracks do occur across a capsule filled with an epoxy or other binding agent. This area of research will become more prevalent in the coming years.

Objectives and Scope

The primary objectives of this research were: (1) to investigate portland cement concrete mix consistency and concrete performance using a two-stage mixing method; (2) to investigate a new method for characterization of portland cements using the early heat generation; (3) to investigate the effects of different air entraining agents (AEA), SCM, and water reducing (WR) agents on the air void structure of fresh mortar; (4) to compare and evaluate the results from the AVA when using differing sampling locations, and (5) to characterize and model ternary mixes using the heat signature.

A laboratory testing program consisting of a paste and concrete study was implemented for the first research objective. Paste study specimens included paste cubes produced using ASTM C 109 for compressive strength at 7, 14, 21, and 28 days for differing mixing energies. Rheology testing was completed on freshly mixed pastes at differing mixing energies. Concrete testing included slump and air content on fresh concrete samples. Hardened concrete analysis included compressive strength at 3, 7, and 21 days, tensile strength at 56 days, and rapid air void analysis.

Several differing cements in the laboratory and two in the field were tested using a thermocouple to determine the early heat generation characteristics. Cements were characterized by their chemical composition and then compared to their corresponding early heat generation curves. Type I/II cement was tested at differing initial water and differing initial cement temperatures to determine the effect of initial water and cement temperatures on the heat generation curve.

Ten ternary mix designs consisting of both ordinary portland cement and blended portland cement and SCMs were batched using differing combinations of AEA and WR in the laboratory. The AVA was used to determine and evaluate the air void characteristics of the fresh mortar samples. Mortar cubes were cast for compressive strength testing at 7 days. The AVA and compressive strength results were used to identify potential incompatibility issues.

The AVA results from a sixteen state pooled fund study were analyzed in regards to sampling locations of before the paver, after the paver on a vibrator, and after the paver between vibrators. T-tests were conducted to determine the significance of the results. The effect of state mix design on the fresh concrete air void structure was also analyzed.

About 120 ternary mixture combinations were tested for the heat signature in laboratory conditions. Fresh mortar samples were tested using thermocouples in a semi-adiabatic condition for 24 hours. The results were analyzed to characterize and model ternary mixes using the heat signature.

Organization

This dissertation is presented as a compilation of five papers, four submitted, or to be submitted, to scholarly journals, and one submitted to a peer reviewed conference. Each paper is presented as a chapter in the dissertation and includes a short literature review, research data, significant findings, and references. A general conclusion section follows the main body of the dissertation and summarizes the significant research findings from each paper and includes recommendations for further research.

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The appendix consists of five sections. Appendix A presents tabulated data obtained from rheology and compressive strength testing. Appendix B provides tabular data from the quick heat generation tests. Appendix C provides the laboratory AVA data set and compressive strength data sets in tabular form. Appendix D provides the AVA data from the sixteen state pooled fund study in tabular form. Appendix E presents the laboratory heat generation data for the selected mixes in tabular form.

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CHAPTER 2. INVESTIGATION OF PORTLAND CEMENT CONCRETE MIX CONSISTENCY ON CONCRETE PERFORMANCE USING A TWO-STAGE MIXING PROCESS

A paper published in the *Transportation Research Record*

Tyson Rupnow, Vernon Schaefer, Kejin Wang, Benjamin Hermanson

Abstract

The objectives of this study were to determine the effects of different mixing processes, particularly a two-stage mixing process, on fresh and hardened characteristics of pastes and concrete. Characteristics studied for pastes included rheological effects (i.e. yield stress, thixotropy, viscosity, and peak stress) and compressive strength for mixes prepared in a Hobart mixer and a high shear mixer. Parameters measured for the concrete study included: fresh concrete air and slump, compressive strength, and hardened concrete air void characteristics. The paste study results show that for increased mixing time the compressive strength is not significantly influenced. The rheology results show that longer mixing times with a high shear mixer lead to lower viscosity, thixotropy, and peak stress indicating better mixed slurry when compared to a shorter mixing time and the Hobart mixer. The fresh concrete made with the two-stage mixing process shows reduction in air content, and the hardened concrete shows little change in compressive strength when compared with the concrete produced with the one-step mixing process. Rapid air void analysis results indicate that the two-stage mixing method may be beneficial for mixes containing Portland cement as a sole binder in freeze-thaw durability.

Introduction

Conventional mixing methods for Portland cement concrete (PCC) have not changed much in several decades. Currently mixing methods are driven by both quality and economics. Quality is ensured by the proper mixing time and economics is driven by the shortest mixing time allowable to produce a homogeneous concrete mixture that provides proper distribution and hydration of all cement particles. Without proper mixing, agglomeration of fine cementitious particles may occur, especially in concrete mixtures made with fine cementitious materials, low water-to-binder ratios, and high binder contents. Such fine cementitious particle agglomerations reduce the workability and uniformity of the resulting concrete.

Many studies have been conducted to relate concrete quality to mixing efficiency. Gaynor (1) studied the influence of concrete mixers and noted that non-uniformity in truck mixed concrete is caused by agglomerations of cementitious materials inside the truck, and suggested adding one-fourth of the mixing water as the last ingredient. Several studies investigated the effects of mixing time. Beitzel (2), Cable and McDaniel (3), and Kirca *et al*. (4) have shown that the optimum mixing time is different for the different concrete properties measured and that a minimum of 60 seconds mixing time for all mixers is sufficient for specified concrete performance.

The two-stage mixing method has the potential to reduce mixing time and increase concrete strength performance leading to a lower water demand for cementitious materials. The reduced mixing time is realized when the paste or mortar is premixed at the concrete plant and the coarse aggregates are added in a mixer truck with the premixed mortar and mixed in route to the job site. The lower demand for cementitious materials, combined with a reduced mixing time leads to more cost efficient concrete for both the producer and owner.

Two-stage mixing is increasingly used in concrete practice. In a two-stage mixing process, the combination of cement and water form a slurry, or the cement-water and sand form a mortar. The resulting slurry, or mortar, is then added to the coarse aggregate in a barrel or truck mixer. The flow characteristics of the paste or mortar are dependent upon the mixing energy and characteristics of the aggregates. Rejeb (5) completed a study comparing the compressive strength and slump test results of a two-stage mixing process to concrete produced using normal mixing methods. The results showed that two-stage mixed mortar had the highest compressive strengths followed by two-stage mixed paste, and the normal mixing had the lowest strengths (5). Pope and Jennings (6) noted that the microstructure and paste-aggregate bond were improved using two-stage mixing by limiting the amount of direct contact of water to the aggregate during mixing, and 28-day compressive strengths of samples prepared using two-stage mixing were greater than the normal mixed concrete samples.

The objectives of this study were to determine the effects of different mixing processes on both fresh and hardened paste samples, and determine fresh and hardened characteristics of concrete produced using the two-stage mixing process. The study is divided into two parts: paste, or slurry, and concrete. Parameters measured during the paste study were rheological effects (i.e., yield strength, thixotropic area, and yield stress) and compressive strength. Concrete properties measured included: slump, air content, compressive strength, and air void structure.

Materials and Test Methods

Paste Study

Materials

The materials used for the paste study included: Type I Portland cement (PC), class C fly ash (FA), and grade 120 ground granulated blast furnace slag (GGBFS). Table 2-1 shows the chemical composition of the materials used throughout this study. Table 2-2 shows the mix designs considered with their respective water to cementitious materials (w/cm) ratio. Since the high shear mixing process was of most interest, mix number 1 was the only mix completed using the Hobart mixer.

Mixing Methods

Pastes were mixed on speed one (140 rpm) and two (285 rpm) for 15, 30, 45, and 60 seconds for both the Hobart mixer (ASTM C 305) and the Warring blender high shear mixer. The quantity batched at one time was about 1.6 liters. The Hobart and Warring blender had capacities of 4.73 and 4 liters, respectively. The high shear mixer speed one and two had revolutions per minute of 6,000 and 14,000 respectively and resembled a large kitchen blender.

Table 2-1. Chemical Composition of PC, GGBFS, and FA

		PC	GGBFS	FA
Chemical Composition	CaO	64.24	37.09	27.85
	SiO_2	20.8	36.79	34.23
	Al_2O_3	5.55	9.2	18.91
	Fe_2O_3	2.25	0.76	5.54
	MgO	1.91	9.5	-
	K_2O	0.5	0.41	-
	Na_2O	0.19	0.34	-
	SO_3	2.96	-	2.68
	TiO_2	0.26	0.44	-
	P_2O_5	0.48	0.02	-
	SrO	0.05	0.04	-
	Mn_2O_3	0.05	0.55	-
	S	-	1.07	-
Fineness (m^2/kg)		399	534	*12.44%

***% Retained on #325 sieve**

Table 2-2. Slurry Proportions by Volume

Mix Number	PC	FA	GGBFS	w/cm
1	100%	0%	0%	0.43
2	85%	15%	0%	0.44
3	65%	35%	0%	0.46
4	65%	0%	35%	0.44
5	50%	15%	35%	0.45

<u>Test Methods</u>

Rheology samples prepared as above were immediately transferred into a 3 in x 6 in (75 mm x 150 mm) cylinder for testing using a Brookfield R/S SST 2000 soft/solid rheometer. Rheometer results were obtained through the use of a 40 mm x 80 mm four bladed vane with the exception of the Hobart mixer on speed one. The material for the Hobart mixer on speed one exceeded the maximum shear stress capabilities of the rheometer; therefore these data were collected using a 15 mm x 30 mm four bladed vane.

Compression strength samples were prepared as stated in the mixing methods section, and three 2 in. x 2 in. (50 mm x 50 mm) cubes were prepared for testing at 3, 7, 14, and 28 days for all mixtures investigated. Samples were demolded after 24 hours and placed a fog room at 73°F (23°C) until testing according to ASTM C 511 (7).

Concrete Study

Materials

After the paste study, three concrete mix designs, (Mixes 1, 2, and 3) were selected to determine the effects of two-stage mixing on fresh and hardened concrete properties. The slurries used in concrete mixes 1, 2, and 3 corresponded to paste study mixes 1, 2, and 5. Natural river sand and crushed limestone were used for the fine and coarse aggregate, respectively at a ratio of 50:50 coarse to fine aggregate by volume. The fine aggregate had a fineness modulus and absorption of 2.90 and 1.1% respectively, and the coarse aggregate had absorption of 3.2%. Table 2-3 shows the batch weights for the concrete study. A liquid air entraining agent, Daravair 1400, was used.

Table 2-3. Concrete Mix Design Proportions

Concrete Mix Number	PC lbs/yd^3 (kg/m^3)	FA lbs/yd^3 (kg/m^3)	GGBFS lbs/yd^3 (kg/m^3)	Coarse Aggregate lbs/yd^3 (kg/m^3)	Fine Aggregate lbs/yd^3 (kg/m^3)	Water lbs/yd^3 (kg/m^3)	w/cm
Concrete 1	624.5 (283.3)	--	--	1,449.2 (657.5)	1,467.2 (665.7)	268.0 (121.6)	0.43
Concrete 2	530.8 (240.8)	76.7 (34.8)	--	1,449.2 (657.5)	1,467.2 (665.7)	268.0 (121.6)	0.44
Concrete 3	312.2 (141.7)	76.7 (34.8)	203.9 (92.5)	1,449.2 (657.5)	1,467.2 (665.7)	268.0 (121.6)	0.45

***AEA was added at the rate of 21 oz/yd^3 (607 ml/m^3)**

Mixing Methods

For the concrete study, three mixing procedures were investigated using a drum mixer:

1. Control mixing procedure – the fine and coarse aggregate were mixed with the water together with AEA for 15 seconds. Next the binder(s) were added and

mixing commenced for 60 seconds. During this mixing process, the time for cement to contact with water was 60 seconds.

2. Two–stage mixing with 30 second batch – the cementitious material-water-AEA paste slurry was prepared according to ASTM C 305 (8) deviating from ASTM C 305 though the use of a wire whip to ensure high shear mixing of the slurry. The coarse and fine aggregates were batched in the drum mixer and the slurry was then added and mixed for 30 seconds. During this mixing process, the time for cement to contact with water was 2 minutes and 45 seconds.
3. Two–stage mixing with 60 second batch – the cementitious material-water-AEA paste slurry was prepared according to ASTM C 305 (8) deviating from ASTM C 305 though the use of a wire whip to ensure high shear mixing of the slurry. The coarse and fine aggregates were batched in the drum mixer and the slurry was then added and mixed for 60 seconds. During this mixing process, the time for cement to contact with water was 3 minutes and 15 seconds.

Test Methods

Immediately after mixing, fresh concrete properties of slump (ASTM C 143) (9) and air content (ASTM C 231) (10), were measured. Fifteen 4 x 8 inch (100 mm x 200 mm) cylinders were cast and placed into a fog room at 73°F (23°C) and 95% relative humidity for 24 hours. The specimens were then demolded and cured according to ASTM C 511 (7). Hardened concrete properties investigated included: compressive strength (ASTM C 39/C 39M) (11) at 3, 7, and 28 days, tensile strength (ASTM C 496) (12) at 56 days, and rapid air void analysis at 28 days.

The rapid air test was completed on samples 3 x 4 inches (76 x 100 mm) obtained from the center of the sample. The rapid air test is an automated image analysis system that performs an analysis of the hardened air void system according to ASTM C 457 (13). The samples are cut, polished, and then prepared using a surface enhancement technique where the final result is a black surface with white air voids. The analysis includes: volume of air

(%), specific surface, and spacing factor. Other items are included in the analysis, but are beyond the scope of this study.

Results and Discussion

Paste Study

Rheology

The rheological properties measured in this study were yield stress, viscosity, thixotropic area, and peak shear stress. The rheology results show a general decrease in peak shear stress with increased amounts of supplementary cementitious material's (SCM). This indicates that less force is required for a given deformation of the paste containing more SCM, which is to be expected since the increase in SCM improves workability. Figure 2-1 shows the yield stress data as a function of mixing speed and time. Note the decrease in yield stress with the increased level of SCM replacement. The trend shows a decrease in yield stress as time is increased for mixing speed one, but the opposite is true for mixing speed two. Individual rheology curves and data can be found in Hermanson (14).

The viscosity results are shown in Figure 2-2. The results show decreasing viscosity values with an increase in mixing time and speed. Note that the Hobart mixer produced pastes with a significantly higher viscosity when compared to the high shear mixer. These results agree with the results attained by Williams *et al.* (13) that noted decreased viscosities with increased shear rates.

Figure 2-3 shows the results for the thixotropic area. The thixotropic area is defined as the area between the up and down curve, or hysteresis loop. The data show a decrease in thixotropic area with increased mixing time for both speeds one and two. It is also of importance to note that the thixotropic area of the Hobart mixer is significantly greater than that produced with the high shear mixer. This shows that the energy required to break down the particle bonds is sufficiently less for the high shear mixed samples compared to the Hobart mixed samples.

The results for peak shear stress, Figure 2-4, follow the results for thixotropic area, viscosity, and yield stress. The results show decreasing peak stress with an increase in mixing time for both speeds one and two. Note that the influence of mixing time is not as great on the peak shear stress when comparing the effects of mixing time with the results on viscosity. Also note that the Hobart mixer produces slurry with a greater peak stress compared to the high shear mixer. This agrees with the results obtained by Yang and Jennings (16) noting that an increase in mixing energy causes a greater breakdown of agglomerates, thus leading to a lower peak stress.

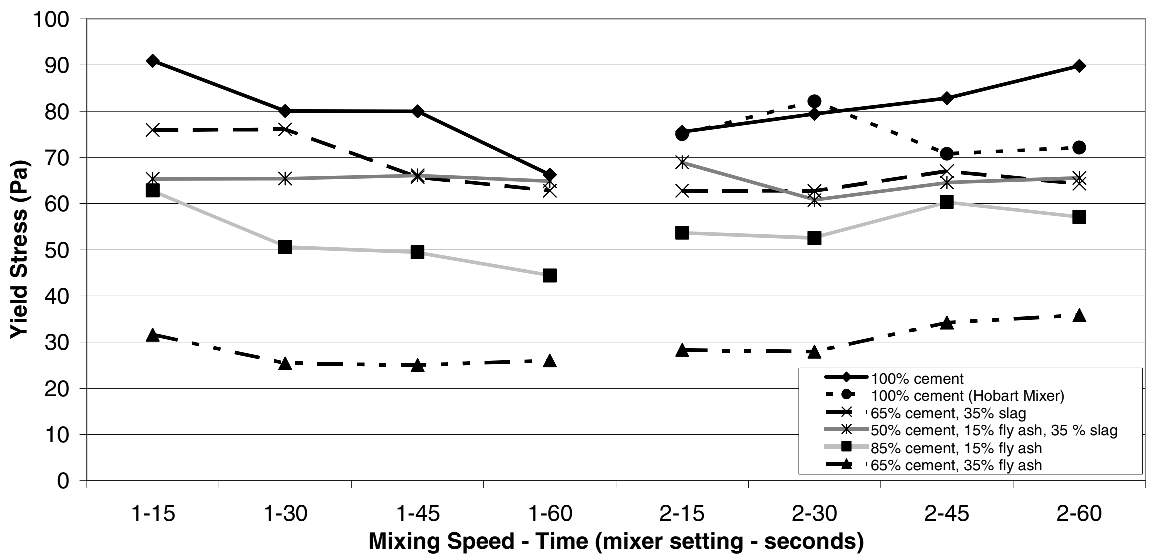

Figure 2-1. Effects of Mixing Speed and Time on the Yield Stress of Slurries Prepared Using the High Shear Mixer

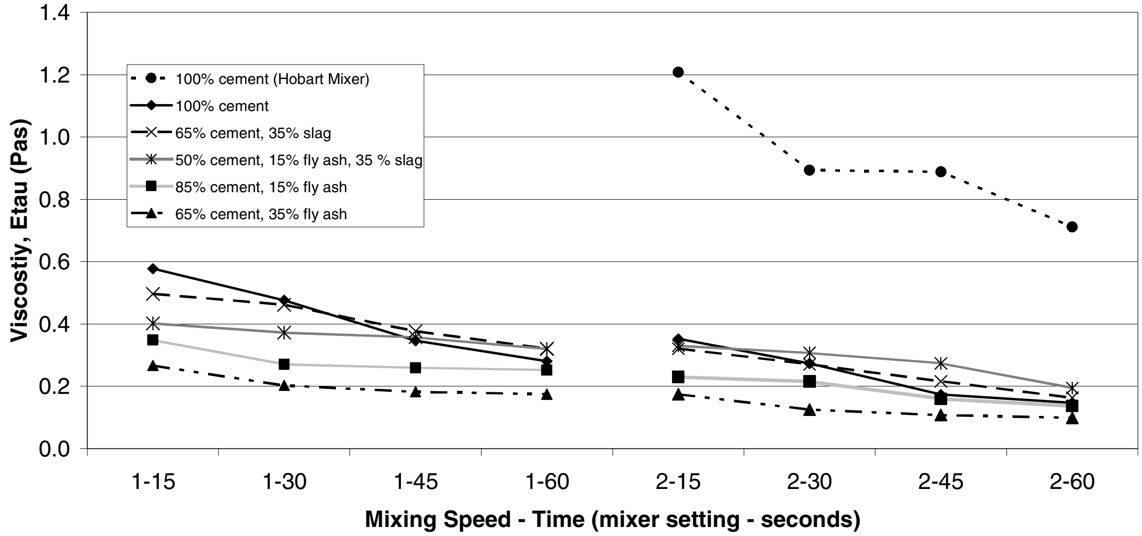

Figure 2-2. Effects of Mixing Speed and Time on Viscosity of Slurries Prepared Using the High Shear Mixer

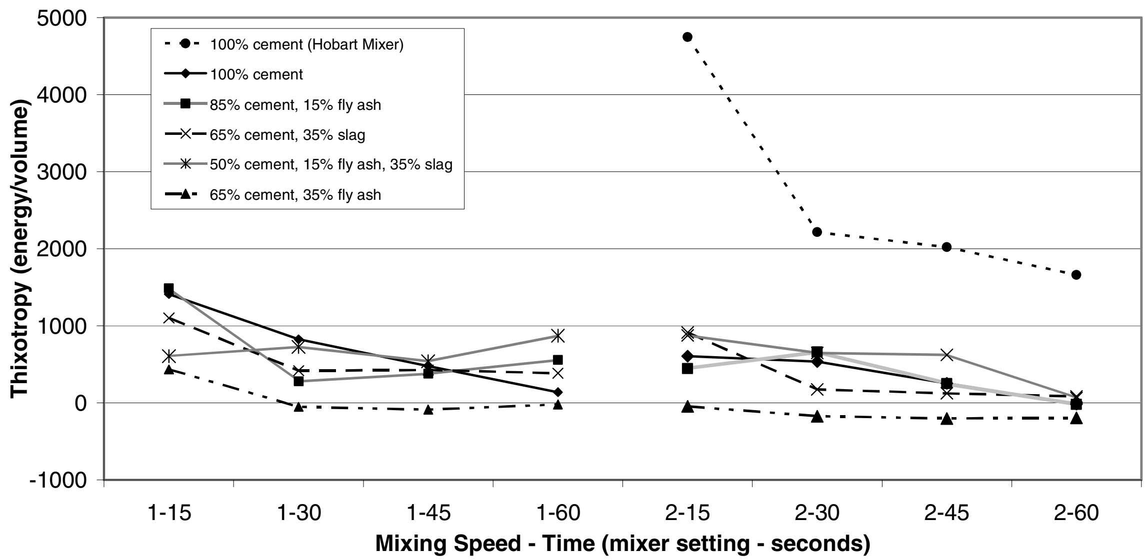

Figure 2-3. Effects of Mixing Speed and Time on Thixotropic Area of Slurries Prepared Using the High Shear Mixer

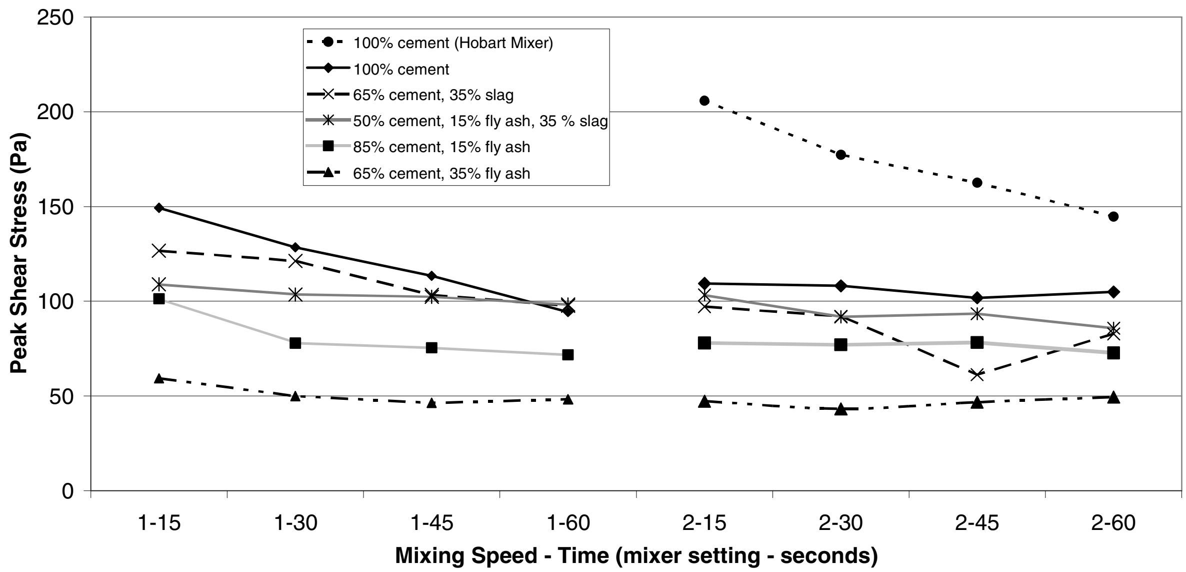

Figure 2-4. Effects of Mixing Speed and Time on Peak Shear Stress of Slurries Prepared Using the High Shear Mixer

The rheology results provide several key points. The most important being that the higher mixing speeds and longer mixing times produced the lowest peak stress values and the lowest mixing speeds and times produced the highest peak stress values. These results point to a more uniform, well-mixed slurry at the higher mixing energies.

Another point is the higher mixing energies producing lower yield stress values. In theory, a lower yield stress value would require less energy to make the material fluid. The lower yield stress allows for faster coating of aggregates in the two-stage mixing process.

The viscosity results show increasing the mixing energy reduces the viscosity, which indicates a greater structural breakdown in the pastes. The thixotropic area results point to a more complete structural breakdown with the increased mixing energy provided by the high shear mixer. The lower viscosities would allow for better and faster coating of aggregate particles in a two-stage mixing process. The thixotropic area results show convergence as the mixing energy is increasing (14). When the mixing energy is increased beyond convergence, optimum mixing energy will be achieved.

Compressive Strength

Table 2-4 shows the effects of mixing time and speed on compressive strength of paste mixed with the Hobart mixer at 3, 7, 14, and 28 days. Note that speed one had to be used for initial mixing due to material loss at speed two. Table 2-5 shows the average compressive strength results for the high shear mixer. The results show the expected increase in compressive strength over time, and the decrease in strength with replacement of PC with supplemental cementitious materials (SCM).

The paste strength results show that the high shear mixer produces higher compressive strengths at early ages. Note that for the high shear mixer, some of the lowest compressive strengths were attained using some of the longer mixing times, in contrast to earlier studies showing that longer mixing times can increase the compressive strength of paste cubes (4). It can be noted that the lowest compressive strengths were produced by speed 1 for each of the mixers with the exception of mix number one in the Hobart. The highest compressive strengths were attained with the higher mixing speed 2 using the high shear mixer.

Maximizing the 28 day compressive strength through the variation of mixing procedures was one of the goals of this study. The results show that for a longer mixing time the compressive strengths do not vary greatly which agrees with results obtained by Kirca *et al.* (4).

Table 2-4. Average Compressive Strengths for the Hobart Mixer for 100% PC Mix 1

	Mixing Speed-Time	Cure Time (Days) and Compressive Strength (psi)			
		3	7	14	28
100% PC	1-15	6508	8774	9166	10318
	1-30	6129	8184	8330	9634
	1-45	6037	7806	9039	9705
	1-60	6111	8118	8359	9109
	1-15, 2-15	6614	7907	8492	10145
	1-15, 2-30	6381	7840	9394	10229
	1-15, 2-45	6487	7857	9556	10106
	1-15, 2-60	6363	8053	9442	10294

***Results are an average of three samples**

Table 2-5. Average Compressive Strengths for the High Shear Mixer for All Mix Designs

	Mixing Speed-Time	Cure Time (Days) and Compressive Strength (psi) 3	7	14	28
100% PC	1-15	7047	8008	9103	10433
	1-30	6881	8062	9735	10252
	1-45	6893	8417	9215	9561
	1-60	6216	8276	8347	9914
	2-15	6721	9325	9845	10162
	2-30	6784	8683	9956	10084
	2-45	6879	8777	9756	9566
	2-60	6175	8271	9140	9732
85% PC – 15% FA	1-15	5507	7231	8101	9554
	1-30	5094	6116	7696	9295
	1-45	5006	5521	8030	8668
	1-60	5434	7513	8419	9261
	2-15	5128	7526	8852	9137
	2-30	5029	5883	8240	9166
	2-45	4965	5668	8014	9561
	2-60	5616	7610	8577	8903
65% PC – 35% FA	1-15	2953	4750	5508	6578
	1-30	2943	5201	6385	6184
	1-45	3056	4638	5631	6490
	1-60	3048	4667	6303	6771
	2-15	2864	4847	5659	6902
	2-30	2997	4489	6356	6967
	2-45	3154	5194	6177	6287
	2-60	3278	5221	6136	6512
65% PC – 35% GGBFS	1-15	4073	6363	8474	10079
	1-30	4142	6380	8250	9251
	1-45	4017	5924	8354	8320
	1-60	3945	6133	7936	9000
	2-15	3960	6099	7970	10294
	2-30	3926	5993	7853	8723
	2-45	3981	5992	7916	8883
	2-60	4422	6563	8409	9780
50% PC – 35% GGBFS – 15% FA	1-15	2290	3859	5562	7423
	1-30	2311	3588	6407	7453
	1-45	2198	3960	5528	7999
	1-60	2152	3818	6245	7461
	2-15	2070	3867	6537	7502
	2-30	2310	3881	6168	7613
	2-45	2500	4123	5480	7692
	2-60	2617	4237	6627	8208

***Results are an average of three samples**

Concrete Study

Air and Slump Test

Fresh concrete properties are important to a contractor for ease of placement and finishing. It is important to ensure proper air entrainment, as well as the desired workability to achieve a durable concrete. The air test results are shown in Figure 2-5, which indicate a drop in air content for the two-stage pre-mixed concrete samples. This is due to the limited ability of the fine binder materials to entrap air during the slurry mixing.

Figure 2-6 shows the results for the slump test. For Mix 1 (100% PC), a decrease in slump occurs with the two-stage mixing compared to the conventional mixing. This decrease in slump may be related to increased degree of cement hydration in the two-stage mixing process, in which the time for cement to contact water was 2 minutes and 45 seconds. The slump results show the anticipated increase in slump with addition of fly ash or fly ash-slag replacement, and it is important to note that the slump generally increases with increased mixing energy for those mixtures with SCM. The slump and air tests were conducted immediately after mixing, and the cylinder samples were finished about 15 minutes after water contact with cement.

Compressive Strength

The compressive strength was measured at 3, 7, and 28 days to determine the effects of the two-stage mixing process on compressive strength development. The compressive strength development over time for Mixes 1, 2, and 3 are shown in Figure 2-7a, b, and c, respectively. Note that the expected decrease in early age compressive strength due to addition of SCM is apparent when comparing between figures.

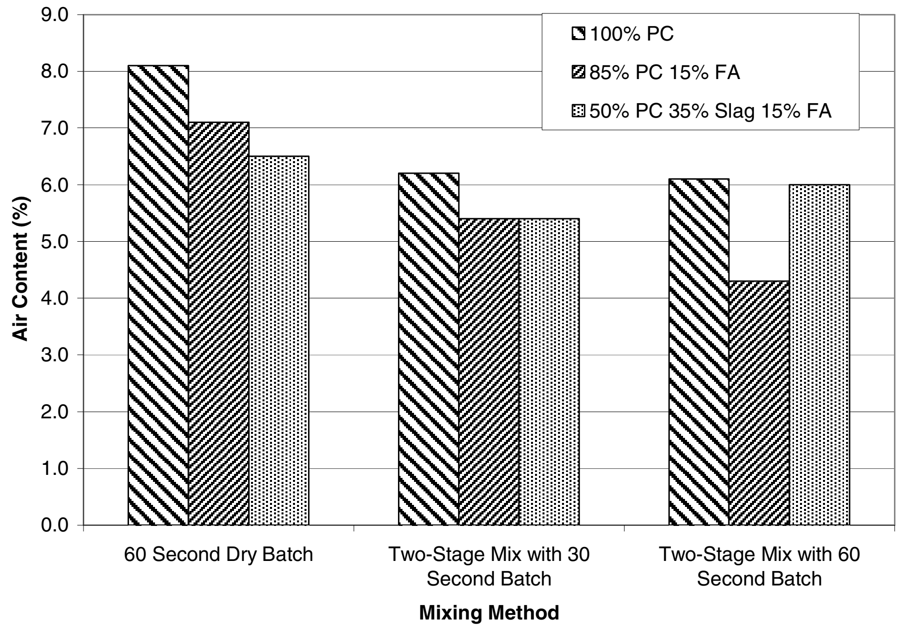

Figure 2-5. Effect of Mixing Method on the Air Content of Fresh Concrete

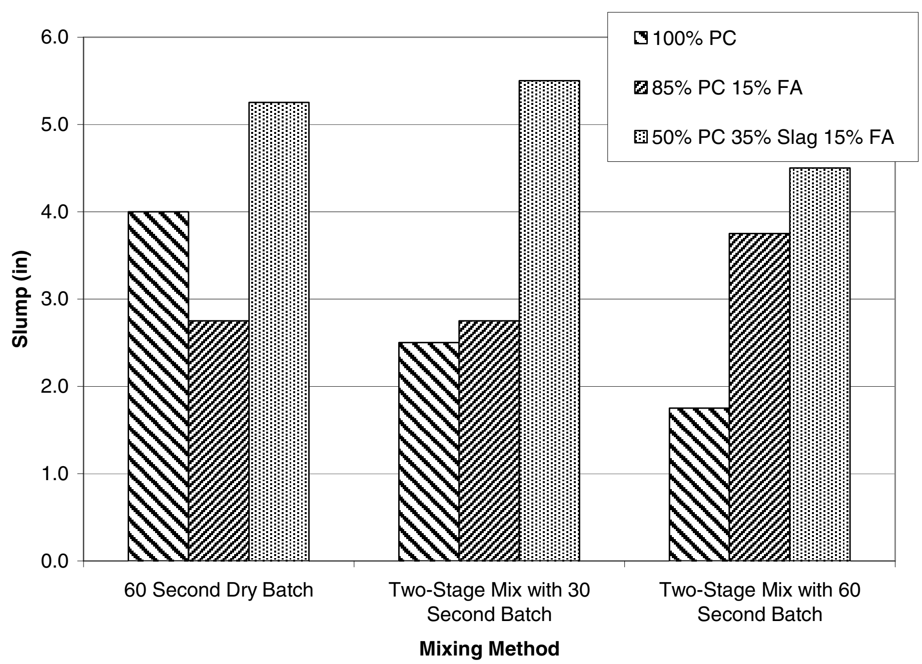

Figure 2-6. Effects of Mixing Method on the Slump of Fresh Concrete

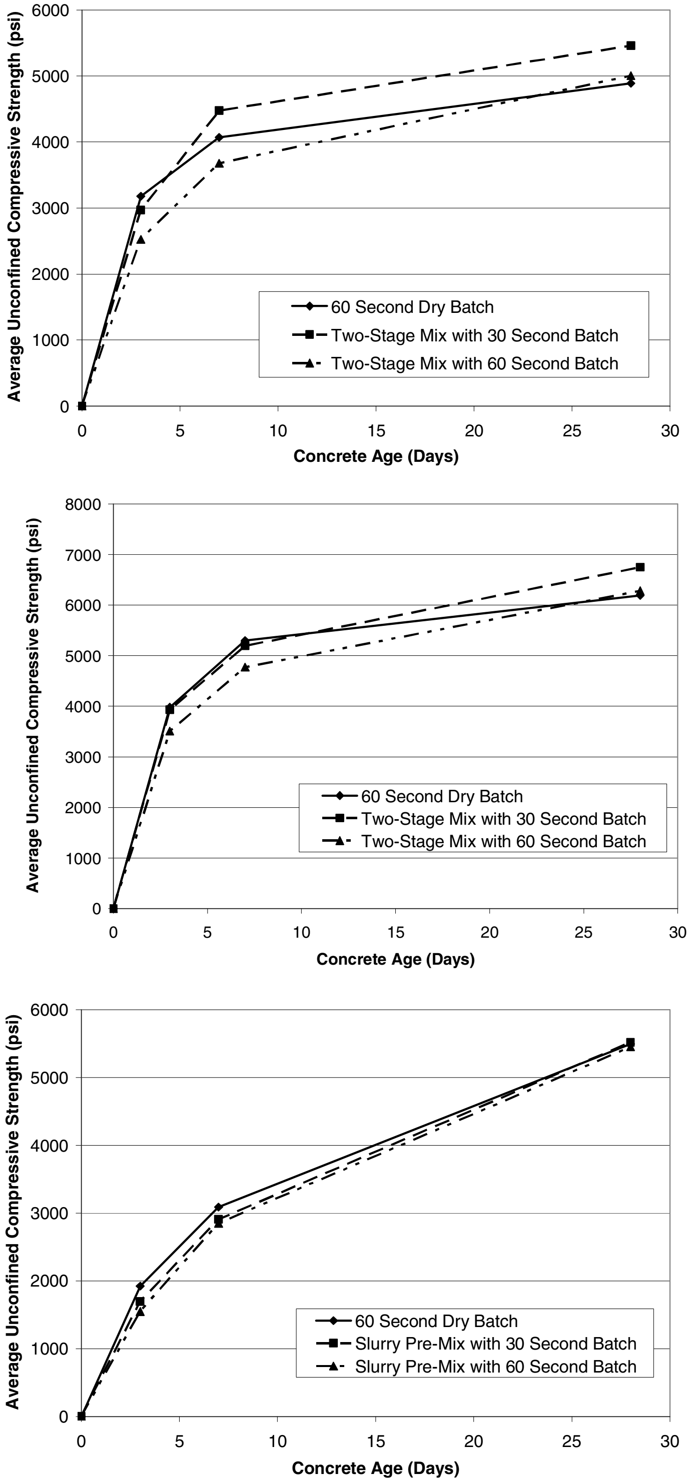

Figure 2-7. (Top) a) Effect of Time on Compressive Strength for Mix 1, 100% PC (Middle) b) Effect of Time on Compressive Strength for Mix 2, 85% PC – 15% FA (Bottom) c) Effect of Time on Compressive Strength for Mix 3, 50% PC – 35% GGBFS – 15% FA

The compressive strength data indicates that the two-stage mixing process produces nearly equal, or slightly higher, compressive strengths at early ages for Mixes 2 and 3 with the two-stage mixed concrete surpassing the standard dry batch process at 28 days. This indicates that two-stage mixing may allow for a slight reduction in cementitious materials and still achieve the same strength. At 28 days, the two-stage, 30 second mix as about a 10% increase in strength compared to the standard dry batch. A conservative engineer may opt to use the same amount of cementitious material and use the two-stage mixing process thus increasing the resultant strength of the placed concrete. It can be noted that for Mix 3, the data at 28 days shows no advantage for any one particular mixing process. This trend is believed to come from the synergistic action of the GGBFS and FA allowing for a more uniform homogeneous concrete.

Rapid Air Void Analysis

The air void system of hardened concrete is characterized by the total air content, specific surface of the air voids, and a spacing factor. Of the three air void parameters, the spacing factor is the best indicator of concrete durability to freeze-thaw action. Table 2-6 shows the results for the rapid air void analysis for all concrete mixes studied. One sample per mix was studies with three different threshold levels.

The results of the rapid air void analysis point several key findings. The total air contents do not correspond well with the air content determined on the fresh concrete. ASTM C 457 (14) states the ranges for the specific surface are 24 to 43 mm^{-1} (600 to 1100 in^{-1}) and the range for spacing factor is 0.1 to 0.2 mm (0.004 to 0.008 in.).

Table 2-6. Effect of Mixing Method on Hardened Concrete Air Properties

Mix Number	Mixing Method	Total Air Content %	Specific Surface mm^{-1}	Spacing Factor mm	Paste-Air Ratio
1	60 Second Dry Batch	10.9	36.54	0.070	2.57
	Two-Stage Mix with 30 Second Batch	6.7	28.37	0.147	4.16
	Two-Stage Mix with 60 Second Batch	7.1	22.41	0.174	3.91
2	60 Second Dry Batch	5.7	45.95	0.100	4.86
	Two-Stage Mix with 30 Second Batch	5.4	50.23	0.093	5.12
	Two-Stage Mix with 60 Second Batch	4.2	46.35	0.133	6.56
3	60 Second Dry Batch	7.1	52.30	0.075	3.92
	Two-Stage Mix with 30 Second Batch	6.9	48.72	0.082	4.00
	Two-Stage Mix with 60 Second Batch	4.9	54.63	0.073	5.68

The following observations can be made from the Rapid Air results in Table 2-6:

1. Two-stage mixing generally reduces the amount of air formed in a given mixture;
2. The air content is reduced further when the two-stage mixing procedure is applied to the concrete containing SCM; and
3. There is a weak relationship between the air void spacing factor and total air content. The air void spacing factor generally increases as the total air content of a concrete mixture decreases.

Therefore, when the two-stage mixing procedure is employed in concrete practice, increased AEA dosage and/or improved AEA application methods need be considered to ensure proper air content and spacing factors in the concrete mixtures.

Conclusions

The results of the paste study warrant the following conclusions. The mixing procedure had little effect on the compressive strength of the paste samples for all binder combinations and mixing energies (mixing speed and time) investigated. Increasing the mixing energy (mixing speed and time) did not affect the yield stress values, but led to a reduction in viscosity and thixotropic area denoting better mixed slurry. The high shear mixer showed superior performance in terms of viscosity and thixotropic flow characteristics over the Hobart mixer.

The results of the concrete study warrant the following conclusions. Air entrainment was difficult to achieve using the two-stage mixing process where the AEA was added in the slurry. A weak relationship exists between the air void spacing factor and total air content. Compressive strength results show the two-stage mixing process produces slightly stronger concrete at 28 days, but the increase is not significant.

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CHAPTER 3. A QUICK HEAT GENERATION TEST FOR CHARACTERIZATION OF CEMENTITIOUS MATERIALS

A paper to be submitted to *ASTM Journal of Testing and Evaluation*

Tyson Rupnow, Vernon Schaefer, Kejin Wang

Abstract

The objective of this study was to evaluate a quick heat generation test. The effects of initial water temperature and initial cement temperature on the quick heat generation curve were evaluated. The effects of different cement chemistries were also studied. The results were also studied to determine the reproducibility of the test procedure. Parameters measured include maximum paste temperature at 15 minutes, cement fineness, and cement chemistry. The field results indicated that the test results are reproducible and the test may have the ability to identify small changes in cement chemistry. The laboratory results showed that the results are indeed reproducible. Results also showed that a relationship exists between the both the initial water temperature and the temperature of the paste at 15 minutes and the initial cement temperature and the temperature of the paste at 15 minutes. Initial water temperature and initial cement temperature results showed that the quick heat generation test results are more influenced by the initial water temperature than the initial cement temperature. A linear relationship also exists between the initial paste temperature and the final paste temperature for a single cement source. Laboratory results also showed that the quick heat generation test capable of identifying changes in cement chemistry between different cement sources.

Introduction

Cement hydration is an important process that often controls concrete workability, setting behavior, strength gain, and pore structure development (1). It is also a complex process because it is influenced by not only the characteristics of the cementitious materials and concrete mix proportions but also the changes in construction and environmental conditions. Further adding to this complexity is the use of various supplementary cementitious materials (SCMs), such as silica fume, fly ash, and ground granulated blast furnace slag (GGBFS), and chemical admixtures, in concrete.

Hydration of the cementitious materials in concrete results in a number of exothermic chemical reactions which liberate heat. Figure 3-1 illustrates the heat evolution of a typical cement hydration process (1).

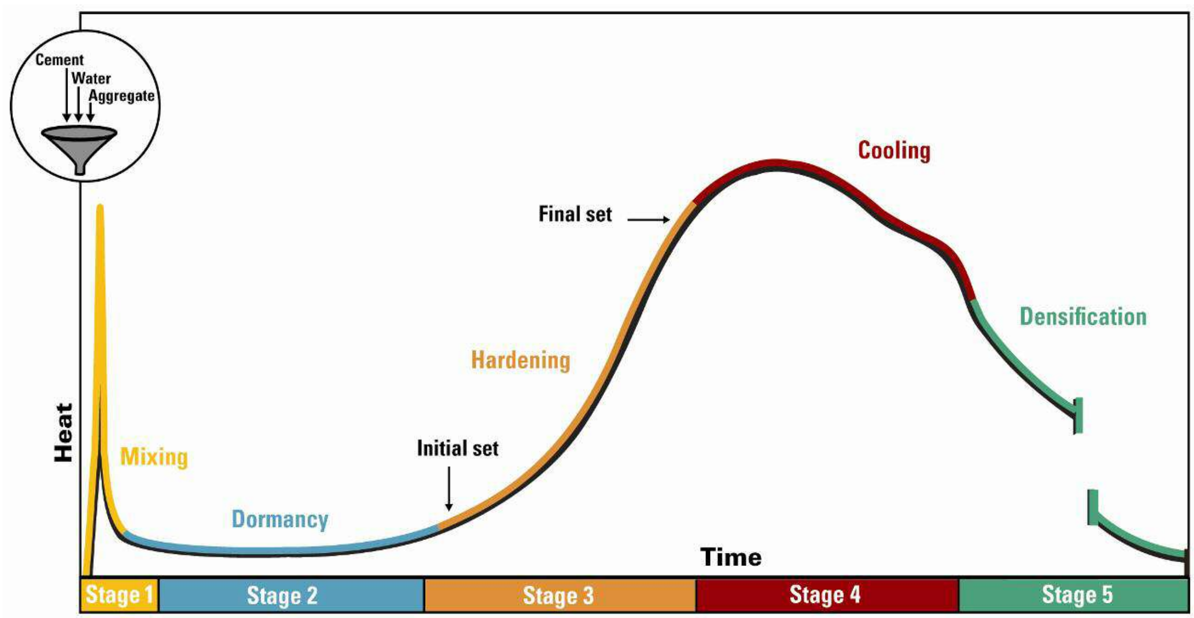

Figure 3-1. Calorimetric Curve for Portland Cement Hydration Depicting the Five Stages of Heat Evolution (2)

As shown in Figure 3-1, cement hydration can be divided into five stages. The first stage (Stage 1) is called initial hydrolysis, which occurs during about 10-15 minutes after cement is in contact with water. During this stage, the chemical ions (such as C_3S, C_3A, sulfates, free lime, and alkalis) of cement dissolve into water, and heat is quickly generated due to the dissolution, hydration, or reaction of these chemical ions. The primary reaction of this hydration stage is the reaction between C_3A and sulfates, which produces ettringite. As cement hydrates, ettringite coats the surface of the cement particles, thus reducing the further ion dissolution from cement and leading the cement hydration into Stage 2: the Dormancy period (3, 4). Information on the dormancy period and the remaining stages can be found in Darwin *et al*. (1).

Based on the features of the early heat generation in Stage 1, researchers and engineers can obtain an insight on to the amount of alkali and free lime in the cementitious materials used. The adverse influences of alkali and free lime on concrete performance have been studied by many researchers [5 – 7]. More importantly, the balance between the sulfate (amount and type) and C_3A in the tested cement system generally controls the characteristics (amount and rate) of the heat evolution in Stage 1. An abnormal heat evolution curve may reveal a potential false set or flash set of the tested concrete materials.

Smith and Matthews (3) studied the effect of sulfates on the hydration reactions of portland cement and noted an increase in gypsum content delayed and modified the aluminate reaction. Trettin *et al*. (8) studied very early heat generation of C_2S polymorphs. Their results showed that hydration was retarded if formation of a reaction layer rich in calcium was present. Atis (9) noted a large decrease in primary temperature rise when incorporating high volumes of fly ash in concrete. Frias, Rojas, and Cabrera (10) noted that addition of metakaolin in amounts of 10% to 12% produced heat evolution curves similar to portland cement concrete curves.

Although having a great interest, the study on the very early heat generation of cementitious materials is still limited due to available testing equipment and test methods. The potential applications of the early heat evolution test results are rarely addressed. Recently, a simple, quick heat generation test, using a thermometer or thermocouple to monitor the heat generated in cement pastes within 15 minutes after mixing, was developed during a research project, and it has been used for field concrete material tests. The objective of the present study is to evaluate this test method for characterization of cementitious materials and its potential applications. In this paper, the repeatability of this simple test and the sensitivity of the test results are studied. The characteristics of the heat revolution curves are discussed for pastes produced with various cementitious materials.

Materials and Test Methods

X-Ray Fluorescence (XRF)

XRF testing was completed for each cementitious material used in the study, according to the applicable ASTM standard, ASTSM C 150 (11) or ASTM C 595 (12) using a Panalytical (Philips) PW-2404 X-ray Spectrometer. The cements selected for this study represent a wide range of available cements in the United States. The XRF results are shown in Table 3-1. Note that LA stands for Louisiana. Blaine fineness was determined according to ASTM C 204 (13).

Table 3-1. XRF Results for All Cements

Chemical %	Type I/II	Type ISM	Type I (a)	Type I (b)	Type IPM	Ternary	Type IP	LA Type I (a)	LA Type I (b)
Ca0	63.00	58.19	61.71	64.20	59.15	53.15	50.88	65.28	64.96
SiO_2	20.70	23.53	19.80	20.80	24.91	26.37	28.88	20.46	19.81
Al_2O_3	4.16	5.29	6.18	5.55	4.38	5.90	8.19	5.46	5.50
Fe_2O_3	3.13	2.97	2.50	2.25	3.12	2.61	3.70	2.89	2.88
MgO	3.02	4.34	2.76	1.91	1.36	4.80	1.60	1.24	1.11
K_2O	0.75	0.58	0.74	0.50	0.56	0.38	0.90	0.25	0.38
Na_2O	0.09	0.13	0.36	0.19	0.22	0.24	0.35	0.20	0.23
SO_3	2.84	2.88	2.63	2.96	3.33	3.03	2.74	2.76	3.12
P_2O_5	0.10	0.09	0.21	--	0.11	0.14	0.22	0.17	0.17
TiO_2	0.33	0.41	0.28	--	0.29	0.35	0.44	0.33	0.33
SrO	0.05	0.04	0.24	--	0.10	0.09	0.20	0.16	0.16
Mn_2O_3	0.56	0.50	0.11	--	0.18	0.26	0.20	0.07	0.07
LOI	1.26	0.70	2.37	0.82	1.60	1.54	1.14	1.04	1.26
Total	99.99	99.66	99.91	99.18	99.3	98.8	99.4	100.3	99.99
Fineness (m^2/kg)	405	378	388	399	450	590	433	--	--
Equivalent Alkali (%)	0.59	0.52	0.85	0.52	0.59	0.49	0.95	0.37	0.48

Quick Heat Generation Test Procedure

The quick heat generation test was completed in the field using the procedure outlined below to determine repeatability of the test results and to gain an understanding of the uniformity of the cementitious materials as delivered. The quick heat generation test was also conducted in a laboratory setting using the modified procedure outlined below to determine repeatability of the test results and to determine if the procedure can flag changes in cement chemistry. The equipment used for the quick heat generation test is shown in Figure 3-2.

The quick heat generation test procedure used in the field is as follows:

1. Obtain representative samples of cementitious materials and record the material temperature.
2. Cool or warm the cementitious materials and water to 21.1˚C ± 1.7˚C (70˚F ± 3˚F).
3. Mix 500g of cement with 200g of water - or 500g of cement and SCM blended at the mixture design ratios:
    a) Vigorously shake the mixture for about 20 seconds in a 1 liter bottle. Start the timer when the water is introduced. Pour the slurry mixture into a 75 mm X 150 mm (3 inch X 6 inch) cylinder when mixing is complete.
    b) Set the container in an insulated enclosure block of styrofoam with a cylindrical void that fits tightly around the container; Open the lid and insert a thermometer, read the temperature 10 seconds after insertion, close the lid and record as initial temperature.
    c) Open the lid and read the temperature at one minute intervals, (timer reads 2, 3, 4, 5, 6, 7, 8, 9, 10, 11 minutes), close the lid and record the temperature readings at each interval.
4. Plot the results with temperature on the y-axis and time on the x-axis.

The above field quick heat generation test procedure has been modified and utilized in the present laboratory study as the following:

1. Obtain representative samples of cementitious materials and record the material temperature.
2. Bring the water and cement to 21.1˚C ± 0.3˚C (70˚F ± 0.5˚F).
3. Mix 500g of cement with 200g of water:
    a. Vigorously shake the mixture for about 20 seconds in a 1 liter bottle. Pour the paste slurry mixture into a 75 mm X 150 mm (3 inch X 6 inch) cylinder when mixing is complete.
    b. Set the container in an insulated enclosure block of styrofoam with a cylindrical void that fits tightly around the container; Open the lid and insert the t-wire thermocouple (temperature readings every 5 seconds) attached to a temperature data logger.
4. Download and plot the results with temperature on the y-axis and time on the x-axis after 15 minutes

Figure 3-2. Laboratory Test Equipment used to Conduct the Quick Heat Generation Test

The laboratory testing plan was carried out such that the effects of initial cement temperature, initial water temperature, and different cement chemistries could be investigated independently. Type I/II portland cement was used to determine the effects of the temperature of the raw materials (cement and water), and various other sources of portland cement were used to determine the effects of cement chemistry change.

Table 3-2 shows the laboratory mixes determining the effects of cement and water temperature on the quick heat generation results. For determining the effects of cement chemistry, all cement and water temperatures were set at 21.1˚C ±0.3˚C (70˚F ±0.5˚F).

Table 3-2. Laboratory Mixes for Determining Effects of (a) Initial Cement Temperature and (b) Effects of Initial Water Temperature

a)

Initial Cement Temperature	Initial Water Temperature
°C (°F)	°C (°F)
15.56 (60)	21.11 (70)
18.33 (65)	21.11 (70)
21.11 (70)	21.11 (70)
23.89 (75)	21.11 (70)
26.67 (80)	21.11 (70)
29.44 (85)	21.11 (70)
32.22 (90)	21.11 (70)
37.78 (100)	21.11 (70)
43.33 (110)	21.11 (70)
48.89 (120)	21.11 (70)

b)

Initial Cement Temperature	Initial Water Temperature
°C (°F)	°C (°F)
21.11 (70)	15.56 (60)
21.11 (70)	18.33 (65)
21.11 (70)	21.11 (70)
21.11 (70)	23.89 (75)
21.11 (70)	26.67 (80)
21.11 (70)	29.44 (85)
21.11 (70)	32.22 (90)
21.11 (70)	37.78 (100)
21.11 (70)	43.33 (110)
21.11 (70)	48.89 (120)

Results and Discussion

Field Observation

Figure 3-3 shows the field results from the Louisiana (Type I portland cement) state visit (note the temperature of the test sample was measured only once per minute creating a less smooth heat generation curve). The results in Figure 3-3 indicate that the test is repeatable, shown by the curves of two tests (1 and 2) for sample A. The slight difference between the two tests may result from the difference in initial paste temperatures.

The results also indicate that cement sample B had a different temperature curve compared to sample A, probably due to the cement chemistry (Table 3-3). Cement sample B has an increased SO_3 content compared to cement sample A, which may contribute to the rise in paste temperature due to more sulfate going into solution. These field results led the authors to further investigate the repeatability and ability of the test procedure to flag cement changes in a laboratory setting.

Table 3-3. XRF Results for Louisiana Type I Portland Cement Samples A and B

Chemical %	LA Type I (A)	LA Type I (B)
Ca0	65.28	64.96
SiO_2	20.46	19.81
Al_2O_3	5.46	5.50
Fe_2O_3	2.89	2.88
MgO	1.24	1.11
K_2O	0.25	0.38
Na_2O	0.20	0.23
SO_3	2.76	3.12
P_2O_5	0.17	0.17
TiO_2	0.33	0.33
SrO	0.16	0.16
Mn_2O_3	0.07	0.07
LOI	1.04	1.26
Total	100.3	99.99
Equivalent Alkali (%)	0.37	0.48

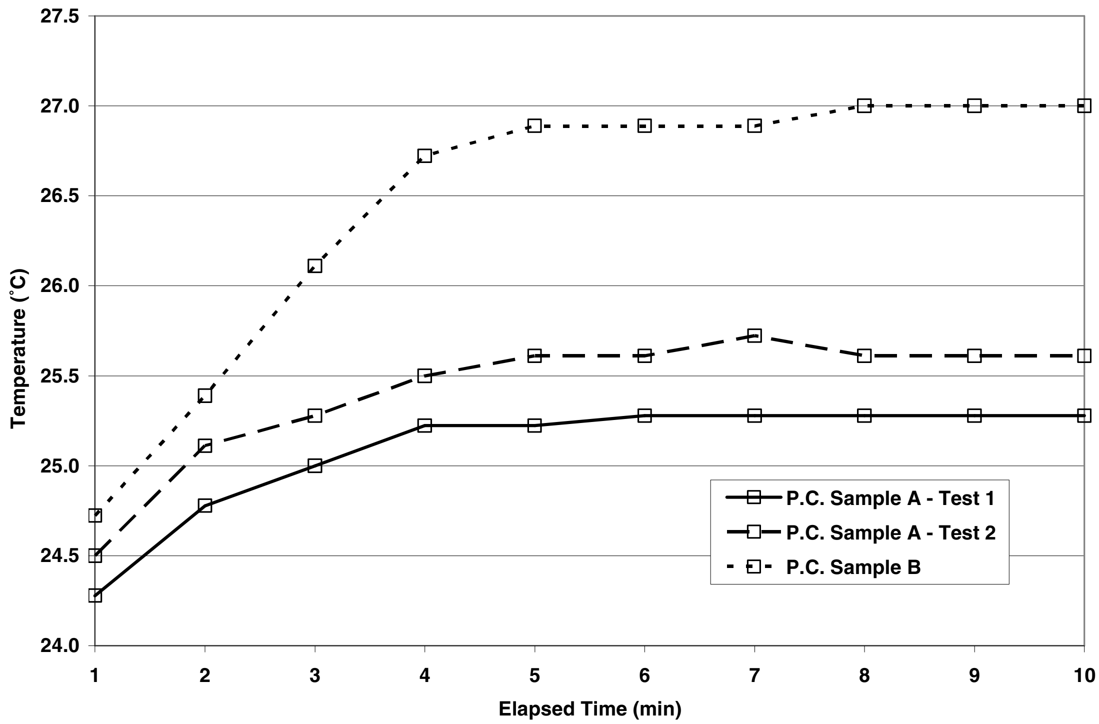

Figure 3-3. Field Results From Louisiana Showing Repeatability and Different Cement Chemistry.

Laboratory Results

To improve the test precision, an improvement was made in the laboratory tests to electronically gather the temperature data using a thermocouple t-wire and a data recorder.

Since initial paste temperature is influenced by both the cement and water temperature, these two variables are studied separately. Laboratory testing results in determining the effects of initial cement temperature for Type I/II portland cement are shown in Figure 3-4. Note the increase in heat generated corresponding to the increase in initial cement temperature as expected. The effect is more significant when the cement temperature is high. The results show nearly identical heat generation curves for initial cement temperatures ranging from 21 – 30°C (70 - 85°F). These results show that the initial test procedure range requiring the cement temperature to be 21.1 ±1.7°C (70˚F ±3˚F) has the possibility to be increased.

Laboratory testing results for determining the effects of initial water temperature for Type I/II portland cement are shown in Figure 3-5. Note the large increase in heat generated corresponding to the increase in initial water temperature as is expected. Figure 3-5 shows a larger increase in heat generation when increasing the initial water temperature compared to increasing the initial cement temperature shown in Figure 3-4. These results show that initial water temperature for mixing influences the heat generation curve more significantly than the initial cement temperature.

The results in Figure 3-5 show nearly identical heat generation curves for initial water temperatures ranging from 18 – 24°C (65 - 75°F). These results show that the initial test procedure range requiring the initial water temperature to be 21.1 ±1.7°C (70˚F ±3˚F) has the possibility to be expanded.

The results shown in Figures 3-4 and 3-5 indicate the test procedure may be changed slightly to increase the initial cement temperature range from 21.1 ±1.7°C (70˚F ±3˚F) to 19.4 – 26.7°C (67˚F - 80˚F) for the Type I/II cement. Although the results point to such a large range of testing temperatures, the authors suggest a narrower range of initial cement testing temperatures of 19.4 – 23.9°C (67˚F - 75˚F). Further testing of other cement chemistries is needed to better define the initial cement temperature range. The authors suggest the range of initial water testing temperature to be 21.1 ±1.7°C (70˚F ± 1˚F) due to the ability to better control water temperature in field conditions. The authors note this is a tight range for temperature, but it is the author's experience that it is achievable with little effort in most field conditions with the aid of a refrigerator and a microwave oven.

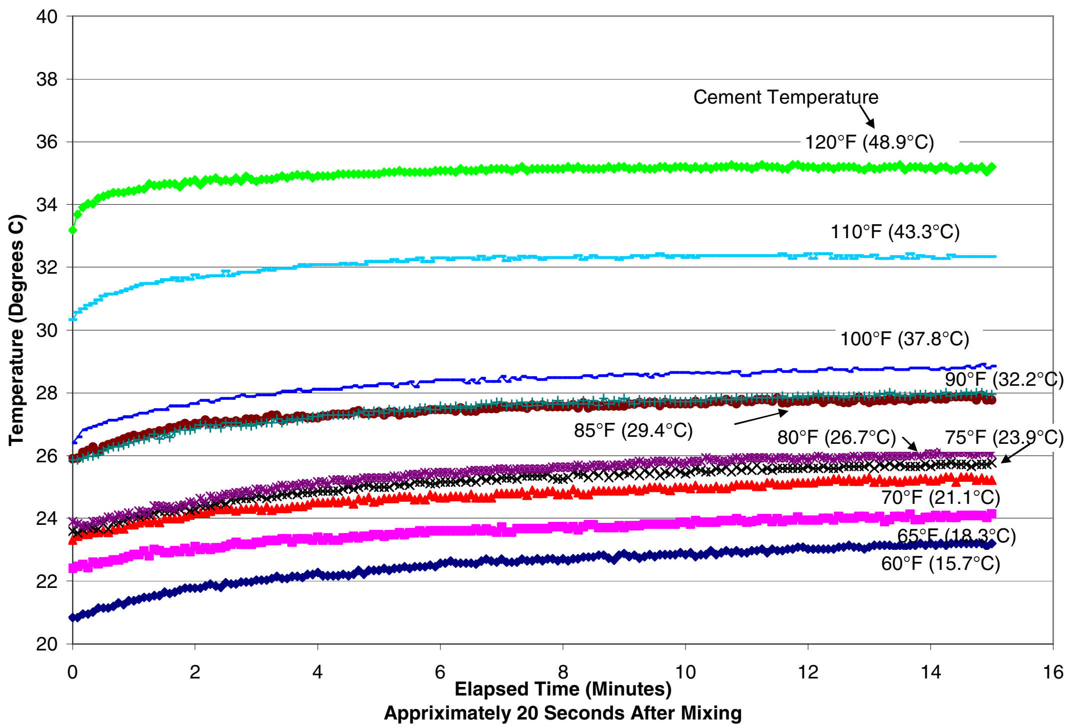

Figure 3-4. Effect of Initial Cement Temperature on Quick Heat Generation for Type I/II Portland Cement (Water Temperature = 21.1°C (70°F))

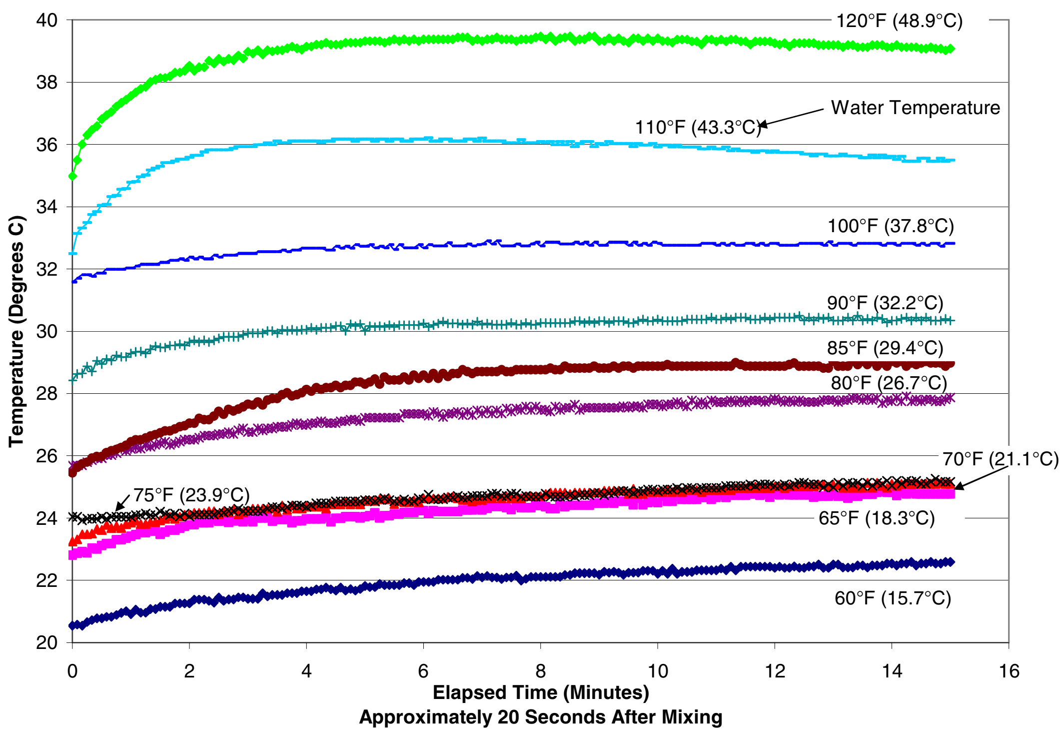

Figure 3-5. Effect of Initial Water Temperature on Quick Heat Generation for Type I/II Portland Cement (Cement Temperature = 21.1°C (70°F))

The results from Figures 3-4 and 3-5 were analyzed to determine if a relationship between the maximum temperature of the paste, the temperature of the paste at 15 minutes, and the initial water or initial cement temperature existed. Analysis of the heat generation profiles showed the maximum temperature of the paste and the final temperature of the paste at 15 minutes differed from as little as 0.1°C to 0.25°C. The difference between the end temperature and the maximum temperature being small, the analysis was conducted using the end temperature at 15 minutes.

Figure 3-6 shows the relationship between the initial cement temperature and the final temperature of the paste at 15 minutes. Note the relationship is linear and the R^2 value is 0.96. The results show with one cement chemistry with varying initial cement temperatures, one can predict the final paste temperature.

Figure 3-7 shows the relationship between the initial water temperature and the final temperature of the paste at 15 minutes. Note the relationship is linear with a R^2 value of 0.99. The results show that with one cement chemistry and varying initial water temperatures, one can predict the final paste temperature at 15 minutes.

It should be noted that the exponential function showed a better relationship (R^2 = 0.97 and 0.99), but the authors noted that if the relationship were to be used in the field, a linear approximation is sufficient.

Using the knowledge obtained in Figures 3-6 and 3-7, a field technician can produce several heat generation curves for the cement delivered to the site and then conduct the test at a much higher cement temperature. The temperature of the paste at 15 minutes would then be compared to the relationship between initial cement temperature and the final paste temperature to determine if the cement chemistry had changed significantly. More research is needed to further define the acceptable range of values for temperature of the paste at 15 minutes in order to ascertain whether or not the cement chemistry has changed significantly.

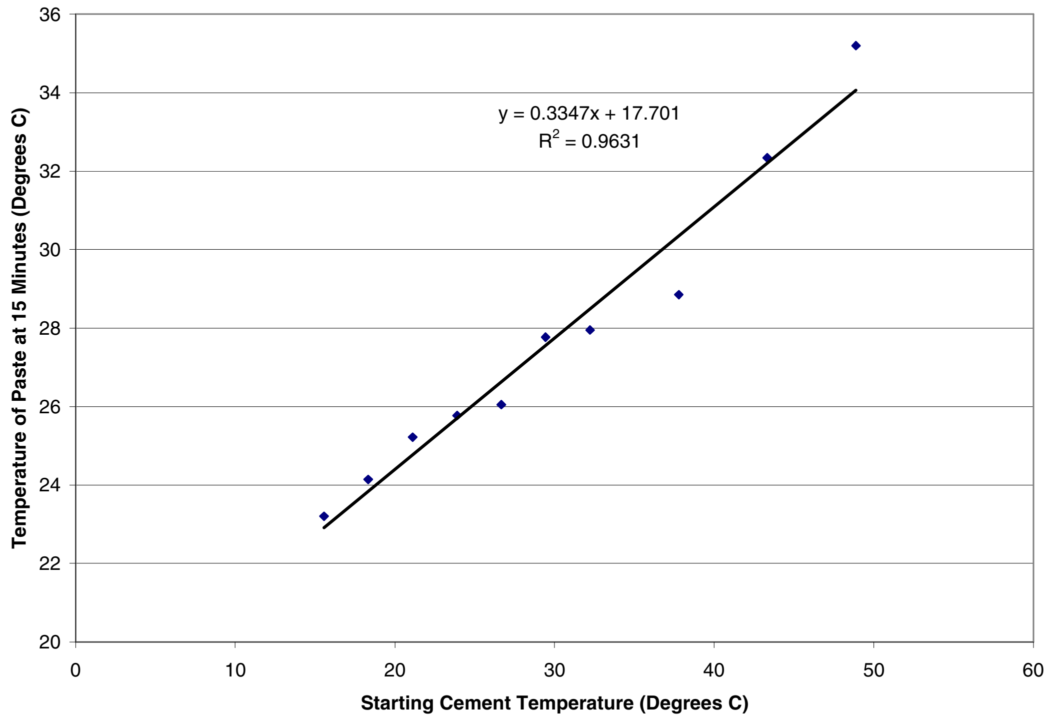

Figure 3-6. Relationship Between Initial Cement Temperature and Final Temperature of the Paste at 15 Minutes for Type I/II PC

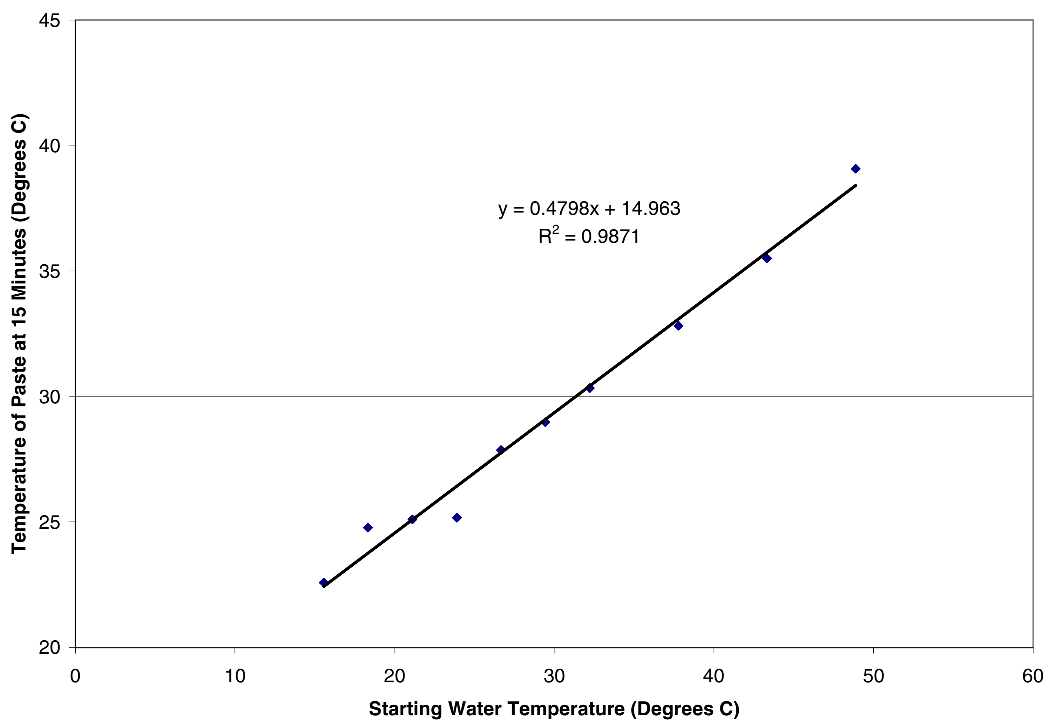

Figure 3-7. Relationship Between Initial Water Temperature and Final Temperature of the Paste at 15 Minutes for Type I/II PC

After noting the relationship between initial water and cement temperature and the final temperature of the paste at 15 minutes, the relationship between the initial paste temperature and the final paste temperature was investigated. The initial paste temperature was taken at time equal to zero. Figure 3-8 shows the excellent linear relationship between the initial paste temperature at time = 0 and the final paste temperature at fifteen minutes for all Type I/II portland cement mixes.

The results in Figure 3-8 show that the quick heat generation test has the possibility to be further shortened to save time in field applications. Field testing would consist of generating a set of curves at different starting temperatures for cement and then plotting the initial paste temperature versus the final paste temperature. This would allow testing of the cement at any cement temperature for a very brief time interval of 30 – 60 seconds to obtain the initial paste temperature. The initial paste temperature could be compared to a graph such as shown in Figure 3-8 to determine if the initial paste temperature matches a final paste temperature on the trend line.

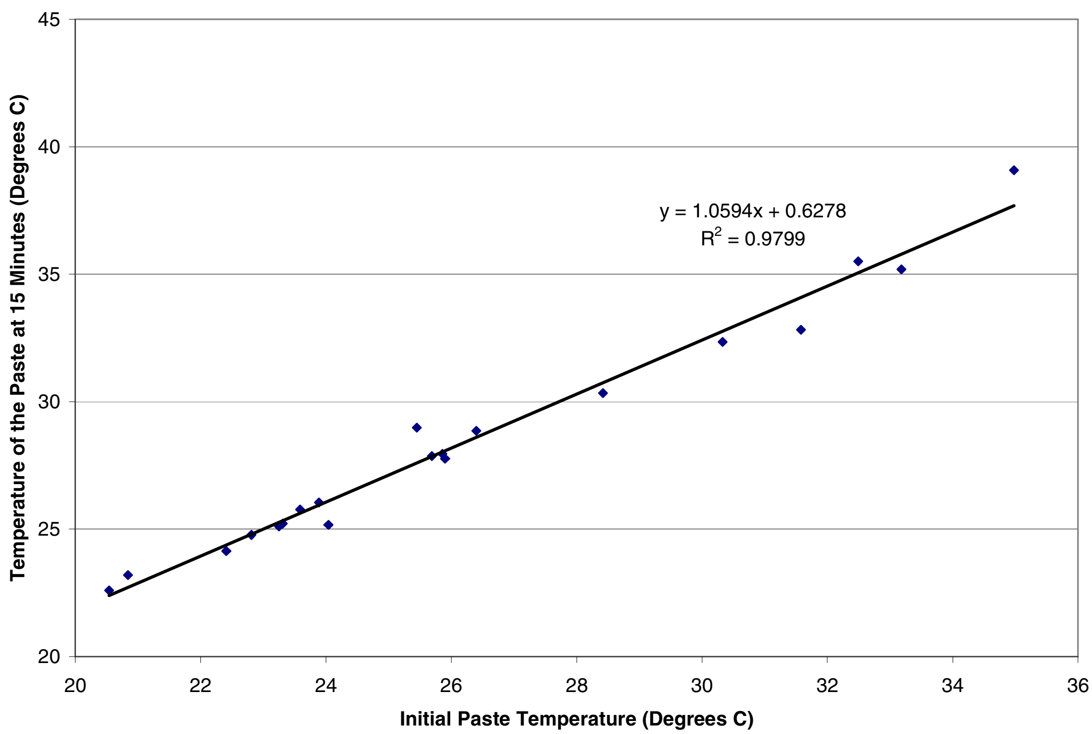

Figure 3-8. Relationship between the Initial Paste Temperature and the Final Temperature of the Paste at 15 Minutes for Type I/II PC

Laboratory testing results in determining the effects of various cement chemistries are shown in Figure 3-9. Note that all initial cement and water temperatures were 21.1˚C ±0.3˚C (70˚F ±0.5˚F) eliminating temperature effects. The results immediately show distinct heat generation curves for each of the differing cement chemistries. The results point to the ability of the early heat generation curve to flag cement changes. Combined with the field results shown in Figure 3-2, the results also point to the ability to flag minor changes in cement chemistry.

Note the results for the Type I/II Test 1 and Test 2 found in Figure 3-9 are further shown in Figure 3-10 to highlight the repeatability of the test results. Note the very narrow range of temperatures measured.

The ability of the quick heat generation test to flag a change in cement chemistry is very important in field applications. If a perceived change in the concrete workability or engineering properties has occurred, and all other factors remain constant, the cement can be tested quickly to determine if a significant change in cement chemistry has occurred. This is beneficial due to the time savings compared to XRD or XRF testing, which can take a mater of days instead of minutes.

The quick heat generation test for characterization of cementitious materials shows much promise for identifying a change in portland cement source or small changes in cement chemistry. The authors note that much more research is needed in determining the sensitivity of the test procedure to day-to-day fluctuations that naturally occur in portland cement production. More research is also needed to determine the minimum change in cement chemistry to significantly affect the test results. To become an accepted test procedure, a precision and bias statement would also need to be produced.

The mixing energy and procedure of the quick heat generation test also needs to be investigated. A standardized mechanical mixing procedure will eliminate error between operators due to inconsistencies in mixing.

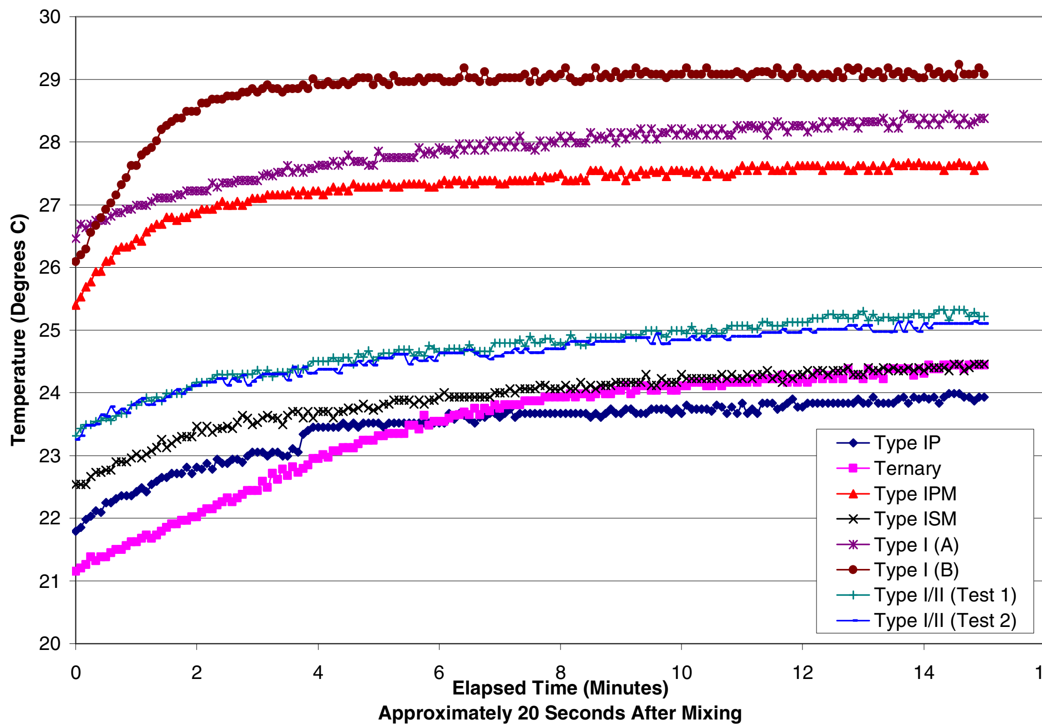

Figure 3-9. Effect of Cement Chemistry on Quick Heat Generation (Cement and Water Temperature = 21.1°C (70°F))

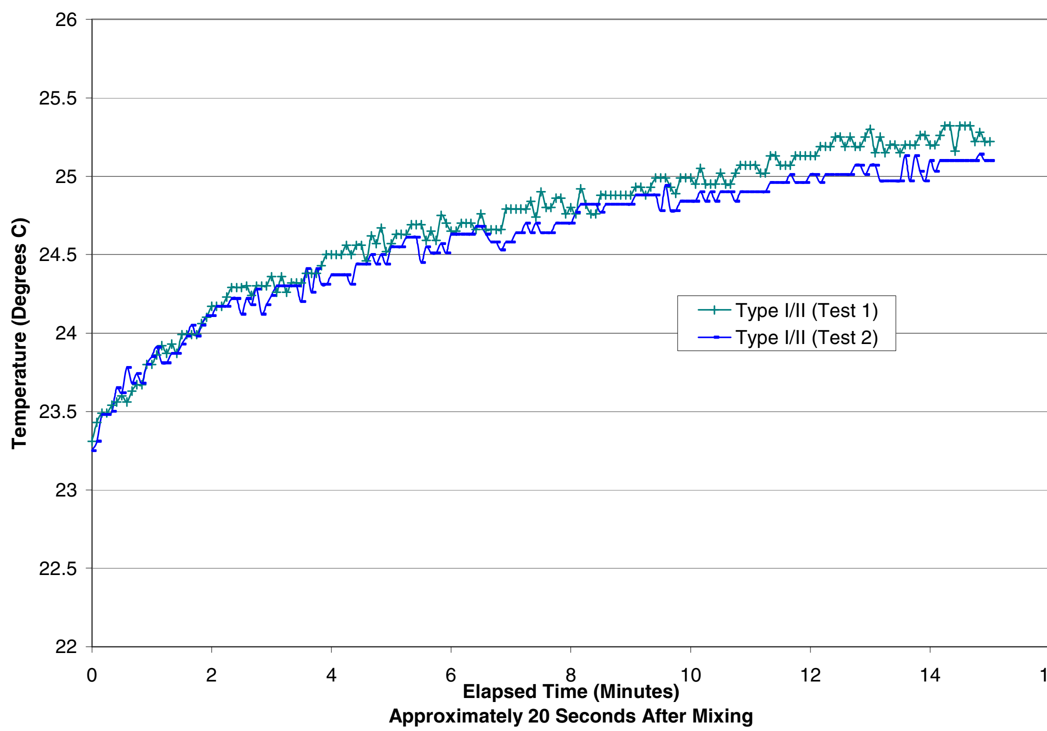

Figure 3-10. Type I/II Quick Heat Generation Results Showing Repeatability of the Test Procedure

Conclusions

The field and laboratory results of this study warrant the following conclusions:

1. The quick heat generation test can identify a cement change.
2. The quick heat generation test results are reproducible.
3. There is a linear relationship between the initial paste temperature and the paste temperature measured at 15 minutes after testing.
4. The initial water temperature affects the results of the quick heat generation test much more than the initial cement temperature.

Recommendations

Further refinement and testing is needed to identify the range of initial temperature values and temperature values at 15 minutes that would indicate whether the cement chemistry had changed when using the relationship between the initial cement temperature and the paste temperature at 15 minutes and the relationship between the initial paste temperature and the final paste temperature. Further testing is also needed on a wider range of cement chemistries to validate the current research. Research on cement produced from day-to-day is also desirable to determine the sensitivity of the quick heat generation test to the day-to-day fluctuations in the cement production process. Further research on a standard mixing procedure for reduction of error between operators is also desirable.

Acknowledgements

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CHAPTER 4. EFFECTS OF DIFFERENT AIR ENTRAINING AGENTS (AEA), SUPPLEMENTARY CEMENTITIOUS MATERIALS (SCM), AND WATER REDUCING AGENT (WR) ON THE AIR VOID STRUCTURE OF FRESH MORTAR

A paper submitted to *International Conference on Optimizing Paving Concrete Mixtures and Accelerated Concrete Pavement Construction and Rehabilitation*: A Peer Reviewed Conference

Tyson Rupnow, Vernon Schaefer, Kejin Wang, Paul Tikalsky

Abstract

In this paper, the effects of different air entraining agents (AEA), cement, supplementary cementitious materials (SCM), and water reducing agent (WR) on the air void structure of fresh mortar were investigated. Any abnormal air void structure of these mixes was subsequently identified. Three AEAs, two WRs, five SCMs, and four different cements were studied. The air void structure of the mortars was examined using an air void analyzer (AVA). The seven-day compressive strength of these mortars was also evaluated. The results show a relationship between the spacing factor, specific surface and percentage of air voids less than 300 μm. AEA3 generally produced an increased air void spacing factor or lower specific surface than the other AEAs used. The spacing factor of the mortar made with class F fly ash and WR1 was significantly greater than that of the mortar made with the class F fly ash and WR2. For the given AEA and WR type and dosage, mixes containing class C fly ash and slag often had a higher percentage of small air voids (diameters less than 300 μm). The seven-day compressive strength results showed an incompatibility (low strength) problem when Type I portland cement was used with 30% class C fly ash and the selected AEAs and WR1. Such an incompatibility problem disappeared when blended cements were used. Disregarding these incompatible mixes, there is a linear relationship between the total air content and the average compressive strength of the mortar.

Introduction

Supplementary cementitious materials (SCM) are increasingly used in concrete construction; however, some combinations of SCM produce incompatibilities with air entraining agent (AEA) or water reducing agent (WR), leading to low air content or retarded strength gain. Low air contents can lead to insufficient air void spacing factors producing concretes susceptible to freeze-thaw deterioration.

Commonly used methods of measuring the total air content of fresh concrete include the volumetric method and the pressure method, ASTM C 173 (1) and ASTM C 231 (2), respectively. The drawback of these methods is that they are only capable of measuring the total air content of the concrete and not the size distribution or dispersion properties of the stabilized air void system. The test results can be greatly influenced by a small number of large air voids that provide little to no protection against freeze-thaw.

The current method for measuring the size distribution of air voids in concrete is ASTM C 457 (3). The drawbacks of this method include the requirement of a highly trained technician and the results can only be obtained on hardened concrete samples.

The two primary air void parameters determined by ASTM C 457 are the spacing factor and specific surface. Spacing factor is defined as the maximum distance in the cement paste from the edge of an air void (3) and is expressed in units of length. Specific surface is defined as the surface area of the air voids divided by their volume (3) and is expressed in units of reciprocal length (i.e. mm^{-1} (in^{-1})). For freeze-thaw resistance concrete, the spacing factor is between 0.1 to 0.2 mm (0.004 to 0.008 inches) and the specific surface is between 24 to 43 mm^{-1} (600 to 1100 in^{-1}).

The development of the Air Void Analyzer (AVA) in the 1980's provided a method to determine (measure) the air void structure in fresh concrete. This test method allows field measurements and potential corrective action in about 30 minutes compared to several days or weeks for a hardened air analysis. The AVA works using a fresh mortar sample of 20 cc that is injected into a column of water containing special fluid. The sample is broken up using a stir bar and the air voids are subsequently released into the column of water. A petri dish collects the bubbles and records the change of mass. The air void distribution is calculated using Stoke's Law. More information on AVA operation can be found in literature by Dansk Benton Teknik (4).

Zhang and Wang (5) studied the effects of materials and mixing procedures on the AVA results. They noted that incorporation of 15 % fly ash as a proportion of the total cementitious mass and water reducer reduces the spacing factor and increases the specific surface. Despite the rapidly increasing use of SCMs, little information exists on the effect of SCMs on the air void structure.

The objective of the present research is to investigate the effects of different AEA, SCM, and water reducing agent on the air void structure of fresh mortar. Any abnormal air void structure of the studied mixes was consequently identified. Parameters measured included spacing factor, specific surface, percent air voids with a diameter less than 300 μm (% D < 300 μm), and seven day compressive strength.

Materials and Test Methods

Materials

Mortar samples were used for the entire study. The cementitious materials used for the mortar study included: ASTM C 150 (6) Type I, ASTM C 595 (7) IPM, ISM, and IP portland cement, ASTM C 618 (8) Class C and two Class F fly ashes (FA), ASTM C 989 (9) grade 120 ground granulated blast-furnace slag (GGBFS), and ASTM C 618 (8) Class N metakaolin. Table 4-1 shows the chemical composition of the portland cements. Table 4-2 shows the chemical composition of the fly ashes, GGBFS, and metakaolin. Note the chemistries of the portland cements and SCMs used are typical for materials available in the United States.

Natural river sand was used for the fine aggregate and had a fineness modulus and absorption of 2.81 and 1.12% respectively. AEA's used included a Vinsol™ Resin and two commercially available ASTM C 260 (10) chemical admixtures. Two water reducers (WR) were used. WR1 is a sucrose based water reducer and WR2 is a polycarboxylate. The name, notation, and dosage of each WR and AEA used are listed in Table 4-3.

Ten basic mixture proportions were selected as shown in Table 4-4. For example, the mixture labeled as 60TI-30C-10F indicates that the mixture contains 60 percent Type I PC, 30 percent Class C fly ash, and 10 percent Class F fly ash (F1) by mass. Each basic mixture design was then produced with combinations of AEA1-WR1, AEA1-WR2, AEA2-WR1, AEA3-WR1, etc., thus creating a total testing matrix of 60 mixtures.

Test Methods

AVA sample preparation was completed by mixing mortar according to ASTM C 305 (11) with a water-to-cementitious materials ratio (w/cm) of 0.45 and a sand to cement ratio of 2.75:1. The fresh mortar was then hand packed into the syringes. The plunger was then inserted and the sample was struck off at the desired 20 cc sample size. Note that this method of sample preparation deviates from the field suggested sampling procedure noted by the AASHTO TIG (12) by using a mortar sample only instead of a mortar sample obtained from fresh, or plastic, concrete.

Table 4-1. Chemical Composition of Portland Cement

		Type I	TIPM	TISM	TIP
Chemical Composition, %	CaO	61.62	59.15	58.23	50.88
	SiO_2	19.79	24.91	23.51	28.88
	Al_2O_3	6.19	4.38	5.27	8.19
	Fe_2O_3	2.50	3.12	2.99	3.70
	MgO	2.76	1.36	4.33	1.60
	K_2O	0.75	0.56	0.59	0.90
	Na_2O	0.34	0.22	0.13	0.35
	SO_3	2.58	3.33	2.87	2.74
	TiO_2	0.28	0.29	0.41	0.44
	P_2O_5	0.21	0.11	0.10	0.22
	SrO	0.24	0.10	0.04	0.20
	Mn_2O_3	0.11	0.18	0.50	0.20
Fineness (m^2/kg)		388	450	378	433

Table 4-2. Chemical Composition of Class C, Class F, GGBFS, and Metakaolin

		Class C	Class F (F1)	Class F (F2)	GGBFS	Metakaolin
Chemical Composition, %	CaO	27.24	3.78	13.26	36.78	0.07
	SiO_2	34.21	45.06	51.31	36.83	52.42
	Al_2O_3	18.31	23.73	16.11	9.65	44.42
	Fe_2O_3	6.60	16.33	6.74	0.62	0.42
	MgO	5.04	0.91	4.44	10.04	0.04
	K_2O	0.35	1.46	2.32	0.36	0.14
	Na_2O	1.55	0.81	2.86	0.31	0.16
	SO_3	2.71	0.69	0.80	-	0.02
	TiO_2	1.57	1.16	0.63	0.49	1.45
	P_2O_5	1.30	0.25	0.15	0.01	0.08
	SrO	0.51	0.18	0.33	0.05	<0.01
	Mn_2O_3	0.06	0.03	0.05	0.39	<0.01
	S	-	-	-	1.10	-
	LOI, %	0.25	5.38	0.04	-	0.30

Table 4-3. AEAs and Water Reducers Used

Admixture	Symbol	Dosage Rate ml/kg (oz/cwt)
Vinsol™ Resin	AEA1	1.3 (2)
AEA Admixture 2	AEA2	1.3 (2)
AEA Admixture 3	AEA3	0.49 (0.75)
Sucrose Base WR	WR1	2.3 (3.5)
Polycarboxylate WR	WR2	2.6 (4)

Table 4-4. Mortar Mixture Designs

Mixture Design
60TI-30C-10F
60TI-30C-10F2
50TI-30C-20G120S
75TIP-25C
75TISM-25C
75TIPM-25C
60TI-30F-10C
60TI-30F-10F2
65TI-30F-5M
75TIP-25F

The AVA testing procedure involves placing water into the riser column. The bottom of the column is then filled with glycerol using a special funnel. The mortar sample is injected into the glycerol and a magnetic stir bar mixes the glycerol and mortar for 30 seconds. The air voids released during and after mixing are recorded on an inverted glass dish as a change in mass over time. The test can take up to 30 minutes to complete, and the software displays the cumulative distribution of air voids, a histogram of the air voids, and numerical values of spacing factor and specific surface.

For early age strength characteristics, 2 in x 2 in cubes were cast according to ASTM C109 (13) and tested at 7-days.

Results and Discussion

Figure 4-1 shows the relationship between spacing factor and specific surface. Figure 4-2 shows the relationship between spacing factor and % D < 300 μm and Figure 4-3 shows the relationship between total air and % D < 300 μm. Note the correlation between all variables is good as was noted by Grove *et al*. (14).

The relationship shown in Figure 4-1 is as expected with a decrease in spacing factor as the specific surface is increased. This shows an increasingly finer air void system leading to shorter distances between air voids. Note the very good correlation in Figure 4-2 between the spacing factor and the % D < 300 μm. The results show that decreasing the spacing factor increases the amount of air voids less than 300 µm in diameter. Increasing the total air content of the mortar increases the % D < 300 µm as shown in Figure 4-3 as is expected.

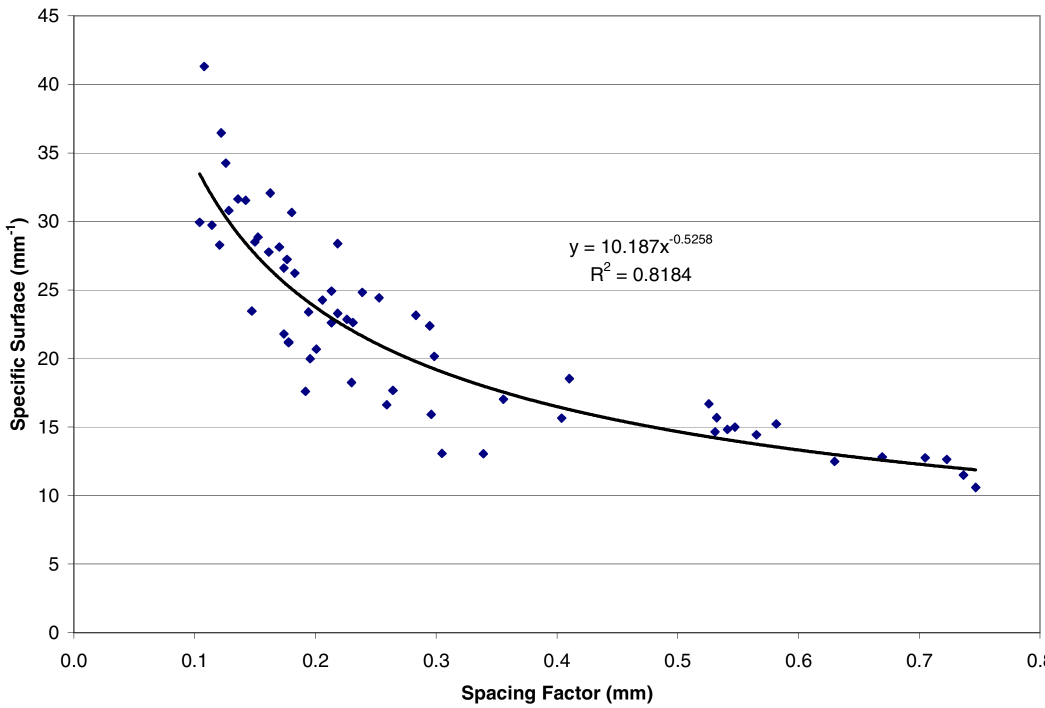

Figure 4-1. Relationship between Specific Surface and Spacing Factor for All Mixtures

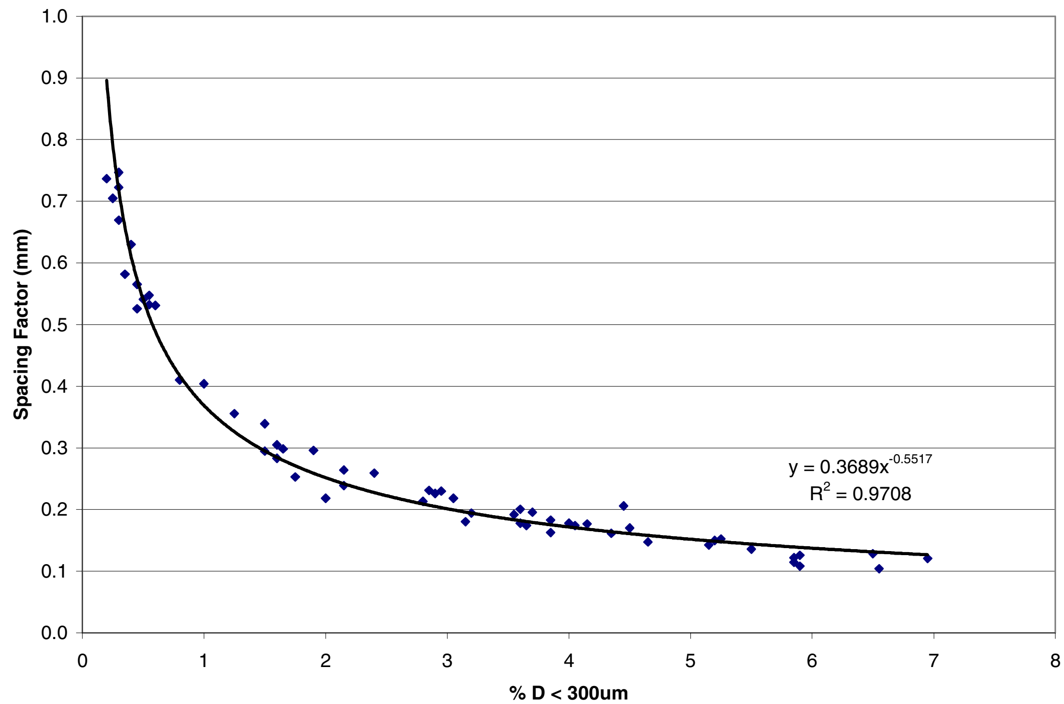

Figure 4-2. Relationship between Spacing Factor and % D <300 μm for All Mixtures

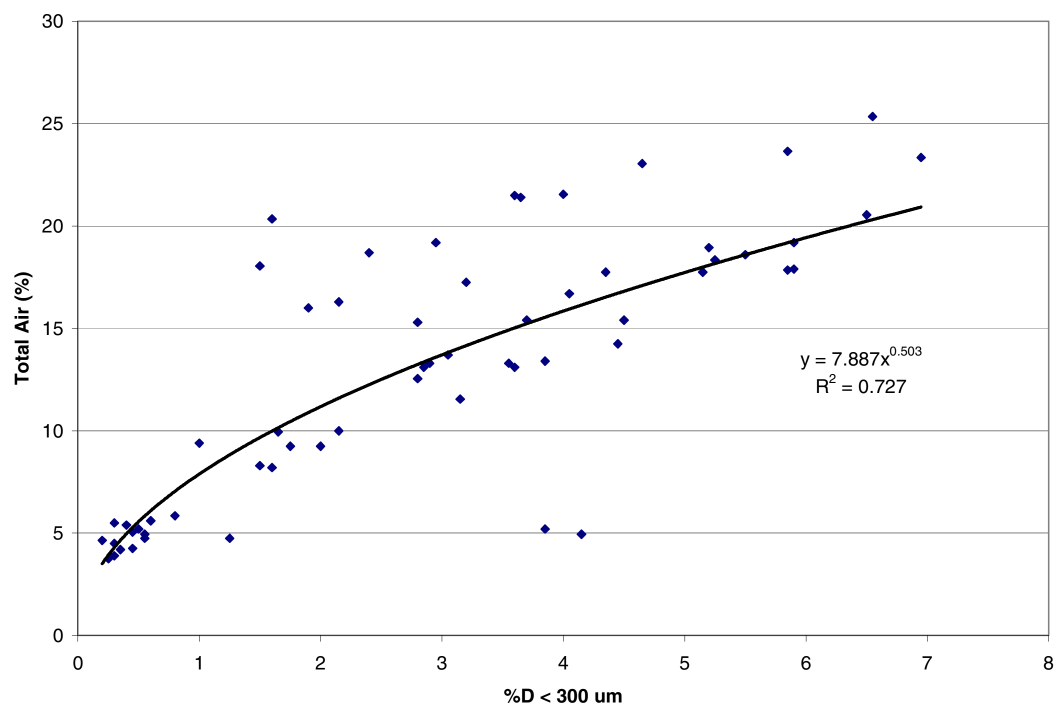

Figure 4-3. Relationship between Total Air and % D < 300 μm for All Mixtures

Figure 4-4 shows the effect of the mortar air content on the average 7-day compressive strength for all mixes. The general trend shows an increase in compressive strength with a decrease in the air content as expected due to lower air contents leading to increased strengths. Note the low compressive strength results for three mixes with class C fly ash replacement combined with WR1, indicating an incompatibility.

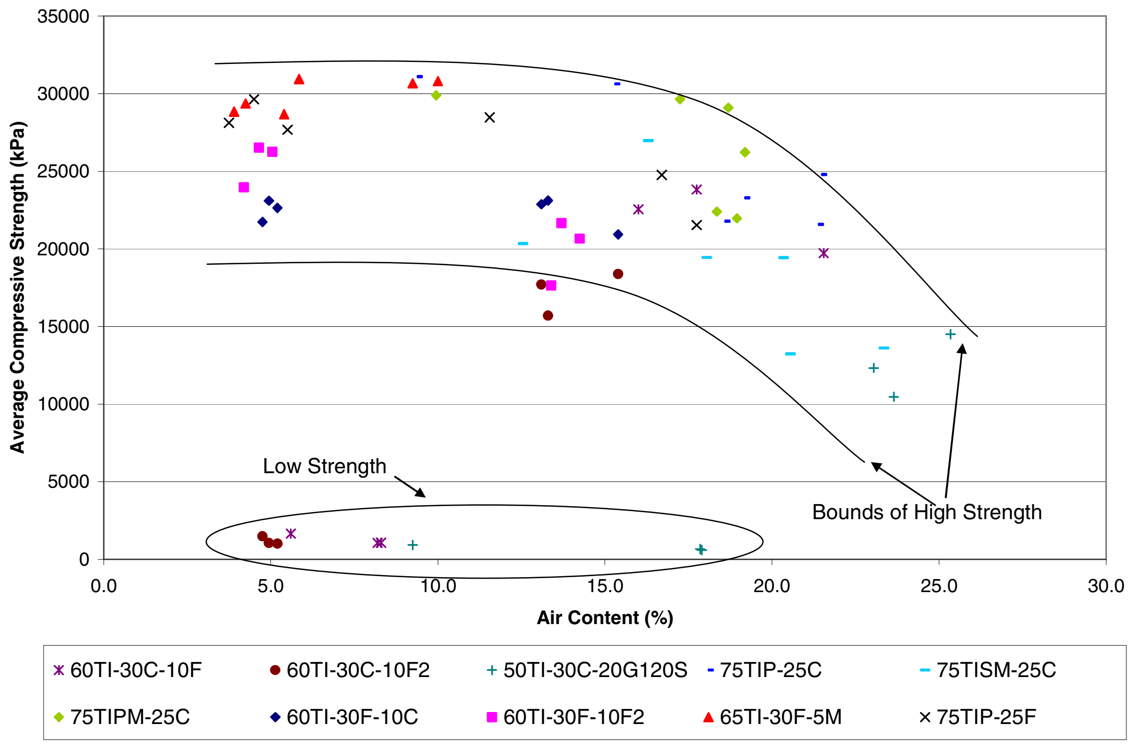

Figure 4-4. Effect of the Total Air Content on the Average Compressive Strength for All Mixtures

Figures 4-5 and 4-6 show the relationship between spacing factor and combinations of AEA and water reducer for the mixtures containing high amounts of class C and class F fly ash, respectively. As shown in Figure 4-5, the blended cements (TIP, TISM, TIPM) generally produced better air void structure, and the reverse is true for mixtures containing large amounts of class F fly ash as shown in Figure 4-6. Note that all three AEAs used in the study seem to produce similar spacing factors when comparing results with the same water reducer.

Note in Figure 4-6 the significant difference between the spacing factor results for the two water reducers. The results show mixtures containing high LOI Class F fly ash; a polycarboxylate high range water reducer may be better suited for aiding in generation of an adequate air void system for freeze-thaw durability. When comparing the results for spacing factor between Figures 4-5 and 4-6, the increased spacing factors for mixtures containing the high LOI Class F fly ash are expected due to the inherent difficulty in entraining air into those mixtures.

When comparing the results in Figures 4-5 and 4-6, it is important to note that the majority of mixtures in Figure 4-5 meet the maximum threshold of a 0.2 mm (0.008 in.) spacing factor, but the mixtures shown in Figure 4-6 do not meet the threshold unless WR2 is used. These results show that a greater dosage of AEA is needed in a mixture when incorporating a high LOI Class F fly ash.

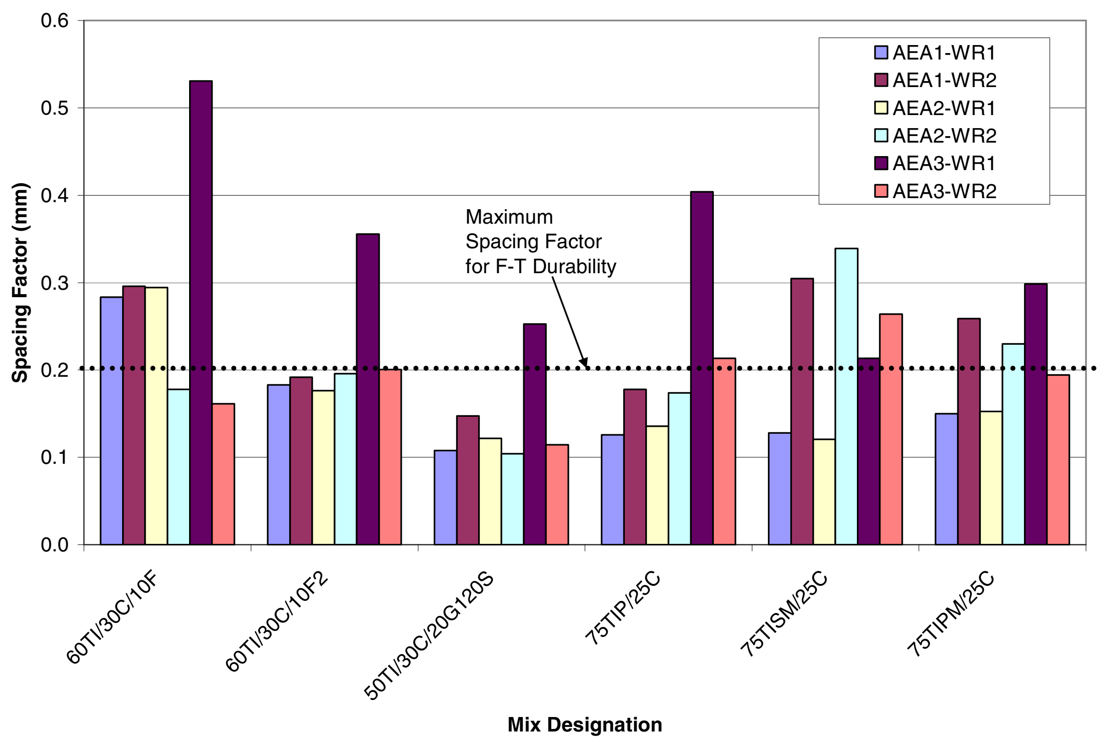

Figure 4-5. Effect of Admixture Combination on the Spacing Factor for Mixtures Containing Large Amounts of Class C Fly Ash

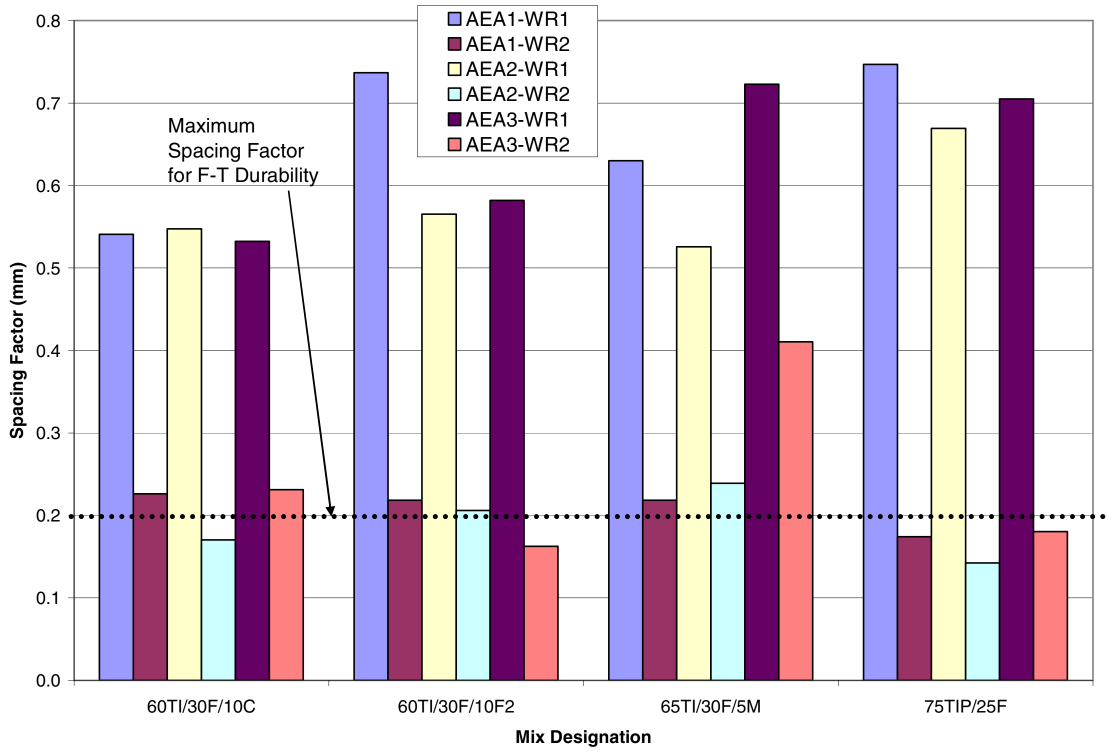

Figure 4-6. Effect of Admixture Combination on the Spacing Factor for Mixtures Containing Large Amounts of Class F Fly Ash

Figure 4-7 shows the effect of admixture combination on the specific surface for mixtures containing large amounts of Class C fly ash. Note that the AEA3 combinations produced mixtures with lower specific surface values compared to combinations with AEA2 and AEA1. This seems counter intuitive because AEA3 is noted for producing a finer air void system.

Figure 4-8 shows the effect of admixture combinations on the specific surface for mixtures containing large amounts of Class F fly ash. Note the results for specific surface are generally the same for combinations containing WR1. When comparing the results shown in Figure 4-7 to those in Figure 4-8, the mixtures containing Class F fly ash significantly reduced the specific surface of the air void structure. These results show that a greater dosage of AEA is required when incorporating a high LOI Class F fly ash.

Although most mixtures meet the threshold of 0.2 mm (0.008 in) spacing factor (see Figure 4-5 and 4-6), the majority of mixtures do not meet the minimum criteria of 23 – 43 mm^{-1} (600 – 1000 in^{-1}) for specific surface. This does not necessarily mean the corresponding concrete will fail in freeze-thaw, but steps should be taken to increase the specific surface and create a finer air void system.

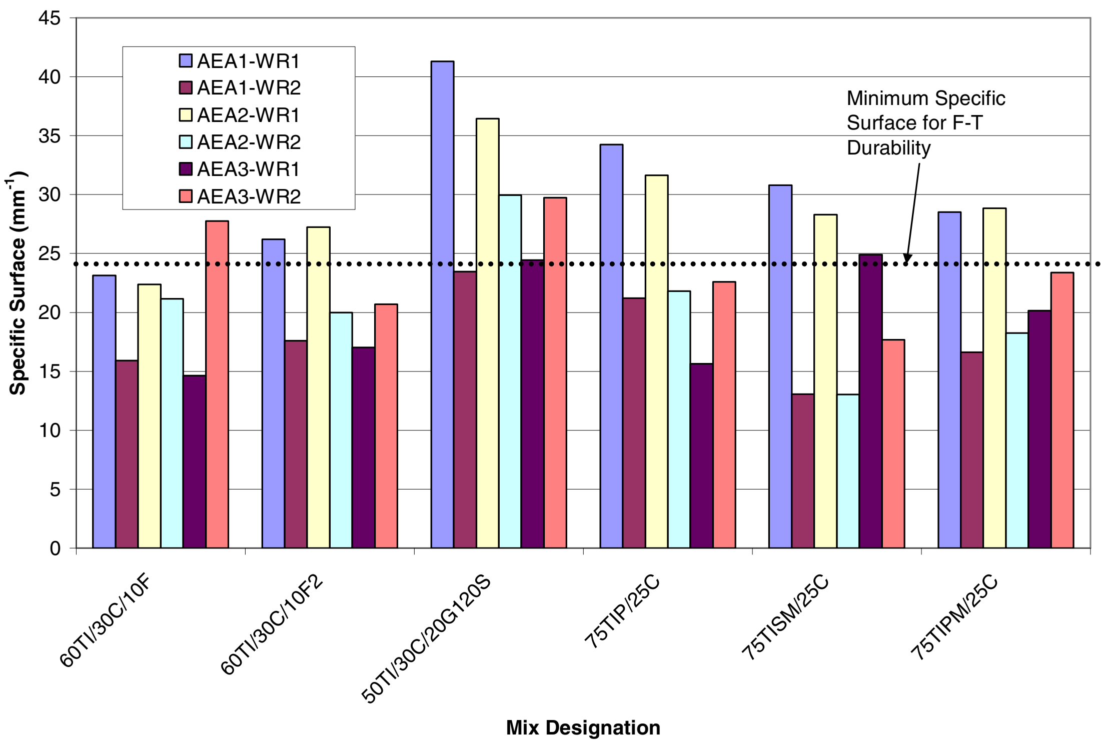

Figure 4-7. Effect of Admixture Combination on the Specific Surface for Mixtures Containing Large Amounts of Class C Fly Ash

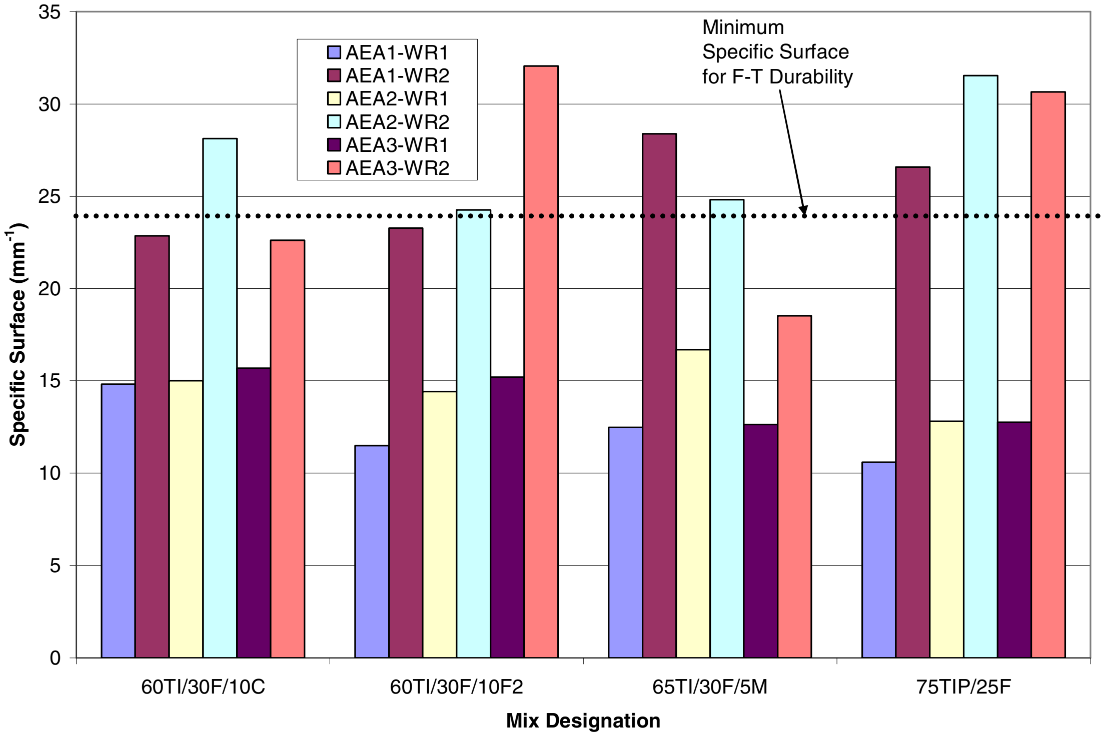

Figure 4-8. Effect of Admixture Combination on the Specific Surface for Mixtures Containing Large Amounts of Class F fly Ash

Figures 4-9 and 4-10 show the effect of admixture combination on the percent of air voids less than 300 µm for mixtures containing Class C and Class F fly ashes, respectively. The percentage of air voids less than 300 µm is important as it is the effective size in prevention of freeze-thaw damage (4).

For mixtures containing large amounts of Class C fly ash (Figure 4-9), note that WR2 tended to decrease the percentage of air voids less than 300 µm in diameter except for mixtures containing AEA3.

Figure 4-10 shows significantly different results compared to Figure 4-9 for percentage of air voids with a diameter less than 300 µm. Note that WR2 produced a significant increase in percent of air voids less than 300 µm in diameter on the order of 8 times greater when compared to mixes containing WR1.

Although the mixtures containing Class F fly ash showed a reduction in the effective air void size, it is important to note that an increase in the AEA dosage will most likely prove to be an acceptable solution.

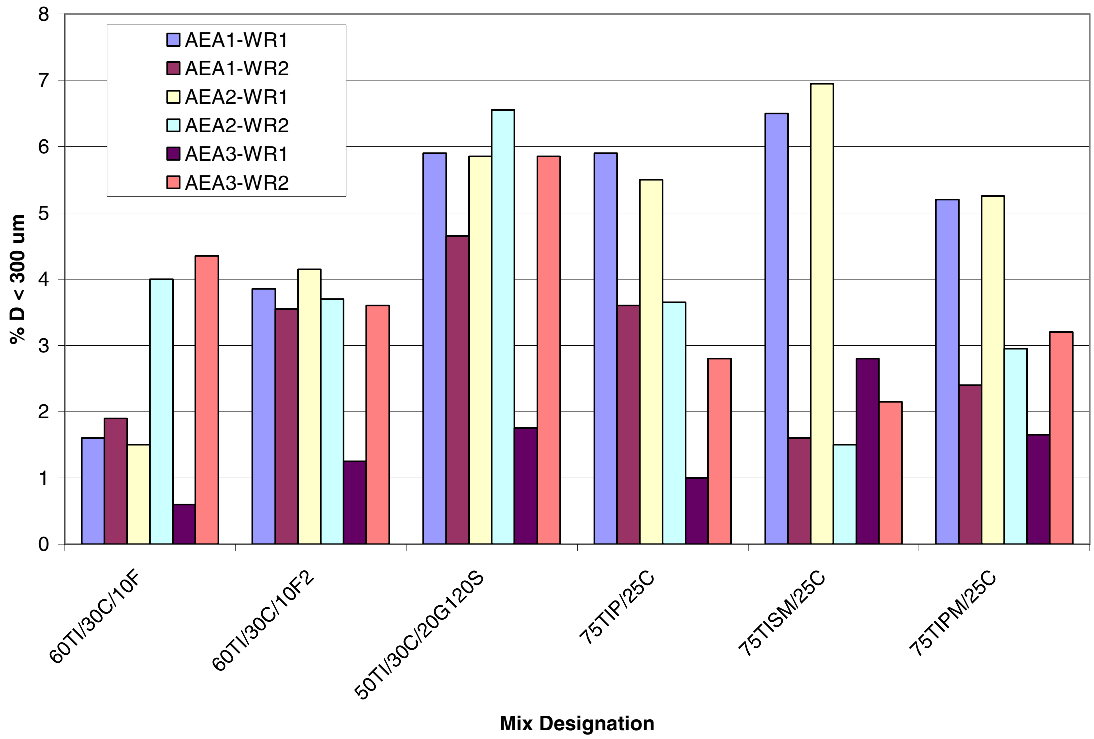

Figure 4-9. Effect of Admixture Combination on the Percent of Air Voids Less than 300 µm for Mixtures Containing Large Amounts of Class C Fly Ash

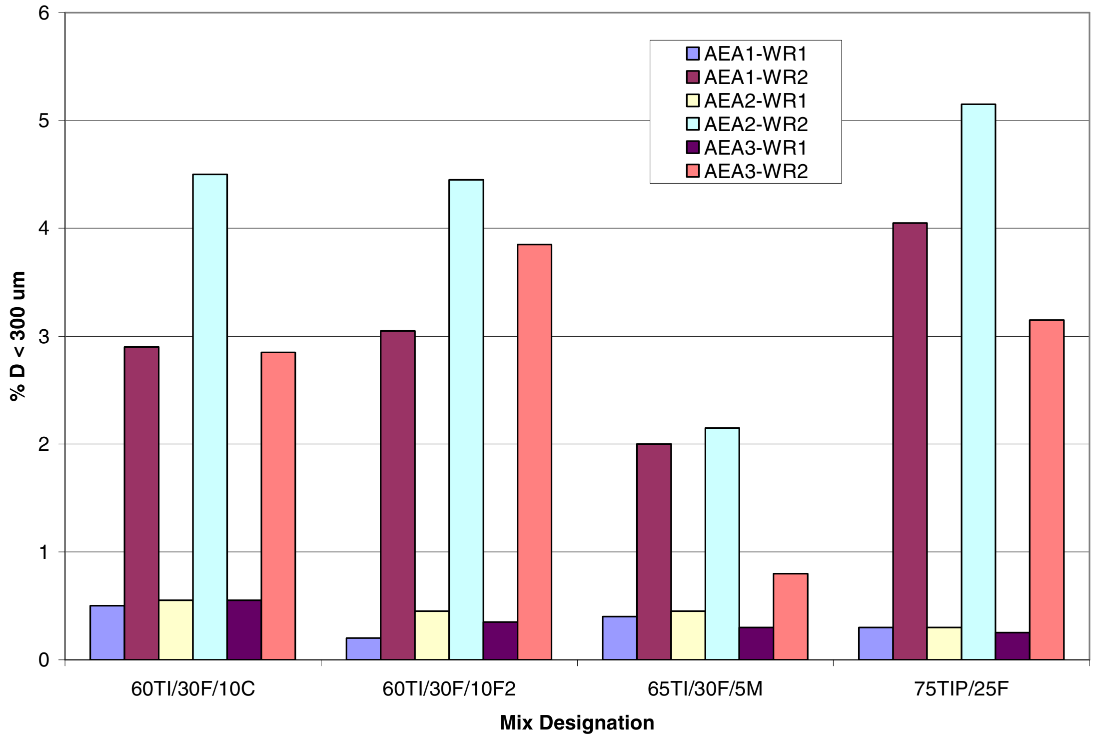

Figure 4-10. Effect of Admixture Combination on the Percent of Air Voids Less than 300 μm for Mixtures Containing Large Amounts of Class F Fly Ash

Figures 4-11 and 4-12 show the effect of admixture combination on the average 7-day compressive strength for mixtures containing Class C and Class F fly ash, respectively. Figure 4-11 immediately indicates an admixture incompatibility issue resulting in retarded compressive strengths for the mixtures containing 30 percent Class C fly ash and Type I portland cement. These results are most likely due to a sulfate imbalance combined with a sucrose based water reducer (15 – 17). These results agree with those found by St. Clair (18) in related research associated with this project.

Although there existed an incompatibility with WR1 in terms of strength gain, the incompatibility is not evident when using WR2. This is important to note for field applications. Also important is the incompatibility was eliminated when a blended cement was used in place of Type I portland cement. In the event this occurs in the field, a simple substitution of water reducers or blended cement may solve the problem.

The results shown in Figure 4-12 note that there are no incompatibility issues such as those found when using Class C fly ash. Note the results are generally the same when comparing between admixture combinations.

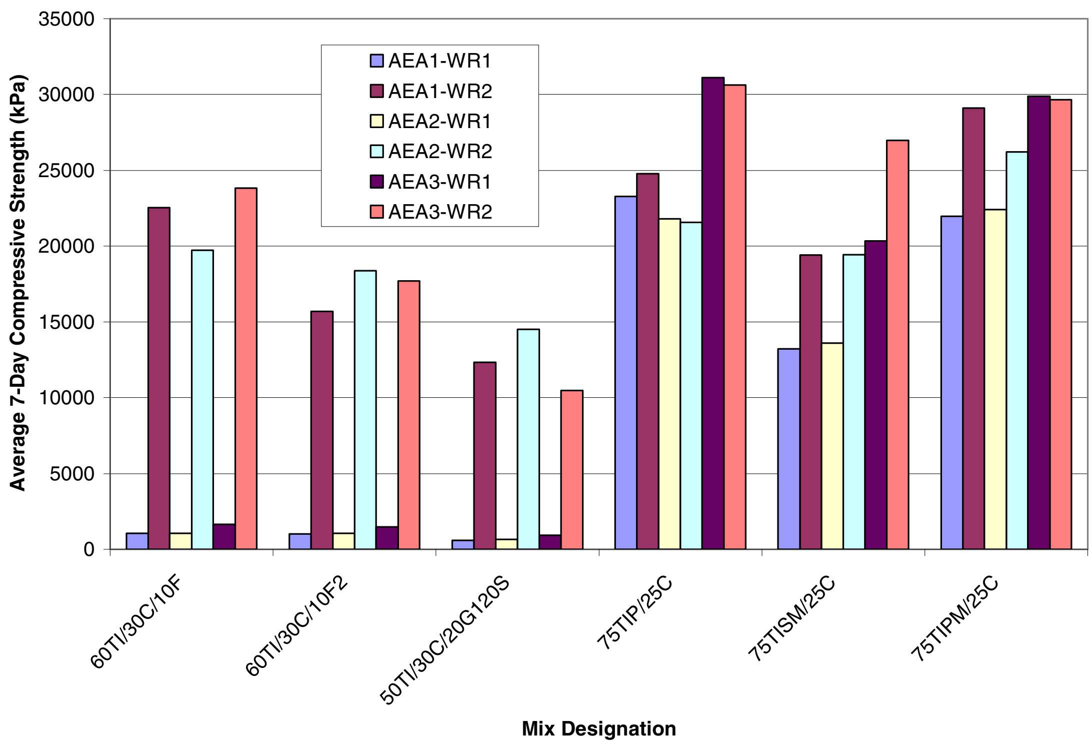

Figure 4-11. Effect of Admixture Combination on the Average Compressive Strength for Mixtures Containing Large Amounts of Class C Fly Ash

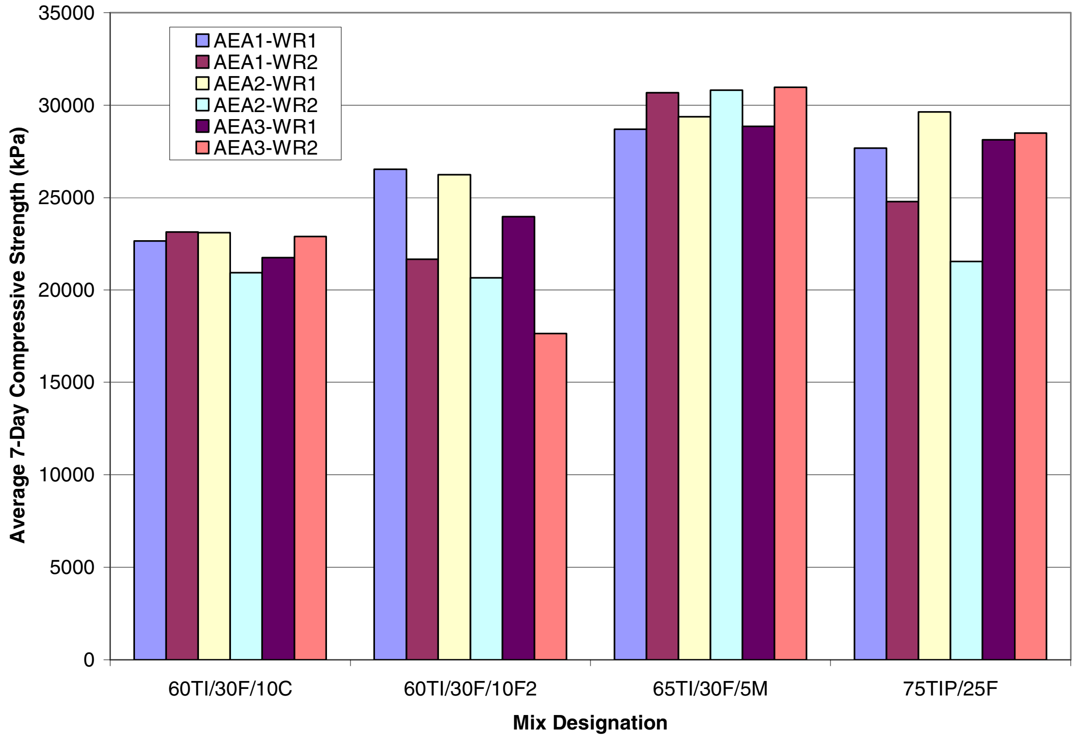

Figure 4-12. Effect of Admixture Combination on the Average Compressive Strength for Mixtures Containing Large Amounts of Class F Fly Ash

Conclusions

The results of this study warrant the following conclusions.

1. A good relationship exists between the spacing factor, specific surface and percentage of air voids less than 300 µm.
2. AEA3 generally provided mortar mixtures with increased spacing factors and lower specific surface values compared to combinations with AEA2 and AEA1 for mixtures containing Class C fly ash.
3. The mortar containing the high LOI Class F fly ash (F1) had much lower percentage of small air voids (less than 300 µm in diameter) than the mortar with other SCMs. However, when WR2 was used together with this fly ash, the percentage of the small air voids significantly increased.
4. An incompatibility with WR1 was evident by the 7-day compressive strength results for mixtures containing Class C fly ash. The incompatibility disappeared when using

WR2 or blended cement. Strength results with Class F fly ash showed no incompatibility issues.

5. Disregarding these incompatible mixes, there is a linear relationship between the total air content and the average compressive strength of the mortar.

Acknowledgements

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CHAPTER 5. EVALUATION OF THE AIR VOID ANALYZER USING DATA FROM A SIXTEEN STATE POOLED FUND PROJECT

A paper to be submitted to *ASTM Journal of Testing and Evaluation*

Tyson Rupnow, Kejin Wang, Vernon Schaefer

Abstract

The objective of this study was to evaluate the effect of sampling location on the air void analyzer results from a sixteen state pooled fund study. The Air Void Analyzer (AVA) results used for this study included the specific surface, spacing factor, and percent of air voids less than 300 μm in diameter. Sampling locations included ahead of the paver, behind the paver on a vibrator, and behind the paver between vibrators. Results showed a drop in total air content when comparing samples from in front of the paver and behind the paver. Statistical analysis of the AVA results showed no significant difference in the AVA results when comparing between the sampling locations of behind the paver on a vibrator and behind the paver between vibrators when using data from all sixteen states. Statistical analysis of the AVA results also showed no significant difference in sampling locations when comparing between ahead of the paver, behind the paver on a vibrator, and behind the paver between vibrators when using data for three states. When observing each state individually, The AVA results for state 1 and 2 did show a significant difference for the ahead of the paver results for percent of air voids less than 300 μm in diameter and specific surface, respectively. The results from state 12 showed that the sampling locations of behind the paver on a vibrator and behind the paver between vibrators significantly affect the AVA results.

Introduction

The materials and construction optimization (MCO) for prevention of premature pavement distress, a sixteen state pooled fun project, had the following objectives. Evaluate conventional and new technologies and procedures for testing concrete and concrete materials to prevent material and construction problems that could lead to premature concrete pavement distress and to develop a suite of tests that provides a comprehensive method of ensuring long-term pavement performance (1). Testing included hardened air analysis, fresh concrete slump and air content, compressive strength, and heat signature and maturity. The air void structure of fresh concrete was also identified using the Air Void Analyzer (AVA).

Freeze-thaw resistance of concrete is directly related to several factors including the air void system of the concrete, low water-to-cementitious materials ratio (w/cm), high quality aggregates, and proper curing. The air void system protects the concrete paste by providing hydraulic pressure relief during the migration and expansion of freezing water (2). The smaller the air voids, the more effective they are in contributing to the freeze-thaw resistance.

Current methods of measuring the air content include the volumetric method and the pressure method, ASTM C 173 (3) and ASTM C 231 (4), respectively. The drawback of these methods is that they are only capable of measuring the total air content of the concrete and not the size distribution of the stabilized air void system. Additionally, the test results can be greatly influenced by a small number of large air voids that provide little to no protection against freeze-thaw.

The current accepted method for measuring the size distribution of air voids in concrete is ASTM C 457 (5). The drawbacks of this method include the results being obtained only on hardened concrete samples and the use of a highly trained technician.

The two primary air void parameters determined by ASTM C 457 are the spacing factor and specific surface. Spacing factor is defined as the maximum distance in the cement paste from the edge of an air void (5) and is expressed in units of length. Specific surface is defined as the surface area of the air voids divided by their volume (5) and is expressed in units of reciprocal length (i.e. mm^{-1} (in^{-1})). For freeze-thaw resistant concrete, spacing factors between 0.1 to 0.2 mm (0.004 to 0.008 inches) and specific surfaces between 24 to 43 mm^{-1} (600 to 1100 in^{-1}) are desirable.

With AVA equipment development in the 1980's, the air void structure could be measured in fresh concrete. This allows field measurements and corrective action in about 30 minutes compared to several days or weeks for a hardened air analysis. Others have conducted research with the AVA (6 – 9) and have commented on its field use. More information on AVA operation can be found in literature by Dansk Benton Teknik (10).

It is commonly known that testing the fresh air content before the paver and after the paver yields differing results, generally a drop in air content. Cable *et al.* (11) investigated the effect of several combinations of vibrator frequency and paver speed on air void parameters in hardened concrete. Results showed differences in the hardened air void structure when comparing samples taken on the vibrator trail versus between the vibrator trails.

The objectives of this research were to evaluate the effect of sampling location and concrete temperature on the spacing factor, specific surface, and percent of air voids with a diameter less than 300 µm (D < 300 µm). Locations tested included in front of the paver on unconsolidated concrete, behind the paver on a vibrator trail, and behind the paver between vibrator trails. For comparison purposes, the pressure air content before and after the paver was also evaluated. Statistical analysis software (JMP) (12) was used to determine the significance of the results.

Test Methods

For the AVA testing conducted, the manufacture-recommended sampling procedure was followed and involves obtaining a 20-cc mortar sample from the fresh concrete using a vibrating wire cage attached to a high speed drill in field locations. The wire cage is vibrated into the fresh concrete through an acetate plate, and the 20-cc sample is obtained with the use of a 20-cc syringe. The sample was removed and stored on ice until testing as recommended by the AASHTO AVA Technical Implementation Group (TIG) (13).

The AVA testing procedure involves placing water into the riser column. The bottom of the column is then filled with glycerol. The mortar sample is injected into the glycerol and a magnetic stir bar mixes the glycerol and mortar for 30 seconds. The air voids released during and after mixing are recorded on an inverted glass dish as a change in mass over time. The test can take up to 30 minutes to complete, and the software displays the cumulative distribution of air voids, a histogram of the air voids, and numerical values of spacing factor, specific surface, and percent of air voids with a diameter less than 300 µm. Table 5-1 shows the states and their corresponding number of AVA samples in the analysis.

Table 5-1. Number of AVA Samples for Each State

State	Number of AVA Samples
1	24
2	30
3	15
4	10
5	6
6	8
7	16
8	10
9	22
10	20
11	16
12	14
13	10
14	12
15	10
16	14
Total	237

Results and Discussion

Figure 5-1 shows the relationship between spacing factor and specific surface for all data. Figure 5-2 shows the relationship between spacing factor and D < 300 µm, and Figure 5-3 shows the relationship between the specific surface and D < 300 µm for all data. Note the strong correlations between spacing factor and specific surface and between spacing factor and D < 300 µm as is expected.

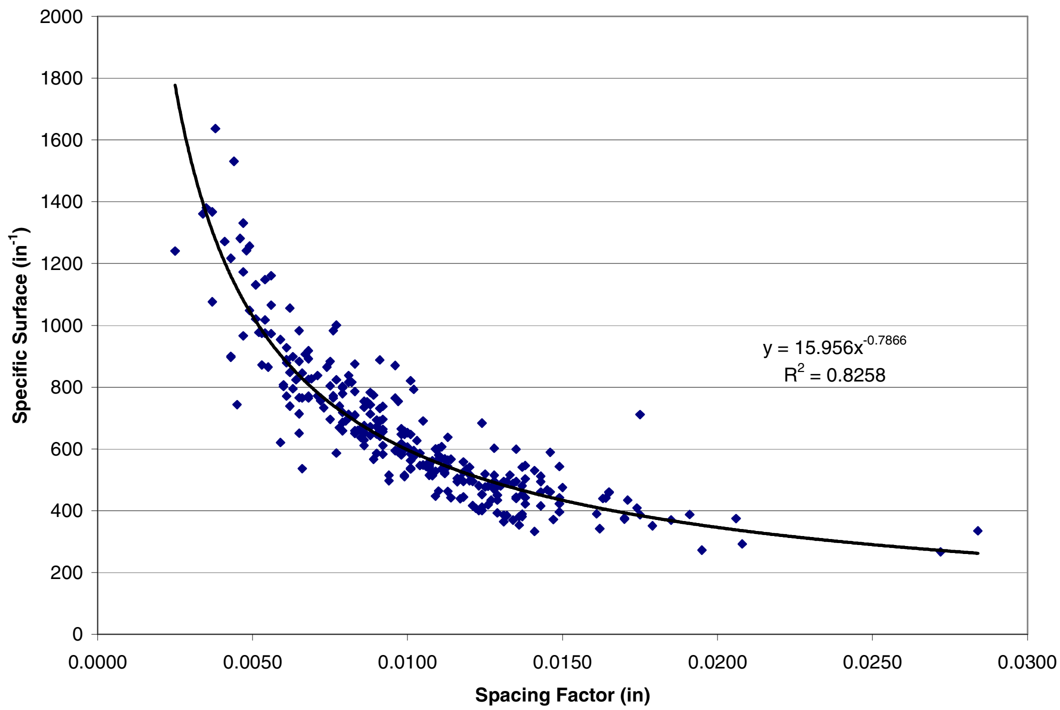

Figure 5-1. **Relationship between Specific Surface and Spacing Factor for All Data (N = 237)**

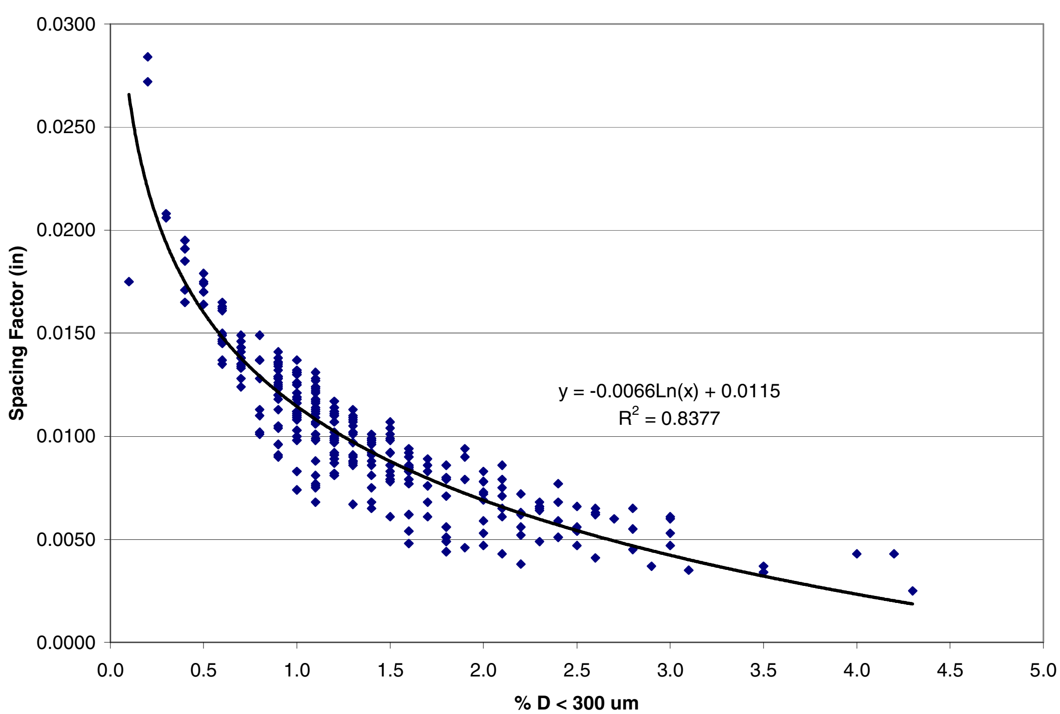

Figure 5-2. **Relationship between Spacing Factor and % D < 300 µm for All Data (N = 237)**

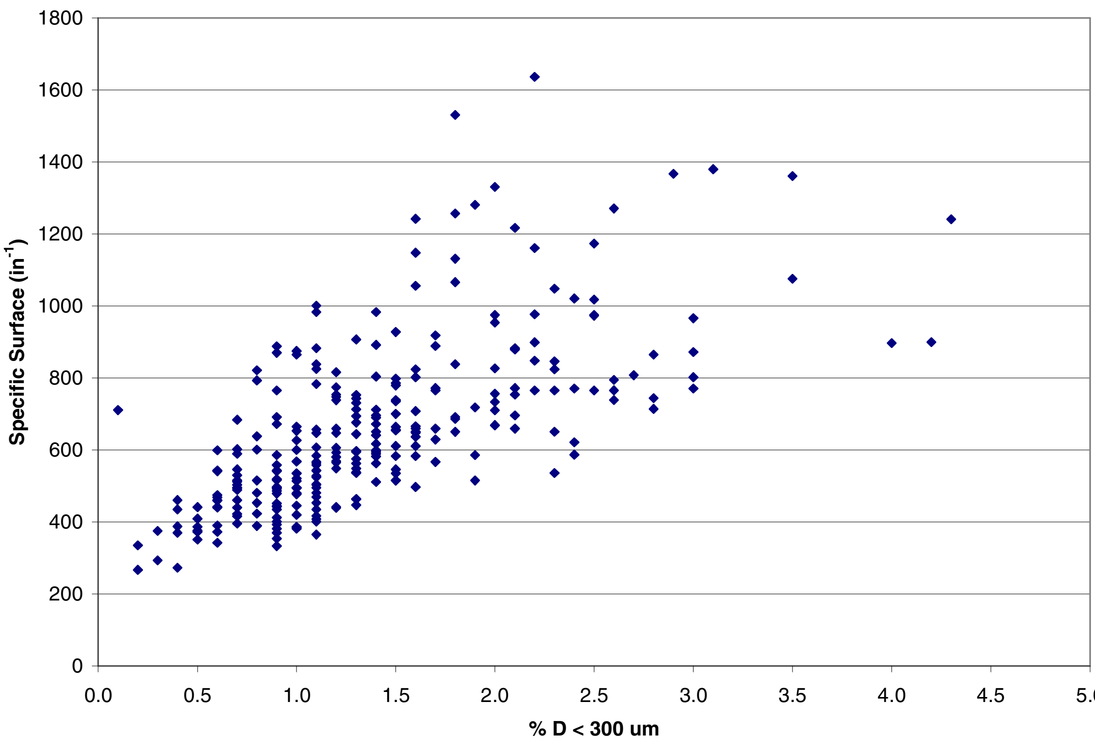

Figure 5-3. Relationship between Specific Surface and % D < 300 μm for All Data (N = 237)

Figures 5-4 to 5-6 show the effect of sampling location on the specific surface, spacing factor, and % D < 300 μm for all states, respectively. Note the results in Figure 5-4 show generally the same specific surface regardless of the sampling location. The results for spacing factor (Figure 5-5) also show generally the same results regardless of the sampling location. The results for % D < 300 μm (Figure 5-6) follow those for the spacing factor and specific surface.

Figures 5-7 to 5-10 show the effect of sampling location on the specific surface and spacing factor for the three states where samples were obtained ahead of the paver, respectively. The results in Figures 5-7 to 5-10 show generally the same specific surface and spacing factor regardless of the sampling location indicating the paving operation had no effect on the entrained air void system. The results in Figures 5-11 and 5-12 show that the % D < 300 μm is significantly affected with the % D < 300 μm being greater before the paver compared to both behind paver sampling locations. The decrease in percent of air voids less than 300 μm in diameter from the ahead of paver to the behind of paver sampling locations agrees with the results from Cable et al. (7) which noted the effects of vibrator frequency on the hardened air void structure.

The pressure air content before and after the paver results are shown in Figure 5-13 for comparison. Note the drop in air content between the sampling locations that is most likely due to the consolidation of the concrete removing entrapped air voids as expected. It is important to note that the air content decreased when observing the pressure air content, but when comparing the AVA results, sampling location was not significant.

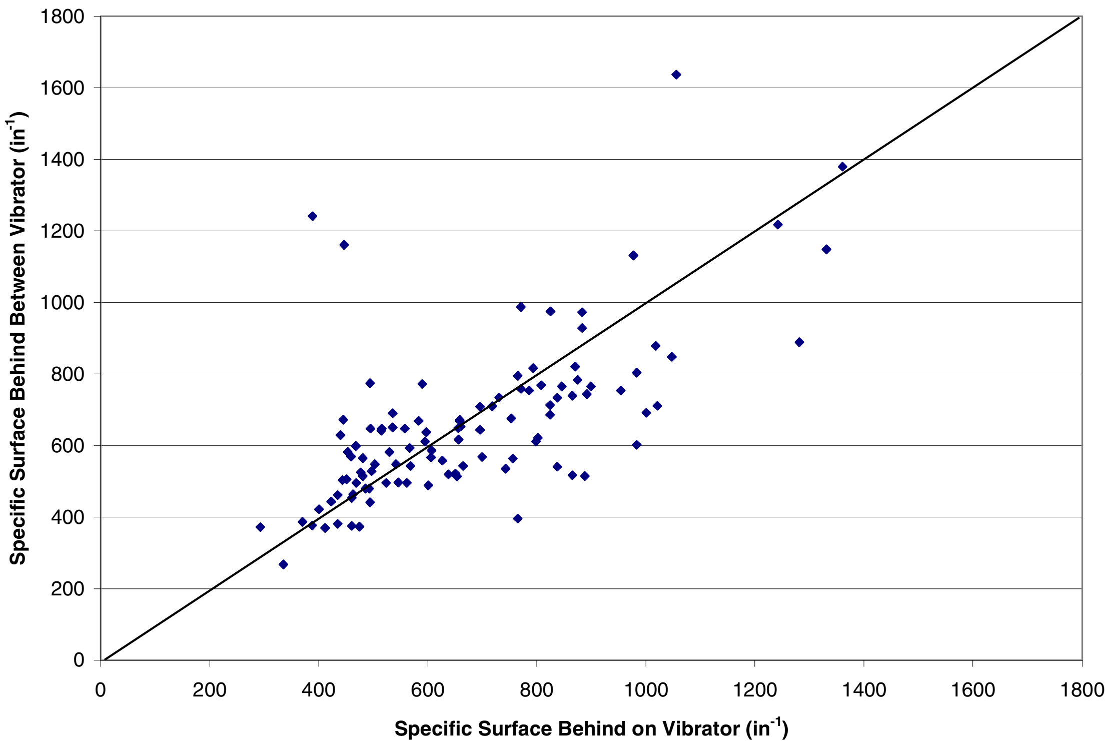

Figure 5-4. Effect of Sampling Location on Specific Surface for All States

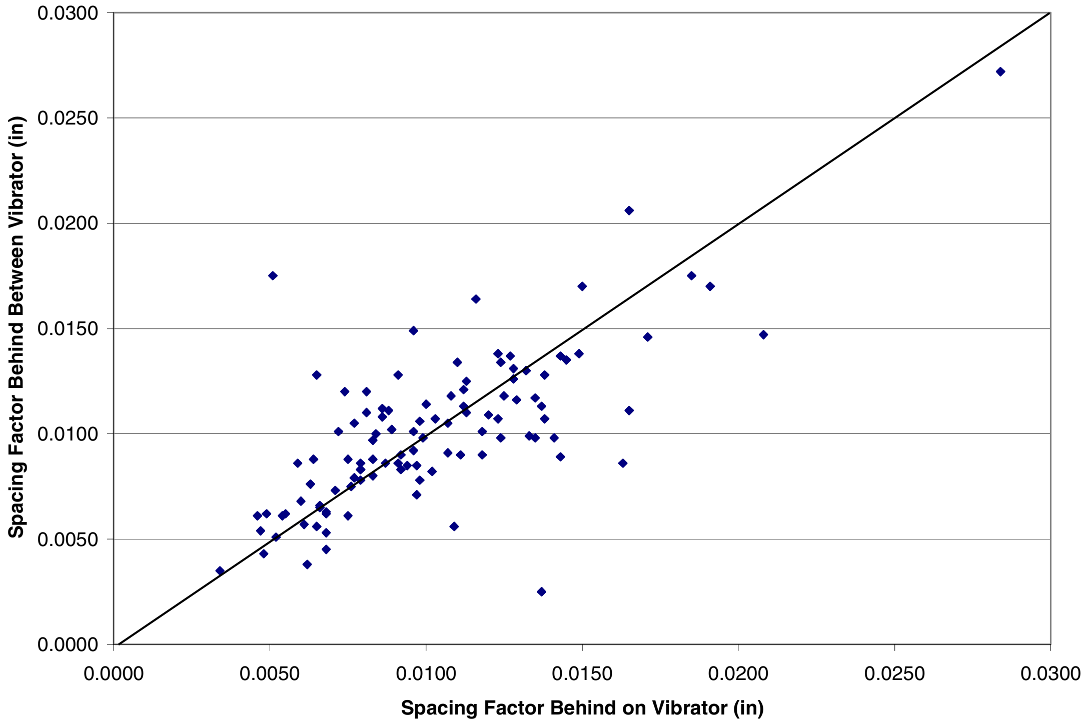

Figure 5-5. Effect of Sampling Location on the Spacing Factor for All States

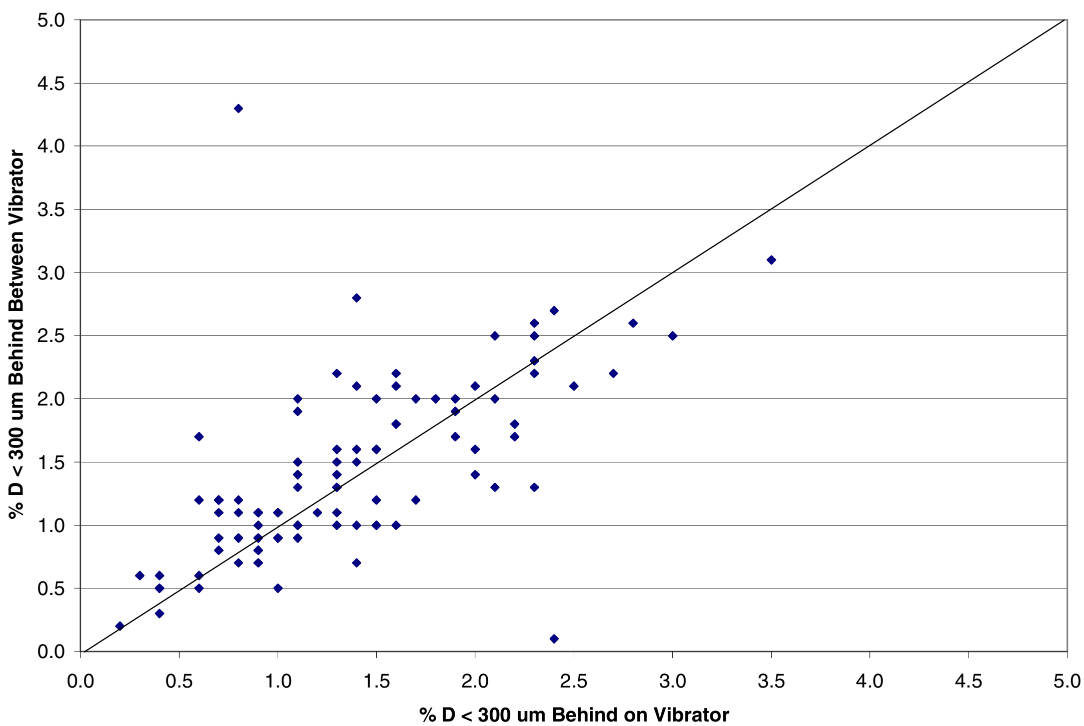

Figure 5-6. Effect of Sampling Location on the Percent of Air Voids Less Than 300 μm in Diameter for All States

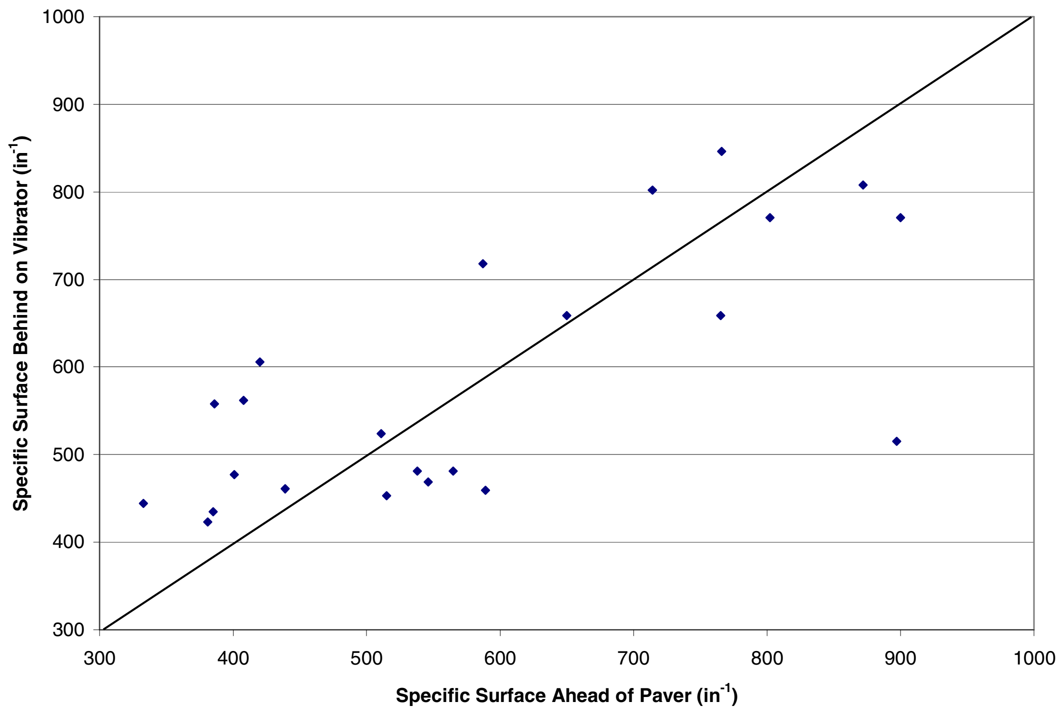

Figure 5-7. Effect of Sampling Location on the Specific Surface When Comparing Ahead of the Paver and Behind on Vibrator Sampling Locations

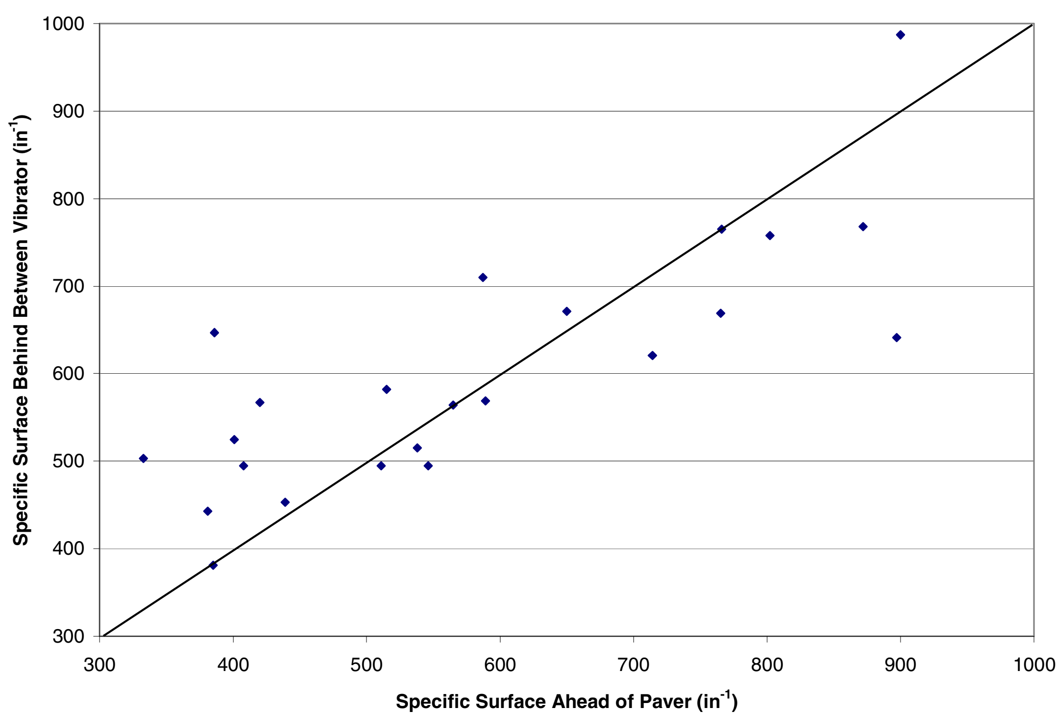

Figure 5-8. Effect of Sampling Location on the Specific Surface When Comparing Ahead of the Paver versus Behind Between Vibrator Sampling Locations

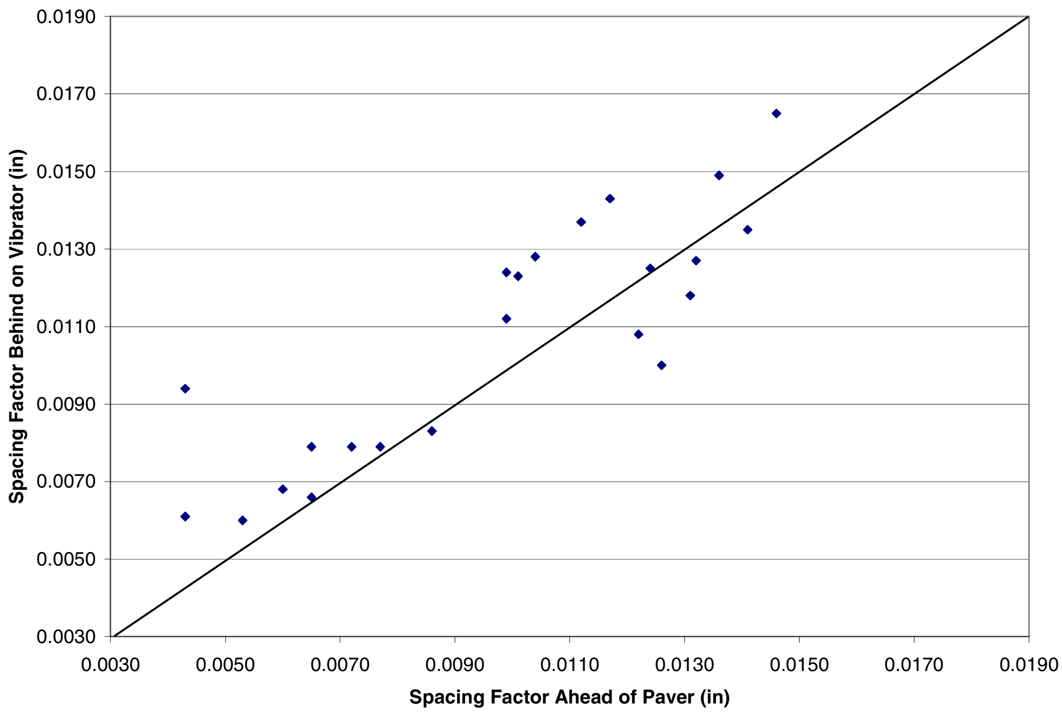

Figure 5-9. Effect of Sampling Location on the Spacing Factor When Comparing Ahead of the Paver and Behind on Vibrator Sampling Locations

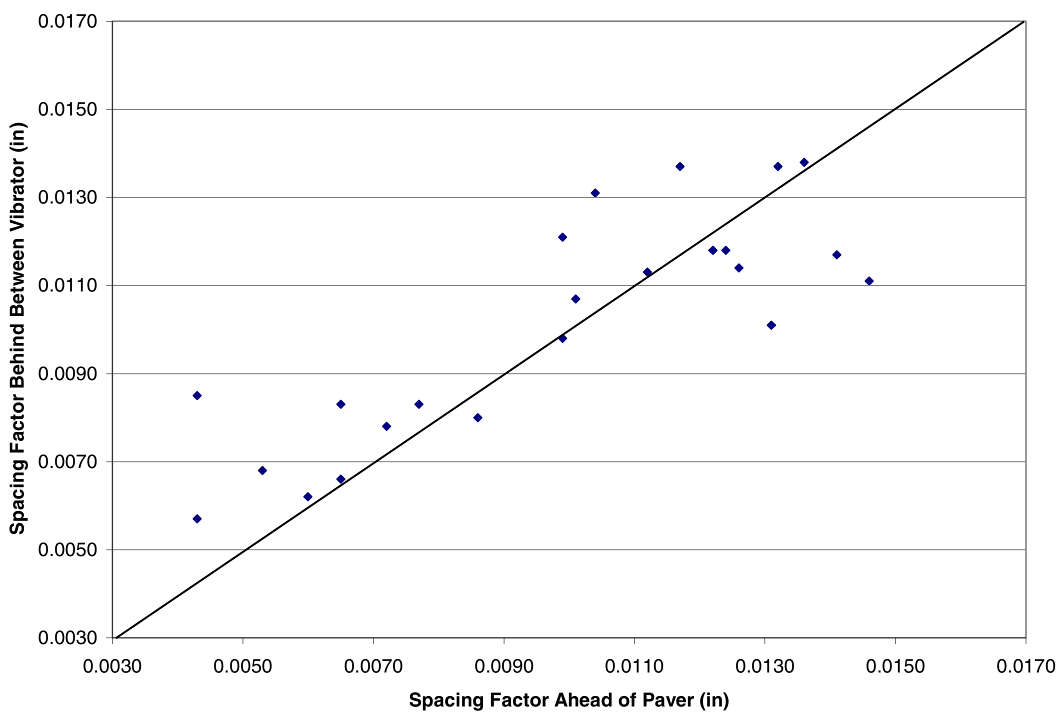

Figure 5-10. Effect of Sampling Location on the Spacing Factor When Comparing Ahead of the Paver and Behind Between Vibrator Sampling Locations

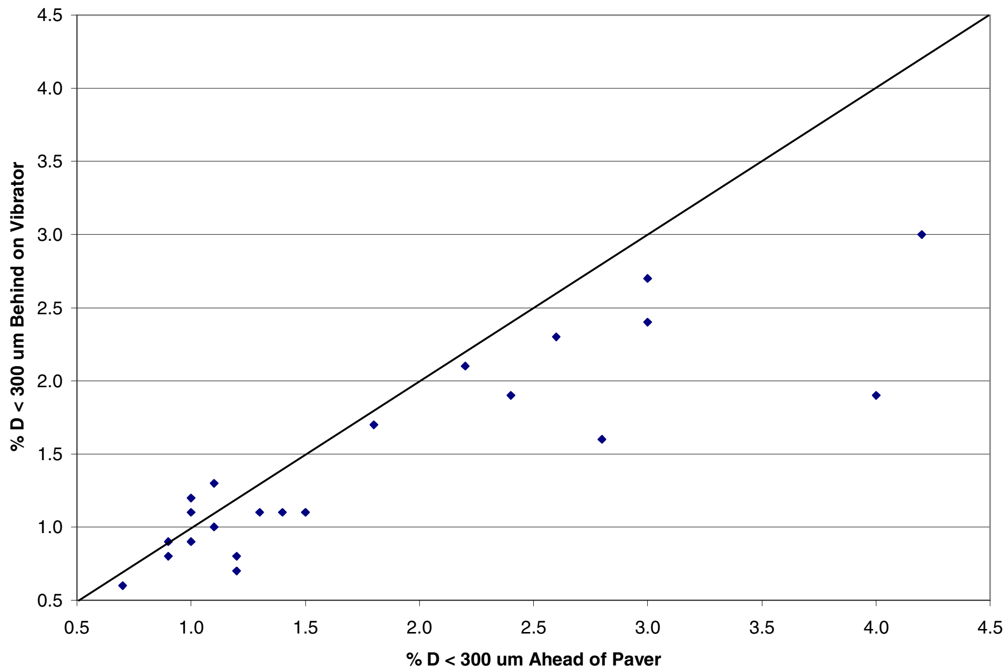

Figure 5-11. Effect of Sampling Location on the Percent of Air Voids Less Than 300 µm in Diameter When Comparing Ahead of the Paver and Behind on Vibrator Sampling Locations

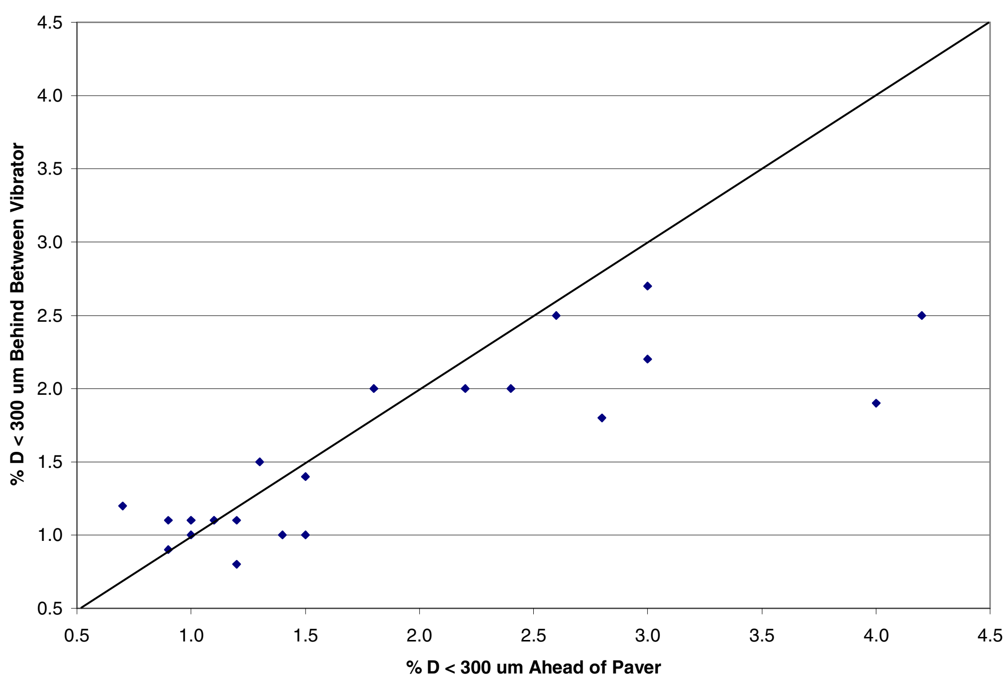

Figure 5-12. Effect of Sampling Location on the Percent of Air Voids Less Than 300 µm in Diameter When Comparing Ahead of the Paver and Behind on Vibrator Sampling Locations

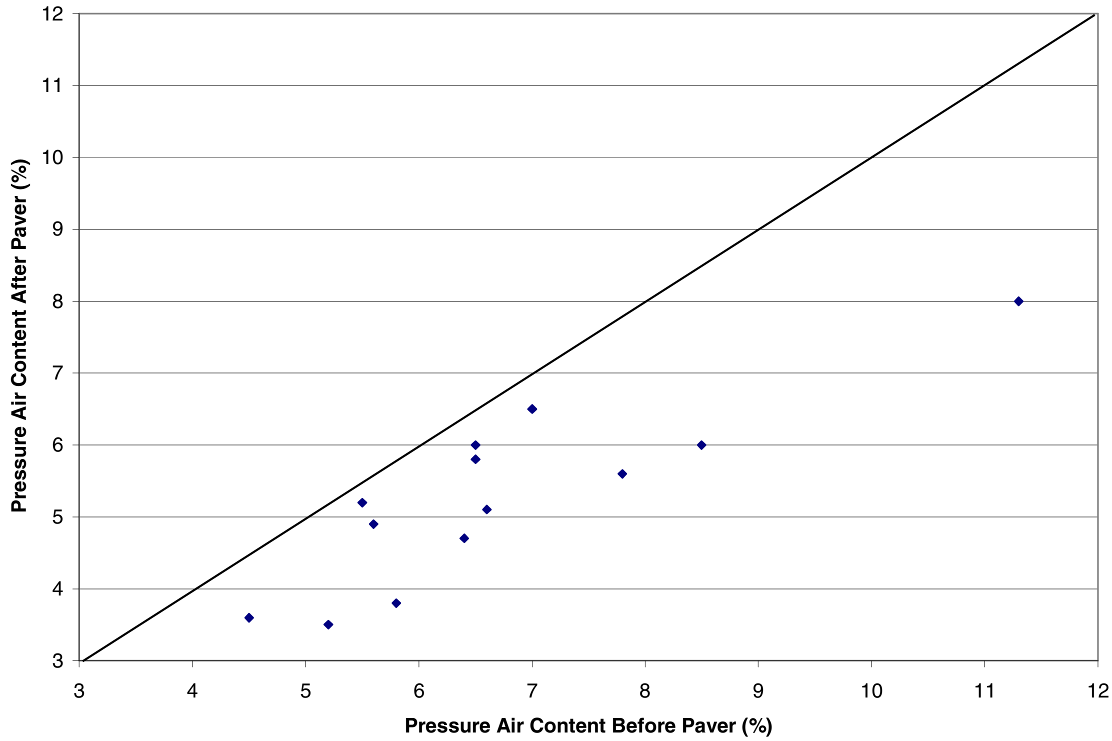

Figure 5-13. Effect of Sampling Location on the Pressure Air Content Results

Table 5-2 shows the average and standard deviations for the AVA specific surface, spacing factor, and % D < 300 μm for ahead of the paver sampling locations. Table 5-3 shows the average and standard deviations for the AVA specific surface, spacing factor, and % D < 300 μm for the behind the paver sampling locations. Note the large standard deviations for all testing locations. This may be due to the inherent variability of the AVA test method.

Table 5-2. Average AVA Values for the Ahead of the Paver Sampling Location

State	Average Specific Surface in^{-1} (Stdev)	Average Spacing Factor in (Stdev)	Average % D < 300 μm % (Stdev)
1	774 (117)	0.0062 (0.0015)	3.0 (0.8)
2	418 (57)	0.0123 (0.0014)	1.0 (0.2)
3	601 (94)	0.0107 (0.0027)	1.0 (0.5)

Table 5-3. Average AVA Values for the Behind the Paver Sampling Location

State	Behind Paver on Vibrator: Average Specific Surface in^{-1} (Stdev)	Behind Paver on Vibrator: Average Spacing Factor in (Stdev)	Behind Paver on Vibrator: Average % D < 300 µm % (Stdev)	Behind Paver Between Vibrator: Average Specific Surface in^{-1} (Stdev)	Behind Paver Between Vibrator: Average Spacing Factor in (Stdev)	Behind Paver Between Vibrator: Average % D < 300 µm % (Stdev)
1	736 (106)	0.0074 (0.0012)	2.2 (0.5)	740 (115)	0.0073 (0.0011)	2.2 (0.3)
2	494 (63)	0.0124 (0.0015)	1.0 (0.2)	509 (76)	0.0120 (0.0014)	1.1 (0.2)
3	510 (84)	0.0126 (0.0031)	1.1 (0.6)	562 (67)	0.0108 (0.0019)	1.4 (0.4)
4	621 (149)	0.0092 (0.0022)	1.7 (0.7)	605 (105)	0.0092 (0.0021)	1.6 (0.6)
5	497 (48)	0.0118 (0.0017)	1.0 (0.3)	752 (354)	0.0089 (0.0029)	1.6 (0.6)
6	777 (183)	0.0086 (0.0009)	1.2 (0.2)	686 (133)	0.0090 (0.0016)	1.3 (0.3)
7	765 (153)	0.0099 (0.0021)	1.0 (0.2)	679 (158)	0.0099 (0.0019)	1.1 (0.2)
8	836 (225)	0.0083 (0.0036)	1.6 (0.7)	845 (454)	0.0103 (0.0052)	1.3 (0.8)
9	453 (135)	0.0158 (0.0061)	0.7 (0.6)	490 (267)	0.0148 (0.0065)	1.1 (1.2)
10	707 (171)	0.0093 (0.0027)	1.4 (0.5)	681 (129)	0.0093 (0.0022)	1.5 (0.5)
11	694 (175)	0.0098 (0.0037)	1.4 (0.6)	734 (56)	0.0082 (0.0011)	1.8 (0.5)
12	674 (111)	0.0087 (0.0019)	1.6 (0.4)	580 (59)	0.0101 (0.0011)	1.2 (0.2)
13	868 (241)	0.0077 (0.0023)	1.2 (0.3)	759 (320)	0.0090 (0.0038)	1.4 (0.6)
14	1106 (255)	0.0056 (0.0019)	2.1 (0.8)	953 (265)	0.0057 (0.0017)	2.1 (0.7)
15	475 (21)	0.0133 (0.0015)	0.8 (0.2)	546 (132)	0.0131 (0.0037)	0.7 (0.3)
16	699 (265)	0.0094 (0.0033)	1.4 (0.6)	648 (254)	0.0101 (0.0034)	1.3 (0.6)

Sampling Location Effects

Data analysis was conducted using JMP (12) to determine the significance of sampling location at alpha = 0.05. One of the main focuses of this research project was to determine whether the sampling location (behind the paver) was significant. Sample results from behind the paver on a vibrator trail, behind the paver between vibrator trails, and ahead of the paver were analyzed to determine if the results were significantly different.

Table 5-4 shows the t-test results comparing sampling locations. Note that a “No” indicates that there is no significant difference between the results of the two sampling locations. Note the first t-test was used to determine if the sampling location significantly affected the results for samples obtained behind the paver either on or between vibrators. The second t-test was used to determine if the sampling location is significant for samples obtained ahead of the paver and behind the paver either on or between vibrators.

Table 5-4. T-test Results Comparing Sampling Locations

Sampling Location*	Specific Surface	Spacing Factor	% D < 300 μm
BOV - BBV	No	No	No
AP – BOV - BBV	No	No	No

***AP, BOV, and BBV represent testing locations of ahead of paver, behind on vibrator, and behind between vibrators, respectively**

The results in Table 5-4 show when all sixteen states are tested together, the sampling location is not significant when interpreting the AVA results. These results show that the paving operations noted in these states did not significantly affect the entrained air void system during the paving operation. These results are important due to the ease of sampling ahead of the paver compared to behind the paver while finishing operations are taking place.

Once the entire data set was analyzed, each state was analyzed by itself to identify is there were significant differences in the AVA results when comparing sampling locations. Table 5-5 shows the results for each state sampling location comparisons. Note a “No” and a “Yes” indicates no significant difference and a significant difference in the sampling locations, respectively.

The results in Table 5-5 show no significant differences in each states results when comparing between the behind the paver between vibrator and behind the paver on vibrator sampling locations when comparing specific surface and spacing factor. Note the results from state 16 did show that sampling location significantly affects the results for % D < 300 μm. These results may explain the increased deterioration that is sometimes observed in the hardened concrete at the vibrator trail locations.

Table 5-5. T-test Results Comparing Sampling Locations for Each State

State	Sampling Locations*	Specific Surface	Spacing Factor	% D < 300 μm
1	BOV - BBV	No	No	No
	AP - BOV	No	No	Yes
	AP - BBV	No	No	Yes
2	BOV - BBV	No	No	No
	AP - BOV	Yes	No	No
	AP - BBV	Yes	No	No
3	BOV - BBV	No	No	No
	AP - BOV	No	No	No
	AP - BBV	No	No	No
4	BOV - BBV	No	No	No
5	BOV - BBV	No	No	No
6	BOV - BBV	No	No	No
7	BOV - BBV	No	No	No
8	BOV - BBV	No	No	No
9	BOV - BBV	No	No	No
10	BOV - BBV	No	No	No
11	BOV - BBV	No	No	No
12	BOV - BBV	No	No	Yes
13	BOV - BBV	No	No	No
14	BOV - BBV	No	No	No
15	BOV - BBV	No	No	No
16	BOV - BBV	No	No	No

***AP, BOV, and BBV represent testing locations of ahead of paver, behind on vibrator, and behind between vibrators, respectively**

The results from Table 5-5 also point that the ahead of the paver sampling location did significantly affect the AVA testing results for specific surface (state 2) and % D < 300 μm (state 1). This result was not observed in the overall analysis most likely due to the variability of the AVA test procedure.

Conclusions

The results of this study warrant the following conclusions.

1. The pressure air content decreased between sampling location before the paver and after the paver as expected.
2. Specific surface, spacing factor, and percent of air voids less than 300 μm in diameter results were not significantly affected by the sampling location when comparing all data. These results allow technicians to sample in front of the paver minimizing interference with finishing and curing operations behind the paver.
3. When comparing each state individually, state 1and state 2 showed that the ahead of the paver sampling location significantly affects the percent of air voids less than 300 μm in diameter and specific surface, respectively, but not the spacing factor results.

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CHAPTER 6. HEAT SIGNATURE CHARACTERIZATION AND MODELING OF TERNARY CEMENTITOUS SYSTEMS

A paper to be submitted to *ACI Materials Journal*

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Abstract

In the present paper, the effects of differing combinations of portland cement and supplementary cementitious materials (SCM) on the heat signature curve of fresh mortar were investigated. Slope 1 and 2, maximum temperature, time to maximum temperature, area under the curve, and time to initial and final set were used to characterize the heat signature curves. Linear least squares and stepwise regression analysis was completed to model the data set using the C_3S, C_2S, C_3A, C_4AF content in the cement. The average calcium oxide content fly ash and the average fineness of the ground granulated blast furnace slag were used as model parameters. The metakaolin and silica fume contents were also used as model parameters. The heat signature was measured using a thermocouple in semi-adiabatic conditions at 21°C ± 1°C (70°F ± 1.5°F). Linear least squares regression analysis showed good R^2 values ranging from 0.65 to 0.76. Stepwise regression analysis simplified the models by removing the non-significant input parameters and showed good R^2 values ranging from 0.65 to 0.76.

Introduction

Supplementary cementitious materials (SCM) are increasingly used in concrete construction; however, some combinations of SCM can significantly affect the heat signature characteristics as the mixture hydrates leading to false set, flash set, or delayed set.

Cement hydration is a complex process that is influenced by not only the chemistry and fineness of the cementitious materials, but also the water-to-cementitious material ratio (w/cm) and environmental condition (such as temperature). Further adding to the complexity is incorporation of SCM such as silica fume, Class C and Class F fly ash, and ground granulated blast furnace slag (GGBFS) and chemical admixtures (such as water reducers) into the system.

Setting and hardening of concrete are result of chemical and physical processes that take place between cement and water. Much of the understanding of cement hydration has come through the study of the heat generated during the hydration process.

The cement hydration process produces a measurable rate of heat evolution and can be expressed as a calorimetric curve shown in Figure 6-1. Note the five stages of cement hydration. There is considerable literature pertaining to heat evolution for portland cement concretes and binary portland cement concrete systems (1 – 4), but little literature on the heat signature of ternary mixtures.

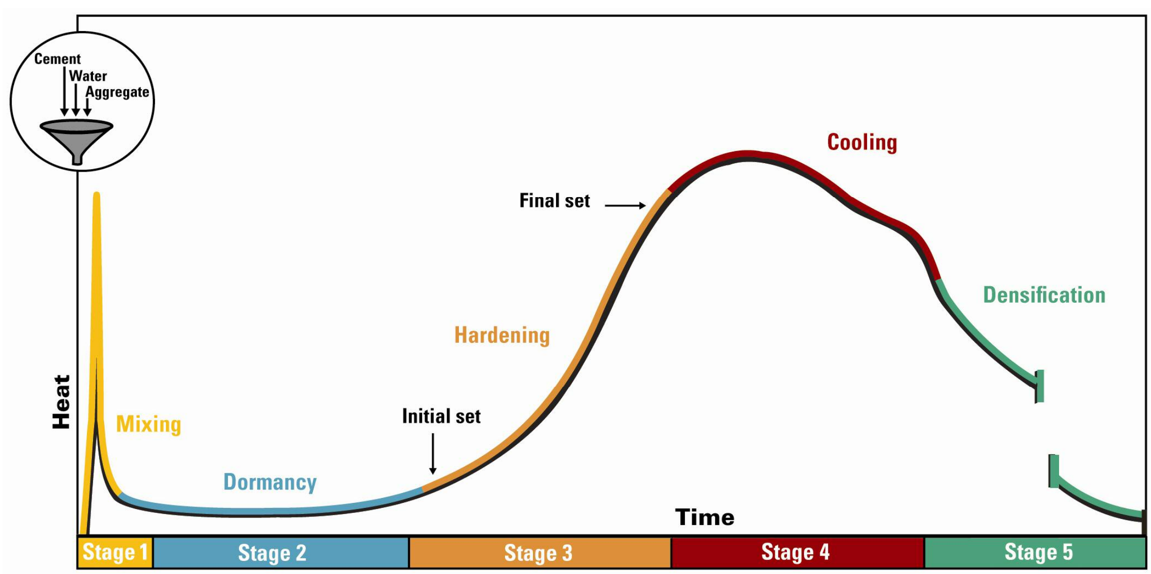

Figure 6-1. Calorimetric Curve (5)

Kashima *et al.* (6) studied a ternary mixture composed of high volumes of slag, fly ash, and low-heat cement for the main tower foundations for the Akashi Kaikyo Bridge. The authors noted for the large mass concrete applications, low-heat cement combined with slag and fly ash allowed for low heat generation for a reduction in thermal stresses.

Kashima *et al*. (7) studied a ternary mixture in a related project for wall foundations and noted a 25 percent reduction in the adiabatic temperature rise of the ternary concrete compared to concrete produced with ordinary portland cement.

Baoyu *et al.* (8) noted a ternary mixture containing fly ash and silica fume showed a great decrease in the total heat of hydration compared to ordinary portland cement concrete. Nehdi *et al*. (9) also noted a reduction in the total heat of hydration when using a ternary mixture replacing 50 percent of the portland cement with slag and fly ash.

Hinczak and Roper (10) studied ternary cements and their impacts on short and long term properties. They noted that the use of fly ash and slag not only reduced the total heat generated, but the rate of heat evolution was also lower indicating greater thermal stability.

The objective of the present research is to investigate the effects of differing combinations of SCM and portland cement on the heat generation curve. Slope 1 and 2, maximum temperature, time to maximum temperature, area under the heat generation curve, and time to initial and final set were used to characterize said curves. A least squares regression analysis was used to model the data. A stepwise regression analysis was used to determine the significant variables used in each model. Parameters measured included portland cement and SCM chemistry, temperature generated, maximum temperature, time to maximum temperature, area under the curve, and time to initial and final set.

Materials and Test Methods

Materials

Mortar samples were used for this study and cementitious materials used include: ASTM C 150 (11) Type I, ASTM C 595 (12) IPM, ISM, IP, and Ternary portland cement, ASTM C 618 (13) Class C and two Class F fly ashes (FA), ASTM C 989 (14) grade 100 and 120 ground granulated blast-furnace slag (GGBFS), ASTM C 1240 (15) silica fume, and ASTM C 618 (13) Class C metakaolin. Table 6-1 shows the chemical composition and symbol notation of the portland cements. Table 6-2 shows the chemical composition and symbol notation of the class C and class F FA, grade 100 and 120 GGBFS, silica fume, and metakaolin. Note the chemistries of the portland cements and SCMs used are typical for materials available in the United States.

Natural river sand was used for the fine aggregate and had a fineness modulus and absorption of 2.81 and 1.12 percent, respectively.

For this research, 120 mixture designs (16) were evaluated. Mixture designs contained portland cement contents ranging from 48 – 100 percent by mass when looking at the breakdown of the binary cements. Class C and F fly ashes, Grade 100 and 120 GGBFS, silica fume, and metakaolin were incorporated at 10 – 51 percent, 13 – 45 percent, 3 – 11.7 percent, and five percent, respectively.

Table 6-1. Chemical Composition of Portland Cement

		Type I	TI/II	TIPM	TISM	TIP	Ternary
Chemical Composition, %	CaO	61.62	63.00	59.15	58.23	50.88	53.15
	SiO_2	19.79	20.70	24.91	23.51	28.88	26.37
	Al_2O_3	6.19	4.16	4.38	5.27	8.19	5.90
	Fe_2O_3	2.50	3.13	3.12	2.99	3.70	2.61
	MgO	2.76	3.02	1.36	4.33	1.60	4.80
	K_2O	0.75	0.75	0.56	0.59	0.90	0.38
	Na_2O	0.34	0.09	0.22	0.13	0.35	0.24
	SO_3	2.58	2.84	3.33	2.87	2.74	3.03
	TiO_2	0.28	0.10	0.29	0.41	0.44	0.14
	P_2O_5	0.21	0.33	0.11	0.10	0.22	0.35
	SrO	0.24	0.05	0.10	0.04	0.20	0.09
	Mn_2O_3	0.11	0.56	0.18	0.50	0.20	0.26
Fineness (m^2/kg)		388	405	450	378	433	590

Test Methods

Heat signature sample preparation was completed by mixing mortar according to ASTM C 305 (17) with a water-to-cementitious materials ratio (w/cm) of 0.45 and a sand to cement ratio of 2.75:1. All materials were batched and mixed at 21°C ± 1°C (70°F ± 1.5°F). The fresh mortar was transferred to 75 mm x 150 mm (3 inch x 6 inch) cylinder molds. A thermocouple was then inserted to approximately the mid height of the sample and the sample was stored at 21°C ± 1°C (70°F ± 1.5°F). Readings were acquired at one minute intervals for approximately 24 hours. The samples were removed from the molds, the wires clipped, and the data downloaded for analysis.

Set time testing was completed on mortar samples according to ASTM C 403 (18) to determine initial and final set.

Table 6-2. Chemical Composition of Class C, Class F, GGBFS, and Metakaolin

		Class C (C)	Class F (F)	Class F (F2)	Grade 100 GGBFS (G100S)	Grade 120 GGBFS (G120S)	Silica Fume (SF)	Metakaolin (M)
Chemical Composition, %	CaO	27.24	3.78	13.26	36.86	36.78	0.42	0.07
	SiO_2	34.21	45.06	51.31	37.40	36.83	97.90	52.42
	Al_2O_3	18.31	23.73	16.11	8.98	9.65	0.18	44.42
	Fe_2O_3	6.60	16.33	6.74	0.76	0.62	0.07	0.42
	MgO	5.04	0.91	4.44	10.60	10.04	0.21	0.04
	K_2O	0.35	1.46	2.32	0.40	0.36	0.59	0.14
	Na_2O	1.55	0.81	2.86	0.29	0.31	0.12	0.16
	SO_3	2.71	0.69	0.80	-	-	0.17	0.02
	TiO_2	1.57	1.16	0.63	0.38	0.49	-	1.45
	P_2O_5	1.30	0.25	0.15	0.02	0.01	0.12	0.08
	SrO	0.51	0.18	0.33	0.04	0.05	0.01	<0.01
	Mn_2O_3	0.06	0.03	0.05	0.73	0.39	-	<0.01
	S	-	-	-	1.03	1.10	-	-
	LOI, %	0.25	5.38	0.04	-	-	-	0.30

Results and Discussion

Heat Signatures

Figure 6-2 shows the heat signature for mixtures containing Type I PC or Type I PC and 20 percent fly ash. Note the large peak for the Type I PC and the effects of FA reducing the total heat generated and the rate of heat evolution. Note the mixture design notation follows that found in Table 6-1 and 6-2. For example the mix 80TI/20F2 would have 80 percent Type I portland cement and 20 percent class F fly ash from source 2 by mass.

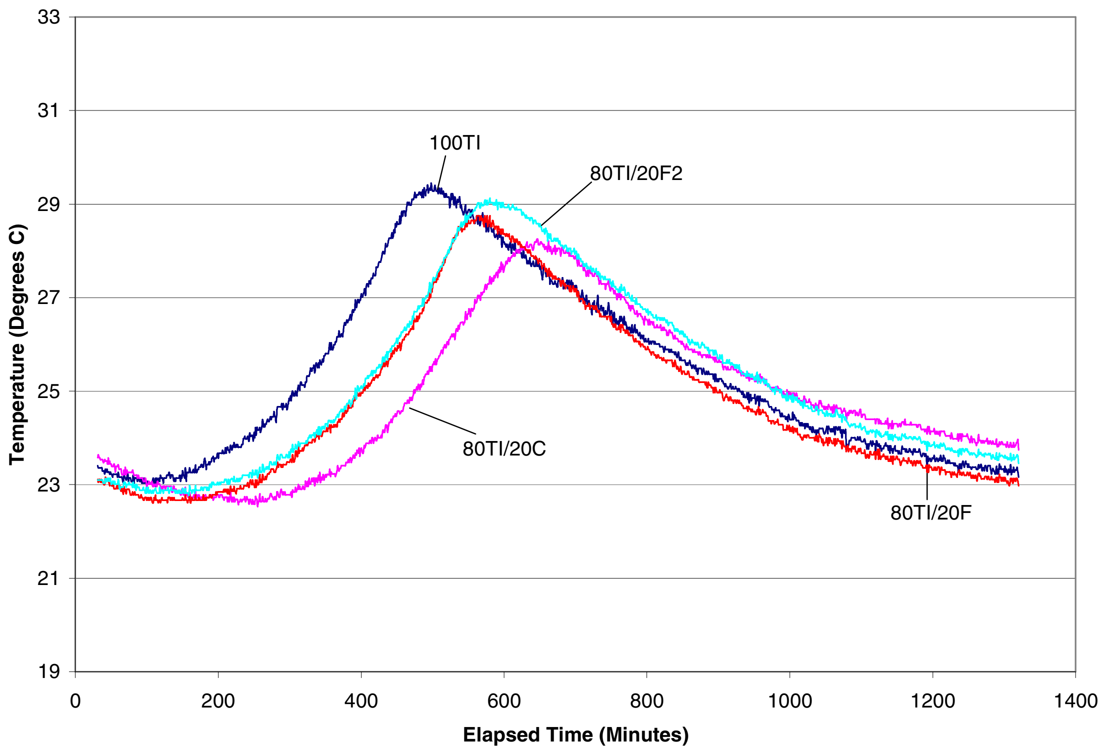

Figure 6-2. Heat Signature for Type I PC and Type I PC with 20 Percent FA

Figure 6-3 shows the heat signature of mixtures containing Type I PC and Type I PC and 35 percent GGBFS. Note the mixture containing 35 percent grade 100 GGBFS which greatly reduces the total heat generated as well as delays the rate of heat evolution. This mixture may be advantageous for hot weather concreting applications.

The study not only looked at ternary mixtures containing Type I PC, but also looked at mixtures containing blended cements. Figure 6-4 shows mixtures containing blended cements and Type I/II PC. Note the low heat generated for the ternary mixture containing silica fume and grade 120 GGBFS. The ternary mixture may be an ideal mixture for hot weather concreting applications with the added benefit that the sulfates are balanced during plant production possible eliminating some incompatibility problems that arise when field blending SCMs.

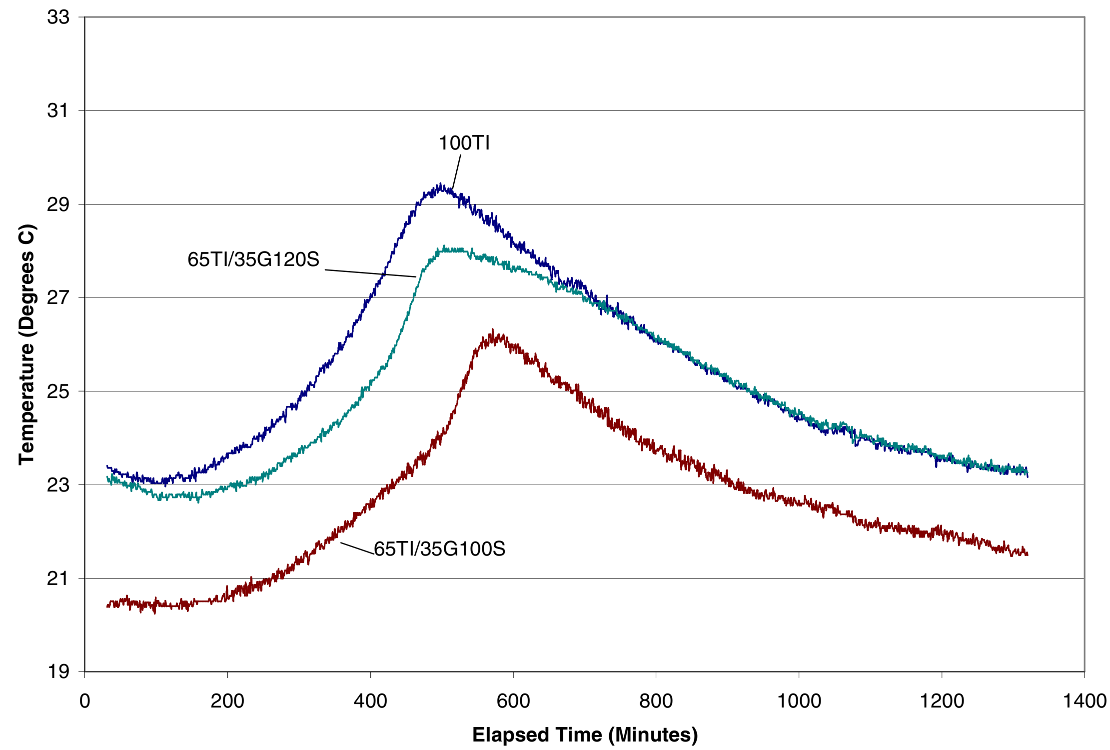

Figure 6-3. Heat Signature for Type I PC and Type I PC and 35 Percent GGBFS

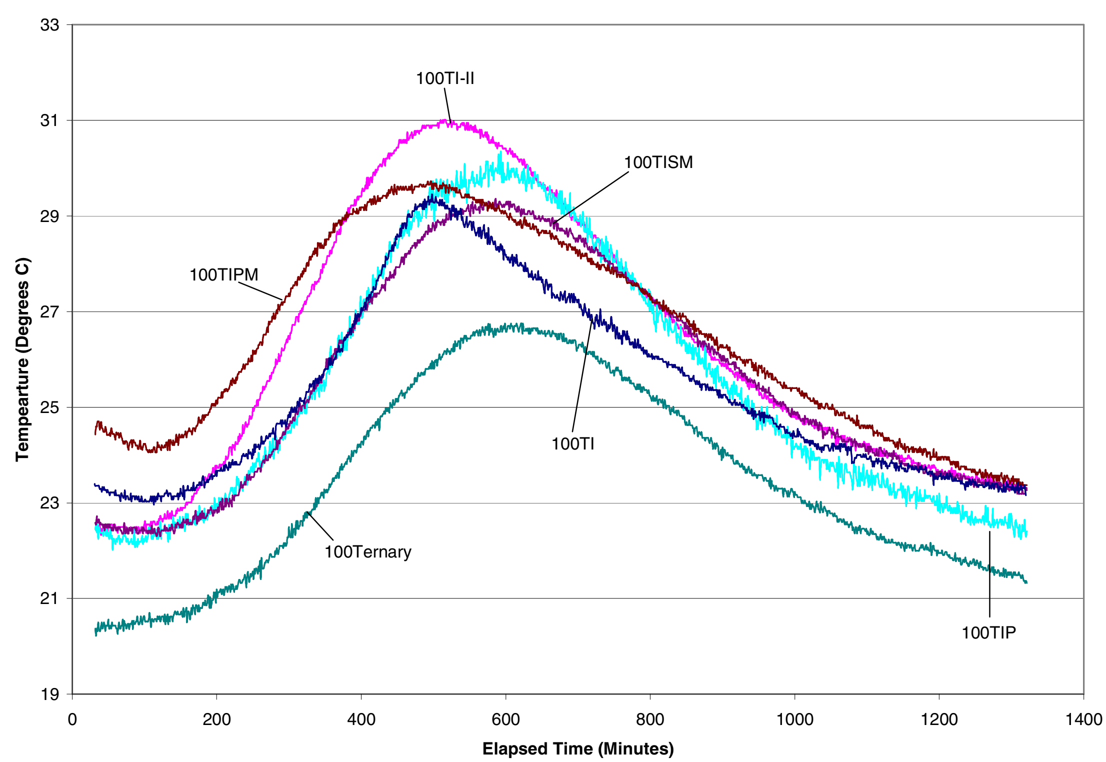

Figure 6-4. Heat Signature for All Cement Types

Heat Signature Characterization

The heat signature mixtures were characterized using key information from the heat signature including the slope 1 and slope 2 lines, maximum temperature, area under the curve, and time to maximum temperature. Figure 6-5 shows slope 1, slope 2, maximum temperature, time to maximum temperature, and area under the curve.

Tables 6-3 to 6-10 show the results for slope 1 and slope 2, the maximum temperature and time to maximum temperature, area under the curve, and time to initial and final set for each mix. Note that slope 1 was calculated using the maximum temperature and the minimum temperature for the data set up to the maximum temperature, and slope 2 was calculated using the maximum temperature and the minimum temperature for the data set after the maximum temperature. Note the mixture labeled as 60TI-30C-10F indicates that the mixture contains 60 percent Type I PC, 30 percent Class C fly ash, and 10 percent Class F fly ash by mass.

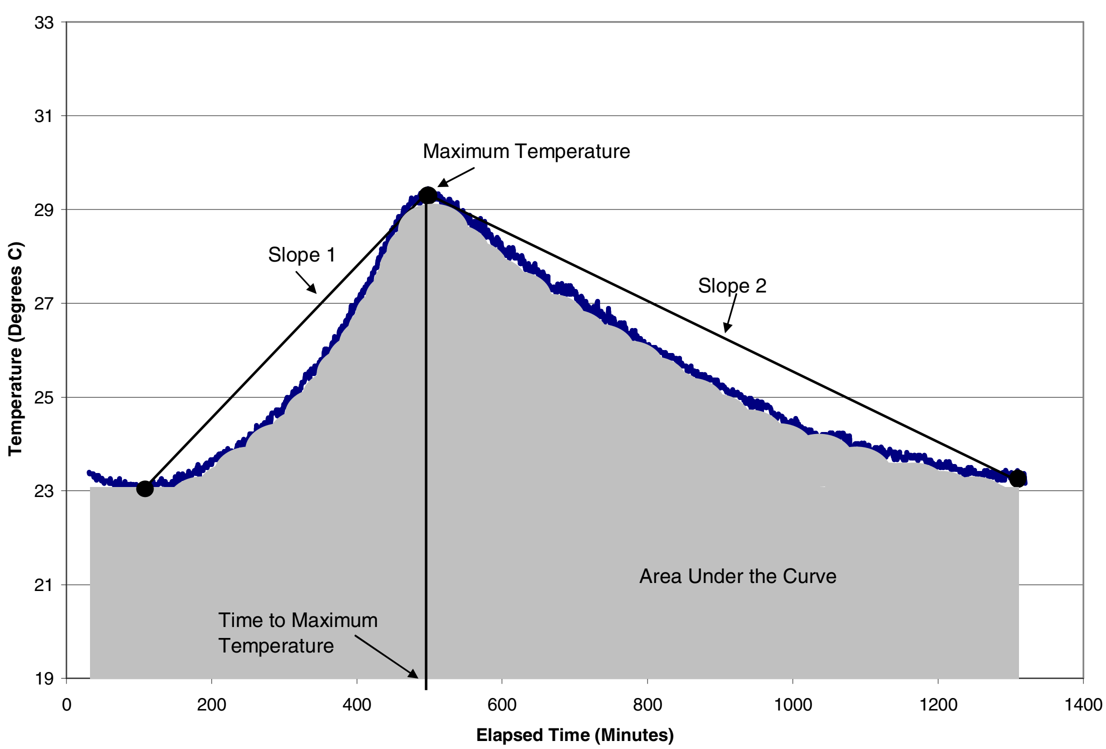

Figure 6-5. Variables Slope 1, Slope 2, Maximum Temperature, Time to Maximum Temperature, and Area Under the Curve

Table 6-3. Characterization Results for the Control Mixtures

Mix Design	Slope 1	Slope 2	Max. Temp. (°C)	Time to Max. Temp. (min)	Area Under the Curve (°C*Hour)	Initial Set (min)	Final Set (min)
100TI	0.0169	-0.0077	29.45	498	545	137	221
80TI/20C	0.0146	-0.0067	28.25	646	534	233	410
80TI/20F	0.0135	-0.0078	28.75	562	533	195	304
80TI/20F2	0.0151	-0.0077	29.13	580	542	232	342
65TI/35G100S	0.0129	-0.0067	26.33	571	488	212	349
65TI/35G120S	0.0160	-0.0060	28.11	503	536	171	274
100TI-II	0.0185	-0.0098	31.01	509	565	134	197
80TI-II/20G120S	0.0152	-0.0077	28.75	534	542	159	230
100TIP	0.0155	-0.0113	30.35	592	548	187	280
100TISM	0.0151	-0.0085	29.36	585	550	169	248
100TIPM	0.0146	-0.0078	29.72	491	569	131	242
100Ternary	0.0115	-0.0075	26.75	598	505	183	283

Table 6-4. Characterization Results for Mixtures Containing Type I PC and 20% FA

Mix Design	Slope 1	Slope 2	Max. Temp. (°C)	Time to Max. Temp. (min)	Area Under the Curve (°C*Hour)	Initial Set (min)	Final Set (min)
60TI/20C/20F	0.0074	-0.0057	26.49	747	526	286	525
60TI/20C/20F2	0.0074	-0.0056	26.24	733	520	387	621
75TI/20C/5SF	0.0129	-0.0044	26.50	667	512	226	405
77TI/20C/3SF	0.0115	-0.0044	26.20	686	507	226	392
60TI/20C/20G100S	0.0070	-0.0059	24.72	799	481	384	594
60TI/20C/20G120S	0.0086	-0.0088	25.59	709	488	342	568
75TI/20C/5M	0.0116	-0.0054	26.84	608	517	257	391
60TI/20F/20F2	0.0101	-0.0069	27.76	623	534	249	394
75TI/20F/5SF	0.0140	-0.0067	27.80	556	520	155	274
77TI/20F/3SF	0.0130	-0.0058	27.27	553	515	166	270
60TI/20F/20G100S	0.0098	-0.0055	25.39	585	488	255	419
60TI/20F/20G120S	0.0120	-0.0066	28.39	507	542	205	326
75TI/20F/5M	0.0132	-0.0070	28.19	518	528	189	282
75TI/20F2/5SF	0.0123	-0.0066	27.80	594	520	188	310
77TI/20F2/3SF	0.0126	-0.0072	28.04	577	518	208	309
60TI/20F2/20G100S	0.0081	-0.0061	25.62	660	492	303	457
60TI/20F2/20G120S	0.0100	-0.0063	27.32	587	530	212	338
75TI/20F2/5M	0.0128	-0.0067	27.92	532	525	211	325

Table 6-5. Characterization Results for Mixtures Containing Type I PC and 30% FA

Mix Design	Slope 1	Slope 2	Max. Temp. (°C)	Time to Max. Temp. (min)	Area Under the Curve (°C*Hour)	Initial Set (min)	Final Set (min)
60TI/30F/10C	0.0099	-0.0054	25.94	695	497	270	407
60TI/30F2/10C	0.0061	-0.0059	25.56	768	493	327	475
60TI/30C/10F	0.0072	-0.0051	26.36	707	526	389	623
60TI/30C/10F2	0.0075	-0.0040	25.53	745	513	339	584
65TI/30C/5SF	0.0119	-0.0046	26.83	639	533	224	491
67TI/30C/3SF	0.0102	-0.0037	26.07	624	523	253	496
50TI/30C/20G100S	0.0056	-0.0049	23.67	862	473	445	811
50TI/30C/20G120S	0.0107	-0.0056	25.47	693	502	341	611
65TI/30C/5M	0.0069	-0.0043	25.15	682	500	317	510
60TI/30F/10F2	0.0108	-0.0072	27.82	605	528	234	360
65TI/30F/5SF	0.0149	-0.0082	28.75	556	537	164	270
67TI/30F/3SF	0.0149	-0.0073	28.55	538	536	173	293
50TI/30F/20G100S	0.0070	-0.0056	25.01	614	479	294	493
50TI/30F/20G120S	0.0107	-0.0063	27.12	578	519	250	383
65TI/30F/5M	0.0154	-0.0067	27.77	506	519	193	322
65TI/30F2/5SF	0.0164	-0.0083	28.99	564	538	244	353
67TI/30F2/3SF	0.0149	-0.0080	29.06	585	540	235	356
50TI/30F2/20G100S	0.0067	-0.0061	24.86	726	480	356	559
50TI/30F2/20G120S	0.0091	-0.0056	26.93	624	521	216	355
65TI/30F2/5M	0.0103	-0.0065	27.05	586	511	249	362

Table 6-6. Characterization Results for Mixtures Containing Type I PC and 35% GGBFS or Type I PC and Metakaolin

Mix Design	Slope 1	Slope 2	Max. Temp. (°C)	Time to Max. Temp. (min)	Area Under the Curve (°C*Hour)	Initial Set (min)	Final Set (min)
50TI/35G100S/15C	0.0055	-0.0051	24.31	704	476	423	688
50TI/35G100S/15F	0.0080	-0.0050	25.34	554	488	292	475
50TI/35G100S/15F2	0.0099	-0.0056	25.61	594	485	262	458
60TI/35G100S/5SF	0.0133	-0.0057	26.54	501	498	211	365
62TI/35G100S/3SF	0.0131	-0.0061	26.66	517	498	203	368
60TI/35G100S/5M	0.0119	-0.0050	25.81	494	492	175	351
50TI/35G120S/15C	0.0075	-0.0037	25.18	685	504	302	493
50TI/35G120S/15F	0.0112	-0.0051	26.96	519	521	190	327
50TI/35G120S/15F2	0.0105	-0.0048	26.65	527	519	138	246
60TI/35G120S/5SF	0.0160	-0.0063	28.3	463	534	187	313
62TI/35G120S/3SF	0.0146	-0.0060	28.3	474	539	215	335
60TI/35G120S/5M	0.0115	-0.0054	27.36	451	522	182	287
90TI/5M/5SF	0.0250	-0.0100	31.96	455	579	133	222
92TI/5M/3SF	0.0216	-0.0096	31.51	460	574	137	231

Table 6-7. Characterization Results for Mixtures Containing Type I/II PC

Mix Design	Slope 1	Slope 2	Max. Temp. (°C)	Time to Max. Temp. (min)	Area Under the Curve (°C*Hour)	Initial Set (min)	Final Set (min)
68TI-II/17G120S/15C	0.0112	-0.0088	28.19	699	534	193	293
68TI-II/17G120S/15F	0.0102	-0.0070	27.79	615	542	150	225
68TI-II/17G120S/15F2	0.0105	-0.0065	27.39	586	534	159	272
76TI-II/19G120S/5SF	0.0176	-0.0103	31.09	551	570	176	247
78TI-II/19G120S/3SF	0.0168	-0.0100	30.38	570	562	163	226
64TI-II/20G100S/16G120S	0.0113	-0.0070	26.38	617	505	212	320
76TI-II/19G120S/5M	0.0174	-0.0104	30.9	538	568	144	218
60TI-II/25C/15G120S	0.0126	-0.0093	28.19	754	532	238	349
60TI-II/25F/15G120S	0.0104	-0.0063	27.22	592	535	144	237
60TI-II/25F2/15G120S	0.0103	-0.0074	27.71	637	539	191	276
52TI-II/35G100S/13G120S	0.0094	-0.0055	25.16	623	491	213	337

Table 6-8. Characterization Results for Mixtures Containing Type IP PC

Mix Design	Slope 1	Slope 2	Max. Temp. (°C)	Time to Max. Temp. (min)	Area Under the Curve (°C*Hour)	Initial Set (min)	Final Set (min)
85TIP/15C	0.0157	-0.0126	30.8	685	554	246	355
85TIP/15F	0.0127	-0.0108	30.04	652	559	187	271
85TIP/15F2	0.0120	-0.0099	28.69	673	541	216	309
95TIP/5SF	0.0167	-0.0116	31.23	585	562	173	247
97TIP/3SF	0.0178	-0.0118	31.16	584	563	169	244
80TIP/20G100S	0.0101	-0.0083	26.12	670	496	215	345
80TIP/20G120S	0.0120	-0.0098	29.39	626	549	190	288
95TIP/5M	0.0198	-0.0121	32.25	542	571	169	246
75TIP/25C	0.0146	-0.0119	30.17	721	550	307	408
75TIP/25F	0.0120	-0.0106	29.19	675	544	194	286
75TIP/25F2	0.0128	-0.0089	28.51	640	539	254	360
65TIP/35G100S	0.0096	-0.0075	25.83	660	492	252	385
65TIP/35G120S	0.0093	-0.0074	27.51	604	523	194	304
90TIP/5M/5SF	0.0210	-0.0118	32.05	525	565	199	300
92TIP/5M/3SF	0.0221	-0.0121	32.39	514	570	163	246

Table 6-9. Characterization Results for Mixtures Containing Type ISM PC

Mix Design	Slope 1	Slope 2	Max. Temp. (°C)	Time to Max. Temp. (min)	Area Under the Curve (°C*Hour)	Initial Set (min)	Final Set (min)
85TISM/15C	0.0126	-0.0090	28.3	707	536	217	323
85TISM/15F	0.0129	-0.0071	27.93	579	539	151	236
85TISM/15F2	0.0106	-0.0063	25.83	691	502	201	307
95TISM/5SF	0.0174	-0.0105	31.12	576	567	201	289
97TISM/3SF	0.0160	-0.0107	30.79	599	564	186	271
80TISM/20G100S	0.0108	-0.0060	25.58	632	497	196	298
80TISM/20G120S	0.0106	-0.0059	26.05	621	506	170	268
95TISM/5M	0.0171	-0.0119	31.58	539	572	161	249
75TISM/25C	0.0101	-0.0100	26.77	864	504	250	386
75TISM/25F	0.0096	-0.0070	26.39	668	509	165	276
75TISM/25F2	0.0104	-0.0063	26.2	666	506	226	339
65TISM/35G100S	0.0077	-0.0058	24.72	711	485	210	346
65TISM/35G120S	0.0084	-0.0057	25.22	691	495	175	283
90TISM/5M/5SF	0.0217	-0.0113	32.15	515	576	172	276
92TISM/5M/3SF	0.0139	-0.0083	27.14	544	507	174	251

Table 6-10. Characterization Results for Mixtures Containing Type IPM PC

Mix Design	Slope 1	Slope 2	Max. Temp. (°C)	Time to Max. Temp. (min)	Area Under the Curve (°C*Hour)	Initial Set (min)	Final Set (min)
85TIPM/15C	0.0135	-0.0083	27.47	641	520	181	275
85TIPM/15F	0.0110	-0.0070	26.82	591	518	123	198
85TIPM/15F2	0.0117	-0.0062	26.71	539	517	149	227
95TIPM/5SF	0.0181	-0.0103	30.9	546	567	125	184
97TIPM/3SF	0.0200	-0.0117	32.02	582	581	129	189
80TIPM/20G100S	0.0106	-0.0070	26.34	636	508	177	251
80TIPM/20G120S	0.0119	-0.0057	26.18	528	510	141	216
95TIPM/5M	0.0132	-0.0080	27.23	516	513	114	171
75TIPM/25C	0.0120	-0.0112	28.12	750	522	202	300
75TIPM/25F	0.0094	-0.0058	26.04	573	512	132	203
75TIPM/25F2	0.0105	-0.0064	26.63	622	516	182	262
65TIPM/35G100S	0.0081	-0.0052	24.62	641	487	186	259
65TIPM/35G120S	0.0085	-0.0057	25.51	626	503	144	228
90TIPM/5M/5SF	0.0168	-0.0086	27.48	517	510	109	166
92TIPM/5M/3SF	0.0139	-0.0086	27.35	535	512	111	168

Least Squares Regression Analysis

A least squares fit analysis was completed using JMP (19) on the data set to determine if the heat signature characterizations fit a linear model. The response variables included: slope 1 and slope 2, maximum temperature, time to maximum temperature, maturity, and initial and final set. Parameters used in the analysis included C_3S, C_2S, C_3A, and C_4AF to model the effects of different cement chemistries. The percentage of C_3S, C_2S, C_3A, and C_4AF was multiplied by the percent of Type I PC present in the mixture design to obtain a value for modeling purposes. These input parameters for the cement were chosen due to the ease in which they can be obtained from mill reports.

A weighted average of the fly ash calcium oxide, (FACaO) was used to model the effect of the FA on the heat signature and a weighted average of the fineness (S) of the GGBFS was used to model the effect of slag on the heat signature. The fly ash calcium oxide content was used as a model parameter because it is readily available on ASTM C 618 (13) reports required by most state agencies. The percent of silica fume (SF) and metakaolin (M) in the mix design were used to model their respective effects. Table 6-11 shows the variables used in modeling and their units.

Equations 1 to 7 (see Table 6-12) show the least squares fit regression equations for slope 1, slope 2, maximum temperature, time to maximum temperature, area under the curve, and initial and final set, respectively. The R-Squared values ranging from 0.6513 to 0.7599 show that the data sets are modeled well as linear approximations. Note the R-Squared values represent the effects of the input variables. Also note that when including only the mixtures containing Type I PC, the R-Squared values were much higher at 0.90 to 0.95. Note this regression analysis included no interaction variables and included all variables regardless of significance.

Table 6-11. Variable and Units Used in Models

Variable Name	Symbol	Units
Tricalcium Silicate	C_3S	%
Dicalcium Silicate	C_2S	%
Tricalcium Aluminate	C_3A	%
Tetracalcium Aluminoferrite	C_4AF	%
Fly Ash Calcium Oxide	FACaO	%
GGBFS Fineness	S	%Retained 325 Sieve
Silica Fume	SF	%
Metakaolin	M	%

Table 6-12. Least Squares Regression Analysis Results

Equation #	Equation	R^2
1	Slope 1 = $3.6E^{-4}C_3S + 1.0E^{-3}C_2S - 7.6E^{-4}C_3A + 2.9E^{-3}C_4AF - 7.21E^{-5}FACaO + 7.2E^{-4}SF - 4.5E^{-4}S + 3.6E^{-4}M + 1.0E^{-3}$	0.7599
2	Slope 2= $4.89E^{-4}C_3S + 8.9E^{-4}C_2S - 8.7E^{-4}C_3A + 4.7E^{-3}C_4AF - 3.8E^{-7}FACaO + 1.9E^{-4}SF + 3.3E^{-4}S - 1.1E^{-4}M - 2.8E^{-3}$	0.6671
3	Maximum Temperature = $-3.0E^{-1}C_3S + 1.4E^{-1}C_2S - 7.4E^{-2}C_3A + 2.6C_4AF - 3.4E^{-2}FACaO + 2.4E^{-1}SF - S + 7.8E^{-2}M + 22.8$	0.7189
4	Time to Maximum Temperature = $2.4C_3S - 7.2C_2S - 4.6C_3A - 12.7C_4AF + 5.4FACaO - 6.4SF + 6.8S - 10M + 672$	0.6871
5	Area Under the Curve = $-1.8C_3S + 6.4C_2S - 7.4C_3A + 15.6C_4AF - 3.9E^{-1}FACaO + 2.3SF - 21S + 1.3E^{-1}M + 477$	0.6513
6	Initial Set = $-1.8C_3S - 3.1E^{-1}C_2S + 3.7C_3A - 9.4C_4AF + 3.3FACaO - 3.3SF - 24.1S - 1.3M + 276$	0.6745
7	Final Set = $4.7E^{-1}C_3S + 15.7C_2S - 9.4C_3A - 56.4C_4AF + 5.9FACaO - 2.4SF + 48.4S - 1.9M + 443$	0.7281

Stepwise Regression Analysis

Upon noting the good linear approximations from the linear least squares regression analyses, a stepwise regression analysis was conducted using JMP (19) to identify the insignificant input variables. The analyses used all possible models to identify potential models with large R-Squared values for further refinement. Once the model input parameters were identified, a least squares fit analysis was conducted to obtain a residual plot. Using the residual plot, the best equation for each response variable was determined.

Equations 8 to 14 (see Table 6-13) show the results of the stepwise regression analysis. The resulting with R-Squared values ranging from 0.6513 to 0.7555 shows that the linear models are good.

By removing the insignificant input parameters, the linear models are simplified. Note the stepwise regression analysis removed from one to four insignificant input variables depending upon the equation.

Table 6-13. Stepwise Regression Analysis Results

Equation #	Equation	R^2
8	Slope 1 = $4.8E^{-4}C_3S + 4.2E^{-4}C_2S + 4.3E^{-3}C_4AF - 6.9E^{-5}FACaO + 6.8E^{-4}SF + 3.6E^{-4}S - 1.9E^{-4}$	0.7555
9	Slope 2 = $5.1E^{-4}C_3S + 9.6E^{-4}C_2S - 9.9E^{-4}C_3A - 5E^{-3}C_4AF - 1.9E^{-4}SF - 1.2E^{-4}M - 2.1E^{-3}$	0.6634
10	Maximum Temperature = $-3.1E^{-1}C_3S + 7.9E^{-2}C_2S + 2.7C_4AF - 3.4E^{-2}FACaO + 2.4E^{-1}SF - S + 7.7E^{-2}M + 22.8$	0.7188
11	Time to Maximum Temperature = $-11.2C_2S + 5.2FACaO - 5.3SF - 9.9M + 705$	0.6578
12	Area Under the Curve = $-3.0C_3S + 28.4C_4AF - 4.0E^{-1}FACaO + 1.7SF - 20.8S + 478$	0.6513
13	Initial Set = $-3.2C_3S + 3.7C_3A + 3.4FACaO - 2.2SF + 27.3S + 264$	0.6551
14	Final Set = $8.0C_2S - 46.5C_4AF + 6.0FACaO - 4.0SF + 50.3S + 436$	0.7262

The equation for slope 1 is as expected. An increase C_3S, C_2S, GGBFS fineness, and silica fume content will increase the slope. Note the influence in C_4AF in nearly all the equations. The influence of C_4AF is usually small due to the smaller quantities of C_4AF in the portland cement, but the heat liberated is moderate leading to significance in the heat signature curve.

Note that the C_3A content is not significant in all equations except the initial set prediction model. This is due to the rapid C_3A hydration not significantly contributing to the later portion of the heat generation curve. Note that C_3S or C_2S are included in nearly every equation. This is due to the high amount of heat liberated for the C_3S and the moderate reaction rate for determination of initial and final setting times. The C_2S input is noted less due to its decreased heat liberation contribution and slower rate of hydration (20, 21).

The maximum temperature is dependent upon C_3S, C_2S, C_4AF, FACaO content, silica fume, GGBFS fineness and metakaolin content. This equation is as expected since an increase in the silica fume and metakaolin content will increase the maximum temperature, and addition of fly ash generally decreased the maximum temperature.

The time to maximum temperature equation shows that an increase in the fly ash calcium oxide content will increase the time to maximum temperature, and an increase in metakaolin and silica fume will decrease the time to maximum temperature. This is expected since silica fume and metakaolin tend to reduce the time to initial and final set when used without a water reducer.

The area under the curve shows that C_4AF is important in determining the area even though it is a small fraction of the cement chemistry. This is most likely due to the moderate amount of heat liberated during hydration. The influence of the GGBFS fineness is also clearly shown as you increase the amount retained on the #325 sieve, the area under the curve becomes smaller due to decrease in the reactivity of the GGBFS.

The equations for initial set and final set are as expected with the C_3S and fly ash calcium oxide content and the GGBFS fineness playing large roles in determination of the set times. The C_3S contributes to early age strength development and the fly ash calcium oxide, free lime, contributes to set.

The stepwise regression analysis results allow a producer or engineer to predict key engineering properties such as the area under the curve, time to initial and final set, and the maximum and time to maximum temperature. This is important due to the wide range of mixture combinations available. By using a prediction model, one can narrow the list of possible mix designs in the preconstruction verification stage using set response criteria, saving money and time.

The linear least squares regression analysis showed very good R^2 values and adequately models the heat signature characterizations. The stepwise regression analysis allowed simplification of the least squares analysis by removing the variables not significantly affecting the model. Interaction effects may further refine the regression models. Interaction effects were not analyzed due to the good R^2 values obtained without interaction effects.

It should be noted that the models described above are valid for the ranges of PC, FA, SF, GGBFS, and Metakaolin used and care should be exercised if extrapolating these models beyond the aforementioned replacement ranges. It is important to note that this study was conducted in a laboratory setting, and field results may differ depending upon climatic conditions.

Conclusions

The results of this study warrant the following conclusions.

1. Ternary mixture designs can be characterized using their respective heat signatures; specifically slope 1 and slope 2, maximum temperature, time to maximum temperature, maturity, and time to initial and final set.
2. Linear least squares regression analysis produces very good R^2 values for the response variables of slope 1 and slope 2, maximum temperature, time to maximum temperature, maturity, and time to initial and final set.
3. The input parameters for the models are easily obtained making the models practical. It is anticipated that the prediction models would be used in the preconstruction stage of a project to narrow a list of potential mix designs based on engineering criteria set forth by the designer.
4. Stepwise regression analysis simplified the prediction equations to contain only significant variables.
5. Care should be exercised when using the prediction models for PC or SCM replacement ranges other than reported and for materials other than what was used for this study.

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CHAPTER 7. GENERAL CONCLUSIONS AND RECOMMENDATIONS FOR FURTHER STUDY

General Conclusions

The papers presented in this dissertation focus on laboratory testing procedures that lead to field QC/QA methods and several test methods to identify potential problems such as admixture incompatibility and changes in cement chemistry. The test methods identified in this dissertation have the ability to improve concrete uniformity. The laboratory results shown in this dissertation also have the ability to improve constructability as well as portland cement concrete pavement performance. These results will lead to improved economics of portland cement concrete construction through the use of innovative mixing procedures. The test methods identified and investigated will allow for a reduction between the time of testing and the respective results, allowing the contractor to make acceptable changes in field operations. The overall results show an economic benefit in reduced construction costs and improved concrete uniformity and performance.

The most important conclusions drawn from the five research papers presented in this dissertation are as follows:

Paper 1

The laboratory two-stage mixing results show promise in field applications in that the mixing time may be shortened and improved concrete strength and uniformity using the two-stage mixing process. By decreasing the mixing time, an increase in production can be realized leading to lower construction costs. Increased strengths and improved concrete uniformity may lead to reduced cement quantities and improved concrete pavement performance, respectively.

Paper 2

The quick heat generation test results show that it is ideally suited for field application. The quick heat generation test can identify a change in cement source and small changes in cement chemistry, and the test results are reproducible. The test results are obtained within fifteen minutes and allowing the contractor to make changes based on the results in a matter of minutes rather than a matter of hours or days.

Paper 3

The AVA is ideally suited for characterizing the air void system of ternary mixtures in a relatively quick manner. Use of the AVA in the pre-construction stage may allow the contractor to identify those ternary mixtures that may pose problems entraining air for proper freeze-thaw durability. The AVA, combined with set time and cube strengths, can identify admixture compatibility issues well before concrete is batched for a particular project. The use of the AVA and set time test in the field will allow the contractor to make changes relatively quickly if problems arise.

Paper 4

This paper produced a large database of AVA results from sixteen states in different climate regions across the United States. The results obtained in the study showed that testing location did not significantly affect the AVA results. This is important for field technicians obtaining samples for AVA tests as sampling ahead of the paver will generally cause less interference with contractor paving operations, specifically finishing and curing operations.

Paper 5

The heat signature of ternary mixture designs can be used to characterize, model, and predict performance. Using information available on mill reports or standard sheets, this relatively inexpensive test can be used to accurately predict time to initial set, final set, time to maximum temperature, and area under the curve in laboratory conditions. The ternary mixture design heat signature results developed a database for field application of ternary mixture designs in that trial mixture designs can be selected on desired performance properties. Care should be exercised when using the prediction models for PC or SCM replacement ranges and materials other than reported.

Recommendations for Further Study

Some recommendations for further study are as follows:

1. A controlled field experiment should be conducted to validate the two-stage mixing results obtained in Chapter 2.

2. Further refinement and testing is needed to identify the precision and bias of the quick heat generation test. Specifically the range of initial temperature values and temperature values at 15 minutes indicating whether the cement chemistry had changed when using the relationship between the initial cement temperature and the paste temperature at 15 minutes and the relationship between the initial paste temperature and the final paste temperature.
3. Validate the current quick heat generation research using several other cement chemistries should be completed.
4. The sensitivity of the quick heat generation test to the day-to-day fluctuations in the cement production process should be determined.
5. A standard mixing procedure for reduction of error between operators should be developed for the quick heat generation test.
6. Modeling of the ternary mix designs using the heat signature characteristics should be refined, specifically looking at interaction between model parameters such as fly ash calcium oxide content and the ground granulated blast furnace slag fineness.
7. Further field testing of the AVA on a wide variety of portland cement concrete slipform paving projects should be conducted to validate the current research findings in Chapter 5.

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APPENDIX A

Table A-1. Rheology Properties for the Hobart Mixer

	Mixing Speed-Time	Yield Stress (Pa)	Viscosity (Pas)	Thixotropic Area (Pa/s)	Peak Stress (Pa)
100% PC	1-15, 2-15	75	1.21	4750	206
	1-15, 2-30	82	0.89	2217	177
	1-15, 2-45	71	0.89	2021	163
	1-15, 2-60	72	0.71	1661	145

Table A-2. Rheology Properties for the High Shear Mixer

	Mixing Speed-Time	Yield Stress (Pa)	Viscosity (Pas)	Thixotropic Area (Pa/s)	Peak Stress (Pa)
100% PC	1-15	91	0.58	1412	149
	1-30	80	0.48	822	128
	1-45	80	0.35	476	113
	1-60	66	0.28	139	94
	2-15	76	0.35	607	109
	2-30	79	0.27	534	108
	2-45	83	0.17	255	102
	2-60	90	0.15	-18	105
85% PC – 15% FA	1-15	63	0.35	1486	101
	1-30	51	0.27	278	78
	1-45	49	0.26	377	75
	1-60	44	0.25	556	72
	2-15	54	0.23	446	78
	2-30	53	0.22	660	77
	2-45	60	0.16	248	78
	2-60	57	0.14	-21	73
65% PC – 35% FA	1-15	32	0.27	434	59
	1-30	25	0.20	-53	50
	1-45	25	0.18	-87	46
	1-60	26	0.17	-22	48
	2-15	28	0.17	-47	47
	2-30	28	0.12	-172	43
	2-45	34	0.11	-202	47
	2-60	36	0.10	-196	49
65% PC – 35% GGBFS	1-15	76	0.50	1100	127
	1-30	76	0.46	418	121
	1-45	66	0.38	425	103
	1-60	63	0.32	385	98
	2-15	63	0.32	913	97
	2-30	63	0.27	174	92
	2-45	67	0.22	122	61
	2-60	64	0.16	83	83
50% PC – 35% GGBFS – 15% FA	1-15	65	0.40	607	109
	1-30	65	0.37	724	104
	1-45	66	0.36	539	102
	1-60	65	0.32	871	98
	2-15	69	0.33	874	103
	2-30	61	0.31	648	92
	2-45	65	0.27	623	93
	2-60	66	0.19	61	86

Table A-3. Fresh Concrete Properties

Mixture	Mixing Procedure	Air Content (%)	Slump (in)
100% PC	60 Second Dry Batch	8.1	4.00
	Slurry Pre-Mix with 30 Second Batch	6.2	2.50
	Slurry Pre-Mix with 60 Second Batch	6.1	1.75
85% PC – 15% FA	60 Second Dry Batch	7.1	2.75
	Two-Stage Mix with 30 Second Batch	5.4	2.75
	Two-Stage Mix with 60 Second Batch	4.3	3.75
50% PC – 35% GGBFS – 15% FA	60 Second Dry Batch	6.5	5.25
	Slurry Pre-Mix with 30 Second Batch	5.4	5.50
	Slurry Pre-Mix with 60 Second Batch	6.0	4.50

Table A-4. Tabular Compressive Strength Data

Mixture	Mixing Procedure	Cure Time (Days) Compressive Strength* (psi)		
		3	7	28
100% PC	60 Second Dry Batch	3179	4071	4889
	Slurry Pre-Mix with 30 Second Batch	2970	4476	5460
	Slurry Pre-Mix with 60 Second Batch	2526	3678	5006
85% PC – 15% FA	60 Second Dry Batch	3979	5298	6187
	Two-Stage Mix with 30 Second Batch	3931	5194	6748
	Two-Stage Mix with 60 Second Batch	3511	4770	6283
50% PC – 35% GGBFS – 15% FA	60 Second Dry Batch	1926	3087	5492
	Slurry Pre-Mix with 30 Second Batch	1697	2907	5519
	Slurry Pre-Mix with 60 Second Batch	1549	2850	5451

***Average of 3 samples**

APPENDIX B

Table B-1. Quick Heat Generation Test Results for Louisiana Type I PC

Elapsed Time (min)	Sample A Test 1 (°C)	Sample A Test 2 (°C)	Sample B (°C)
Initial	23.78	23.89	24.39
1	24.28	24.50	24.72
2	24.78	25.11	25.39
3	25.00	25.28	26.11
4	25.22	25.50	26.72
5	25.22	25.61	26.89
6	25.28	25.61	26.89
7	25.28	25.72	26.89
8	25.28	25.61	27.00
9	25.28	25.61	27.00
10	25.28	25.61	27.00

Table B-2. Quick Heat Generation Test Results for Varying Cement Temperature (Water Temperature = 21.1 °C (70°F))

	Starting Cement Temperature, °F (°C)									
Elapsed Time (Min)	60 (15.6) (°C)	65 (18,3) (°C)	70 (21.1) (°C)	75 (23.9) (°C)	80 (26.7) (°C)	85 (29.4) (°C)	90 (32.2) (°C)	100 (37.8) (°C)	110 (43.3) (°C)	120 (48.9) (°C)
0.0	20.84	22.41	23.31	23.59	23.89	25.9	25.86	26.4	30.33	33.18
0.1	20.84	22.47	23.43	23.54	23.83	25.92	25.86	26.59	30.56	33.68
0.2	20.95	22.53	23.49	23.64	23.77	26.1	25.92	26.82	30.68	33.91
0.3	20.95	22.43	23.49	23.7	23.77	26.16	25.98	26.88	30.79	34.03
0.3	21.01	22.6	23.54	23.7	23.89	26.27	25.98	26.93	30.85	34.03
0.4	21.14	22.55	23.56	23.66	23.89	26.12	26.04	26.99	30.96	34.2
0.5	21.14	22.61	23.6	23.82	23.94	26.29	26.15	27.05	31.08	34.26
0.6	21.14	22.61	23.56	23.66	24.04	26.35	26.22	27.12	31.14	34.32
0.7	21.19	22.67	23.63	23.87	24	26.4	26.28	27.12	31.14	34.38
0.8	21.31	22.67	23.67	23.87	24.1	26.46	26.28	27.17	31.2	34.38
0.8	21.25	22.73	23.67	23.93	24.07	26.53	26.33	27.23	31.25	34.38
0.9	21.37	22.78	23.8	23.99	24.17	26.59	26.39	27.23	31.31	34.43
1.0	21.37	22.84	23.8	24.05	24.07	26.64	26.45	27.29	31.37	34.43
1.1	21.42	22.84	23.86	24.05	24.23	26.6	26.51	27.35	31.43	34.49

1.2	21.48	22.96	23.92	24.1	24.19	26.66	26.51	27.35	31.48	34.49
1.3	21.48	22.8	23.87	24.1	24.19	26.72	26.57	27.41	31.48	34.66
1.3	21.54	23.01	23.93	24.17	24.4	26.72	26.68	27.46	31.48	34.61
1.4	21.54	22.97	23.87	24.23	24.4	26.78	26.52	27.46	31.54	34.61
1.5	21.65	22.91	23.99	24.23	24.36	26.78	26.68	27.46	31.6	34.66
1.6	21.6	22.91	23.99	24.23	24.36	26.89	26.58	27.58	31.6	34.66
1.7	21.65	22.97	23.99	24.23	24.3	26.89	26.75	27.58	31.66	34.66
1.8	21.72	22.94	23.99	24.29	24.4	26.95	26.81	27.58	31.56	34.56
1.8	21.78	23.04	24.06	24.35	24.42	27.02	26.81	27.58	31.66	34.72
1.9	21.78	22.94	24.1	24.25	24.52	26.95	26.81	27.65	31.61	34.72
2.0	21.78	23.1	24.17	24.29	24.47	27.02	26.86	27.65	31.76	34.78
2.1	21.78	23	24.17	24.4	24.63	27.02	26.98	27.76	31.67	34.62
2.2	21.84	23.06	24.17	24.4	24.53	27.13	26.98	27.76	31.7	34.78
2.3	21.9	23	24.23	24.4	24.7	27.03	26.88	27.7	31.73	34.78
2.3	21.84	23.06	24.29	24.46	24.63	27.09	26.98	27.76	31.73	34.84
2.4	21.8	23.06	24.29	24.52	24.7	27.03	26.88	27.82	31.73	34.74
2.5	21.95	23.11	24.29	24.46	24.76	27.09	27.04	27.82	31.88	34.78
2.6	21.91	23.17	24.3	24.58	24.76	27.05	26.94	27.82	31.73	34.74
2.7	21.91	23.23	24.24	24.58	24.81	27.1	27.04	27.88	31.79	34.84
2.8	21.97	23.17	24.3	24.63	24.81	27.05	26.94	27.93	31.84	34.74
2.8	21.97	23.17	24.3	24.63	24.87	27.16	26.99	27.88	31.84	34.9
2.9	21.97	23.17	24.3	24.63	24.81	27.16	26.94	27.88	31.84	34.8
3.0	22.03	23.23	24.36	24.7	24.93	27.16	26.99	27.93	31.84	34.74
3.1	22.03	23.23	24.26	24.7	24.93	27.1	27.05	27.93	31.9	34.8
3.2	22.03	23.29	24.36	24.63	24.87	27.22	27.05	27.93	31.96	34.8
3.3	22.08	23.29	24.26	24.7	24.93	27.28	27.05	27.93	31.9	34.8
3.3	22.15	23.29	24.32	24.7	24.99	27.28	27.17	27.99	31.96	34.85
3.4	22.08	23.34	24.32	24.76	25.05	27.12	27.05	28.05	31.96	34.91
3.5	22.08	23.34	24.32	24.76	24.99	27.18	27.11	28.05	31.96	34.85
3.6	22.15	23.24	24.38	24.82	25.05	27.18	27.17	28.05	31.96	34.91
3.7	22.15	23.34	24.38	24.76	25.05	27.25	27.11	28.11	32.02	34.95
3.8	22.11	23.34	24.38	24.82	25.1	27.25	27.17	28.05	32.08	34.91
3.8	22.21	23.34	24.43	24.82	25.1	27.2	27.17	28.05	32.02	34.95
3.9	22.21	23.3	24.5	24.82	25.05	27.2	27.24	28.11	32.08	34.85
4.0	22.27	23.4	24.5	24.87	25.16	27.2	27.24	28.11	32.08	34.91
4.1	22.17	23.3	24.5	24.87	25.16	27.26	27.29	28.11	32.08	34.91
4.2	22.17	23.37	24.5	24.87	25.1	27.26	27.29	28.11	32.08	34.91
4.3	22.17	23.3	24.56	24.87	25.22	27.32	27.29	28.11	32.08	34.91
4.3	22.17	23.3	24.5	24.87	25.22	27.32	27.29	28.11	32.08	34.97
4.4	22.22	23.37	24.56	24.93	25.22	27.32	27.29	28.18	32.12	34.97
4.5	22.17	23.37	24.56	24.99	25.16	27.32	27.29	28.18	32.08	34.97
4.6	22.22	23.43	24.46	24.93	25.22	27.38	27.29	28.22	32.12	34.97
4.7	22.34	23.37	24.62	24.99	25.22	27.43	27.35	28.18	32.08	34.97
4.8	22.22	23.43	24.57	25.05	25.29	27.33	27.41	28.22	32.08	34.97
4.8	22.34	23.43	24.67	25.05	25.29	27.33	27.29	28.22	32.18	34.97
4.9	22.34	23.48	24.52	24.99	25.29	27.33	27.41	28.22	32.18	34.97
5.0	22.34	23.48	24.57	24.99	25.29	27.39	27.41	28.29	32.18	34.97
5.1	22.4	23.43	24.63	24.99	25.29	27.29	27.35	28.29	32.18	35.03
5.2	22.34	23.48	24.63	24.99	25.29	27.39	27.47	28.29	32.18	35.03

5.3	22.4	23.48	24.63	25.11	25.34	27.39	27.41	28.19	32.24	35.03
5.3	22.4	23.54	24.69	25.05	25.29	27.29	27.41	28.29	32.18	35.08
5.4	22.46	23.48	24.69	25.11	25.34	27.35	27.41	28.29	32.18	35.03
5.5	22.4	23.54	24.69	25.05	25.4	27.35	27.47	28.35	32.24	35.03
5.6	22.46	23.54	24.59	25.16	25.4	27.35	27.41	28.19	32.24	35.03
5.7	22.46	23.6	24.65	25.16	25.4	27.41	27.52	28.35	32.3	35.03
5.8	22.46	23.54	24.59	25.16	25.46	27.41	27.52	28.35	32.18	35.03
5.8	22.51	23.6	24.75	25.11	25.4	27.46	27.47	28.35	32.18	35.03
5.9	22.46	23.6	24.7	25.11	25.46	27.46	27.47	28.41	32.3	35.08
6.0	22.57	23.6	24.65	25.16	25.46	27.46	27.58	28.41	32.3	35.08
6.1	22.57	23.6	24.65	25.16	25.46	27.46	27.52	28.41	32.3	35.08
6.2	22.64	23.6	24.7	25.16	25.46	27.46	27.52	28.41	32.24	35.08
6.3	22.57	23.6	24.7	25.16	25.4	27.42	27.58	28.41	32.3	35.03
6.3	22.57	23.6	24.7	25.22	25.46	27.52	27.52	28.41	32.3	35.14
6.4	22.57	23.6	24.66	25.16	25.46	27.42	27.58	28.31	32.3	35.08
6.5	22.57	23.6	24.76	25.22	25.52	27.42	27.52	28.41	32.3	35.08
6.6	22.54	23.66	24.66	25.16	25.52	27.42	27.58	28.31	32.25	35.08
6.7	22.64	23.6	24.66	25.29	25.52	27.49	27.64	28.46	32.35	35.14
6.8	22.7	23.66	24.66	25.22	25.52	27.49	27.64	28.36	32.25	35.08
6.8	22.64	23.6	24.66	25.29	25.52	27.49	27.64	28.36	32.3	35.14
6.9	22.6	23.56	24.79	25.22	25.57	27.49	27.7	28.36	32.35	35.14
7.0	22.7	23.72	24.79	25.29	25.57	27.55	27.7	28.52	32.35	35.14
7.1	22.6	23.56	24.79	25.29	25.57	27.55	27.58	28.36	32.21	35.14
7.2	22.6	23.56	24.79	25.29	25.52	27.55	27.64	28.48	32.3	35.08
7.3	22.6	23.67	24.79	25.25	25.57	27.55	27.64	28.42	32.25	35.14
7.3	22.7	23.67	24.84	25.35	25.57	27.55	27.7	28.52	32.35	35.2
7.4	22.65	23.67	24.74	25.35	25.57	27.51	27.58	28.48	32.31	35.08
7.5	22.65	23.67	24.9	25.35	25.57	27.61	27.7	28.48	32.35	35.14
7.6	22.71	23.67	24.8	25.35	25.57	27.56	27.6	28.42	32.31	35.14
7.7	22.65	23.67	24.8	25.35	25.57	27.61	27.7	28.42	32.25	35.14
7.8	22.71	23.67	24.86	25.4	25.57	27.56	27.65	28.48	32.31	35.14
7.8	22.71	23.73	24.86	25.29	25.63	27.56	27.64	28.48	32.31	35.14
7.9	22.65	23.73	24.76	25.25	25.63	27.56	27.75	28.48	32.31	35.14
8.0	22.71	23.73	24.8	25.25	25.63	27.56	27.64	28.48	32.31	35.14
8.1	22.65	23.67	24.76	25.3	25.63	27.56	27.65	28.48	32.31	35.2
8.2	22.71	23.73	24.92	25.46	25.63	27.62	27.7	28.48	32.31	35.14
8.3	22.71	23.63	24.82	25.4	25.69	27.52	27.65	28.48	32.37	35.2
8.3	22.77	23.73	24.76	25.4	25.63	27.68	27.75	28.54	32.25	35.14
8.4	22.77	23.8	24.76	25.3	25.63	27.52	27.65	28.54	32.31	35.14
8.5	22.77	23.8	24.88	25.46	25.69	27.58	27.75	28.48	32.37	35.14
8.6	22.83	23.7	24.88	25.36	25.69	27.58	27.6	28.54	32.31	35.14
8.7	22.83	23.7	24.88	25.52	25.69	27.58	27.82	28.54	32.31	35.14
8.8	22.73	23.7	24.88	25.3	25.63	27.58	27.65	28.59	32.31	35.2
8.8	22.67	23.7	24.88	25.46	25.69	27.58	27.75	28.54	32.31	35.14
8.9	22.83	23.76	24.88	25.36	25.69	27.58	27.72	28.54	32.25	35.2
9.0	22.88	23.7	24.88	25.46	25.69	27.58	27.82	28.59	32.31	35.2
9.1	22.78	23.76	24.93	25.42	25.75	27.64	27.72	28.59	32.31	35.14
9.2	22.83	23.76	24.93	25.52	25.75	27.64	27.65	28.59	32.37	35.14
9.3	22.73	23.76	24.88	25.36	25.82	27.69	27.78	28.55	32.37	35.2

9.3	22.78	23.81	24.93	25.52	25.75	27.64	27.72	28.59	32.31	35.14
9.4	22.84	23.81	24.99	25.42	25.75	27.69	27.72	28.49	32.37	35.14
9.5	22.78	23.81	24.99	25.58	25.82	27.69	27.72	28.59	32.37	35.14
9.6	22.84	23.81	24.99	25.36	25.82	27.59	27.72	28.54	32.43	35.2
9.7	22.84	23.81	24.93	25.48	25.82	27.69	27.78	28.59	32.37	35.2
9.8	22.84	23.81	24.89	25.42	25.75	27.65	27.78	28.65	32.31	35.14
9.8	22.84	23.81	24.99	25.58	25.82	27.65	27.72	28.65	32.37	35.2
9.9	22.9	23.87	24.99	25.48	25.75	27.65	27.72	28.65	32.37	35.2
10.0	22.84	23.87	24.99	25.42	25.75	27.65	27.72	28.65	32.31	35.2
10.1	22.9	23.81	24.95	25.48	25.82	27.65	27.72	28.62	32.37	35.14
10.2	22.78	23.93	25.05	25.58	25.82	27.72	27.78	28.65	32.31	35.2
10.3	22.84	23.87	24.95	25.53	25.82	27.65	27.72	28.62	32.37	35.14
10.3	22.84	23.87	24.95	25.48	25.93	27.65	27.78	28.65	32.37	35.2
10.4	22.97	23.87	24.95	25.48	25.87	27.72	27.78	28.62	32.37	35.14
10.5	22.84	23.87	25.02	25.58	25.87	27.72	27.84	28.65	32.37	35.2
10.6	22.9	23.93	24.95	25.53	25.82	27.72	27.84	28.62	32.37	35.2
10.7	22.97	23.93	24.95	25.63	25.82	27.78	27.78	28.62	32.37	35.2
10.8	22.9	23.93	25.02	25.48	25.87	27.72	27.78	28.68	32.37	35.26
10.8	22.97	23.99	25.07	25.63	25.93	27.65	27.84	28.68	32.37	35.2
10.9	22.9	23.93	25.07	25.53	25.87	27.78	27.78	28.55	32.37	35.2
11.0	22.9	23.87	25.07	25.63	25.93	27.72	27.84	28.55	32.37	35.2
11.1	22.97	23.89	25.07	25.53	25.93	27.72	27.84	28.62	32.37	35.14
11.2	22.97	23.93	25.02	25.69	25.93	27.78	27.84	28.62	32.37	35.2
11.3	23.02	23.99	25.02	25.53	25.93	27.78	27.84	28.68	32.37	35.26
11.3	22.9	23.99	25.13	25.59	25.93	27.78	27.84	28.68	32.37	35.2
11.4	23.02	23.89	25.13	25.53	25.87	27.73	27.84	28.68	32.37	35.2
11.5	22.97	23.99	25.07	25.59	25.93	27.83	27.84	28.74	32.37	35.2
11.6	22.97	23.89	25.07	25.59	25.93	27.68	27.9	28.68	32.43	35.14
11.7	23.02	23.94	25.07	25.59	25.93	27.68	27.84	28.68	32.37	35.14
11.8	23.02	23.94	25.13	25.59	25.87	27.73	27.84	28.74	32.28	35.26
11.8	23.08	24.04	25.13	25.59	25.87	27.73	27.9	28.68	32.37	35.26
11.9	23.08	23.94	25.13	25.59	25.93	27.73	27.84	28.68	32.37	35.2
12.0	23.02	23.94	25.13	25.65	25.87	27.73	27.9	28.68	32.43	35.2
12.1	23.02	23.94	25.13	25.59	25.93	27.79	27.9	28.68	32.28	35.2
12.2	23.02	23.94	25.19	25.59	25.99	27.79	27.95	28.74	32.43	35.14
12.3	23.02	24	25.19	25.65	25.93	27.69	27.9	28.74	32.43	35.2
12.3	23.02	24	25.19	25.59	25.93	27.79	27.9	28.79	32.43	35.2
12.4	23.02	23.94	25.25	25.59	25.87	27.79	27.9	28.74	32.28	35.14
12.5	23.08	24.06	25.25	25.59	25.93	27.73	27.9	28.74	32.37	35.2
12.6	23.08	24	25.19	25.65	25.93	27.69	27.84	28.74	32.28	35.2
12.7	23.14	24	25.25	25.65	25.93	27.69	27.9	28.68	32.37	35.2
12.8	23.08	24	25.19	25.65	25.99	27.75	27.9	28.79	32.28	35.2
12.8	23.08	24.06	25.19	25.65	25.93	27.85	27.9	28.74	32.37	35.14
12.9	23.02	24.06	25.25	25.65	25.99	27.75	27.9	28.74	32.34	35.1
13.0	23.08	24	25.3	25.72	25.99	27.69	27.9	28.74	32.34	35.2
13.1	23.14	24	25.15	25.59	25.99	27.75	27.9	28.74	32.39	35.14
13.2	23.14	24.06	25.25	25.72	25.93	27.75	27.95	28.74	32.28	35.14
13.3	23.14	23.9	25.15	25.65	25.99	27.75	27.95	28.79	32.28	35.2
13.3	23.14	23.96	25.2	25.75	25.99	27.81	28.01	28.79	32.28	35.2

13.4	23.08	24.06	25.2	25.65	25.99	27.75	27.95	28.74	32.34	35.2
13.5	23.14	24.06	25.15	25.72	25.99	27.81	27.9	28.74	32.34	35.26
13.6	23.08	24.03	25.2	25.65	25.99	27.81	27.9	28.74	32.28	35.1
13.7	23.14	24.13	25.2	25.65	25.99	27.75	27.9	28.79	32.43	35.2
13.8	23.14	23.96	25.2	25.65	26.05	27.81	27.95	28.79	32.28	35.2
13.8	23.2	23.96	25.26	25.65	25.99	27.81	27.95	28.79	32.37	35.2
13.9	23.14	24.03	25.26	25.72	26.05	27.81	27.95	28.79	32.34	35.14
14.0	23.2	24.03	25.2	25.65	26.05	27.87	27.9	28.74	32.34	35.2
14.1	23.14	24.09	25.2	25.72	26.05	27.81	27.95	28.74	32.28	35.1
14.2	23.2	24.03	25.26	25.72	26.1	27.81	27.95	28.79	32.28	35.2
14.3	23.14	24.09	25.32	25.72	26.05	27.81	28.01	28.74	32.28	35.2
14.3	23.2	24.03	25.32	25.77	26.05	27.87	27.9	28.79	32.39	35.1
14.4	23.2	24.03	25.16	25.72	26.1	27.87	27.95	28.79	32.34	35.1
14.5	23.2	24.09	25.32	25.72	26.1	27.87	27.95	28.79	32.34	35.2
14.6	23.2	24.09	25.32	25.72	26.1	27.87	28.01	28.85	32.34	35.1
14.7	23.2	24.09	25.32	25.65	26.05	27.87	27.95	28.79	32.34	35.2
14.8	23.2	24.09	25.22	25.72	26.05	27.77	28.01	28.85	32.34	35.14
14.8	23.2	24.09	25.28	25.72	26.1	27.92	28.01	28.91	32.34	35.2
14.9	23.1	24.03	25.22	25.72	26.1	27.77	27.95	28.79	32.34	35.04
15.0	23.2	24.14	25.22	25.77	26.05	27.77	27.95	28.85	32.34	35.2

Table B-3. Quick Heat Generation Test Results for Varying Water Temperature (Cement Temperature = 21.1 °C (70°F))

	Starting Cement Temperature, °F (°C)									
Elapsed Time (Min)	60 (15.6) (°C)	65 (18,3) (°C)	70 (21.1) (°C)	75 (23.9) (°C)	80 (26.7) (°C)	85 (29.4) (°C)	90 (32.2) (°C)	100 (37.8) (°C)	110 (43.3) (°C)	120 (48.9) (°C)
0.0	20.54	22.81	23.25	24.04	25.69	25.45	28.42	31.58	32.49	34.98
0.1	20.58	22.87	23.31	24.04	25.69	25.63	28.63	31.7	33.14	35.5
0.2	20.54	22.92	23.48	23.92	25.69	25.74	28.65	31.81	33.32	36.01
0.3	20.66	22.88	23.48	23.98	25.8	25.8	28.87	31.81	33.49	36.3
0.3	20.72	23.04	23.5	23.98	25.86	25.92	28.71	31.76	33.75	36.47
0.4	20.78	23.01	23.65	23.98	25.92	25.98	29.05	31.87	33.84	36.59
0.5	20.78	23.12	23.62	24.04	25.92	25.98	28.95	31.87	34.04	36.82
0.6	20.83	23.18	23.78	23.98	26.03	26.1	29.11	31.99	34.07	36.94
0.7	20.83	23.18	23.68	24.04	26.03	26.16	29.06	31.99	34.33	37.05
0.8	20.89	23.3	23.74	24.04	26.09	26.21	29.22	31.99	34.36	37.22
0.8	20.95	23.3	23.68	24.04	26.22	26.27	29.18	31.99	34.56	37.34
0.9	21.01	23.35	23.8	24.04	26.15	26.33	29.18	32.03	34.58	37.44
1.0	20.91	23.41	23.85	24.04	26.22	26.45	29.29	32.03	34.79	37.56
1.1	21.06	23.47	23.91	24.1	26.27	26.51	29.34	32.09	34.81	37.68
1.2	20.96	23.53	23.81	24.1	26.23	26.51	29.35	32.15	34.96	37.79
1.3	20.96	23.53	23.81	24.15	26.33	26.57	29.29	32.15	35.02	37.85
1.3	21.08	23.58	23.87	24.1	26.29	26.63	29.42	32.15	35.18	38.01
1.4	21.08	23.58	23.87	24.1	26.35	26.68	29.52	32.15	35.24	38.08
1.5	21.15	23.48	23.93	24.21	26.4	26.74	29.48	32.21	35.3	38.14
1.6	21.15	23.55	23.98	24.15	26.45	26.8	29.48	32.21	35.42	38.14
1.7	21.15	23.61	24.05	24.1	26.35	26.8	29.54	32.28	35.42	38.19

1.8	21.26	23.61	23.98	24.15	26.4	26.86	29.54	32.28	35.47	38.31
1.8	21.26	23.67	24.05	24.05	26.46	26.93	29.59	32.32	35.53	38.31
1.9	21.26	23.73	24.11	24.15	26.52	26.97	29.54	32.28	35.53	38.37
2.0	21.26	23.78	24.11	24.05	26.52	27.04	29.65	32.38	35.59	38.53
2.1	21.38	23.78	24.17	24.11	26.52	27.04	29.71	32.32	35.65	38.37
2.2	21.38	23.84	24.17	24.11	26.58	27.2	29.65	32.38	35.65	38.48
2.3	21.38	23.84	24.17	24.11	26.65	27.16	29.71	32.32	35.76	38.48
2.3	21.34	23.84	24.22	24.11	26.65	27.16	29.65	32.32	35.82	38.69
2.4	21.28	23.96	24.22	24.11	26.65	27.27	29.71	32.44	35.82	38.6
2.5	21.45	23.9	24.12	24.17	26.7	27.43	29.77	32.38	35.82	38.75
2.6	21.34	23.91	24.22	24.17	26.7	27.33	29.82	32.44	35.82	38.66
2.7	21.39	23.86	24.18	24.23	26.76	27.49	29.82	32.44	35.82	38.75
2.8	21.39	23.91	24.28	24.23	26.7	27.44	29.82	32.44	35.88	38.71
2.8	21.45	23.91	24.12	24.3	26.82	27.5	29.82	32.5	35.93	38.86
2.9	21.45	23.88	24.18	24.23	26.88	27.57	29.88	32.5	35.93	38.77
3.0	21.41	23.94	24.24	24.23	26.76	27.66	29.94	32.5	35.93	38.98
3.1	21.41	23.88	24.3	24.23	26.76	27.63	29.94	32.5	35.93	38.92
3.2	21.41	24	24.3	24.23	26.88	27.73	29.94	32.55	35.99	39.03
3.3	21.58	24	24.3	24.23	26.82	27.63	29.94	32.55	35.99	38.89
3.3	21.48	24	24.3	24.3	26.88	27.79	30.01	32.55	36.05	39.03
3.4	21.53	23.9	24.3	24.35	26.88	27.84	30.01	32.55	35.99	38.99
3.5	21.53	23.95	24.2	24.35	26.93	27.84	29.94	32.55	36.11	39.03
3.6	21.53	23.95	24.41	24.3	26.93	27.96	30.05	32.61	36.05	39.03
3.7	21.59	23.95	24.26	24.35	26.93	28.02	30.01	32.55	36.05	39.09
3.8	21.59	23.85	24.41	24.41	26.99	27.92	30.05	32.61	36.11	39.15
3.8	21.59	23.91	24.31	24.41	27.05	27.96	30.01	32.61	36.11	39.09
3.9	21.65	23.91	24.31	24.41	26.99	28.02	30.05	32.67	36.11	39.05
4.0	21.65	23.97	24.37	24.35	26.99	28.13	30.05	32.67	36.11	39.15
4.1	21.65	23.97	24.37	24.41	27.05	28.07	30.11	32.67	36.11	39.15
4.2	21.71	23.97	24.37	24.47	27.05	28.19	30.05	32.67	36.11	39.21
4.3	21.71	23.97	24.37	24.47	27.11	28.13	30.11	32.67	36.05	39.21
4.3	21.77	24.03	24.31	24.47	27.05	28.19	30.11	32.61	36.11	39.27
4.4	21.71	23.87	24.44	24.47	27.05	28.19	30.11	32.61	36.11	39.21
4.5	21.67	23.99	24.44	24.53	27.05	28.26	30.17	32.73	36.17	39.21
4.6	21.77	23.99	24.44	24.53	27.11	28.19	30.17	32.67	36.17	39.21
4.7	21.67	24.04	24.5	24.53	27.11	28.26	30.02	32.73	36.17	39.27
4.8	21.72	24.04	24.44	24.53	27.16	28.26	30.23	32.67	36.17	39.27
4.8	21.67	24.04	24.5	24.53	27.16	28.37	30.17	32.78	36.11	39.27
4.9	21.72	24	24.44	24.53	27.11	28.37	30.23	32.73	36.17	39.27
5.0	21.82	24.04	24.55	24.58	27.22	28.3	30.02	32.73	36.17	39.32
5.1	21.78	24.07	24.55	24.58	27.22	28.37	30.17	32.78	36.17	39.32
5.2	21.78	24.17	24.55	24.53	27.22	28.46	30.14	32.68	36.11	39.32
5.3	21.88	24	24.61	24.58	27.22	28.3	30.17	32.73	36.17	39.32
5.3	21.84	24.07	24.61	24.64	27.22	28.53	30.14	32.68	36.17	39.27
5.4	21.84	24.07	24.61	24.58	27.22	28.43	30.2	32.78	36.11	39.32
5.5	21.84	24.13	24.45	24.54	27.22	28.43	30.14	32.63	36.17	39.38
5.6	21.84	24.13	24.55	24.54	27.22	28.43	30.2	32.78	36.17	39.32
5.7	21.91	24.18	24.51	24.6	27.35	28.53	30.2	32.68	36.11	39.38
5.8	21.91	24.18	24.51	24.54	27.35	28.43	30.2	32.68	36.11	39.32

5.8	21.84	24.18	24.57	24.54	27.35	28.59	30.2	32.68	36.17	39.38
5.9	21.95	24.24	24.51	24.64	27.35	28.49	30.2	32.78	36.17	39.32
6.0	21.95	24.24	24.63	24.6	27.35	28.59	30.25	32.68	36.17	39.38
6.1	21.95	24.14	24.63	24.76	27.29	28.49	30.14	32.78	36.22	39.38
6.2	21.95	24.24	24.63	24.6	27.41	28.64	30.2	32.74	36.11	39.38
6.3	22.02	24.2	24.63	24.6	27.35	28.49	30.25	32.74	36.11	39.38
6.3	22.02	24.2	24.63	24.6	27.25	28.64	30.31	32.74	36.17	39.38
6.4	22.02	24.2	24.68	24.66	27.35	28.54	30.25	32.84	36.17	39.38
6.5	22.02	24.2	24.68	24.66	27.36	28.64	30.25	32.74	36.11	39.38
6.6	22.02	24.2	24.63	24.71	27.41	28.64	30.25	32.74	36.11	39.44
6.7	22.08	24.26	24.58	24.66	27.31	28.76	30.21	32.74	36.11	39.44
6.8	22.08	24.26	24.58	24.66	27.41	28.7	30.25	32.8	36.17	39.44
6.8	22.04	24.26	24.53	24.71	27.31	28.64	30.21	32.74	36.17	39.32
6.9	22.14	24.31	24.58	24.71	27.46	28.7	30.31	32.78	36.11	39.38
7.0	22.09	24.26	24.58	24.71	27.36	28.7	30.21	32.8	36.21	39.32
7.1	22.14	24.31	24.64	24.71	27.46	28.7	30.25	32.9	36.11	39.38
7.2	22.09	24.37	24.64	24.78	27.36	28.7	30.21	32.8	36.11	39.38
7.3	22.09	24.37	24.7	24.78	27.46	28.7	30.21	32.9	36.11	39.44
7.3	22.04	24.37	24.64	24.71	27.36	28.76	30.21	32.74	36.11	39.38
7.4	22.09	24.33	24.7	24.71	27.52	28.7	30.21	32.74	36.05	39.38
7.5	22.09	24.27	24.64	24.78	27.42	28.7	30.27	32.74	36.05	39.38
7.6	22.15	24.4	24.64	24.78	27.52	28.76	30.21	32.8	36.05	39.32
7.7	21.99	24.33	24.64	24.68	27.48	28.76	30.21	32.74	36.15	39.38
7.8	22.05	24.33	24.7	24.71	27.58	28.76	30.27	32.74	36.05	39.38
7.8	22.11	24.33	24.7	24.68	27.48	28.76	30.21	32.8	36.05	39.38
7.9	22.11	24.4	24.7	24.68	27.58	28.76	30.21	32.86	36.05	39.44
8.0	22.11	24.4	24.7	24.68	27.48	28.76	30.27	32.74	36.09	39.47
8.1	22.11	24.36	24.77	24.78	27.48	28.76	30.27	32.86	36.05	39.38
8.2	22.11	24.3	24.82	24.68	27.42	28.82	30.27	32.86	36.09	39.47
8.3	22.11	24.3	24.82	24.68	27.58	28.76	30.27	32.86	35.99	39.32
8.3	22.11	24.51	24.82	24.68	27.48	28.76	30.27	32.8	36.09	39.41
8.4	22.17	24.36	24.82	24.68	27.54	28.88	30.27	32.8	35.99	39.44
8.5	22.17	24.41	24.77	24.74	27.54	28.82	30.27	32.8	36.09	39.47
8.6	22.23	24.41	24.82	24.68	27.64	28.82	30.33	32.86	35.93	39.32
8.7	22.23	24.41	24.82	24.74	27.48	28.82	30.33	32.8	36.03	39.38
8.8	22.23	24.41	24.82	24.74	27.54	28.82	30.27	32.86	36.09	39.38
8.8	22.23	24.41	24.82	24.74	27.54	28.82	30.33	32.76	36.09	39.47
8.9	22.23	24.47	24.82	24.8	27.54	28.88	30.27	32.86	35.93	39.47
9.0	22.18	24.47	24.82	24.8	27.54	28.82	30.33	32.76	36.03	39.32
9.1	22.28	24.47	24.88	24.74	27.54	28.82	30.33	32.76	35.99	39.32
9.2	22.25	24.53	24.88	24.8	27.54	28.82	30.27	32.86	36.09	39.41
9.3	22.28	24.47	24.88	24.8	27.54	28.88	30.33	32.86	36.03	39.32
9.3	22.25	24.53	24.88	24.86	27.54	28.82	30.33	32.86	36.03	39.41
9.4	22.18	24.53	24.88	24.86	27.59	28.88	30.33	32.86	36.03	39.32
9.5	22.25	24.53	24.78	24.86	27.54	28.88	30.27	32.76	36.03	39.27
9.6	22.25	24.43	24.94	24.8	27.59	28.82	30.27	32.86	35.93	39.41
9.7	22.25	24.64	24.78	24.86	27.59	28.88	30.33	32.76	36.03	39.41
9.8	22.31	24.43	24.78	24.86	27.54	28.88	30.38	32.82	35.98	39.32
9.8	22.31	24.49	24.84	24.91	27.65	28.88	30.33	32.76	35.98	39.41

9.9	22.31	24.54	24.84	24.91	27.65	28.88	30.33	32.86	36.03	39.32
10.0	22.21	24.49	24.84	24.86	27.65	28.88	30.38	32.82	35.92	39.41
10.1	22.31	24.7	24.84	24.91	27.59	28.88	30.33	32.76	35.98	39.32
10.2	22.21	24.54	24.9	24.91	27.65	28.93	30.33	32.76	35.98	39.32
10.3	22.37	24.54	24.84	24.91	27.65	28.88	30.33	32.76	35.92	39.27
10.3	22.21	24.7	24.9	24.97	27.72	28.88	30.33	32.76	35.98	39.37
10.4	22.27	24.6	24.84	24.91	27.65	28.88	30.33	32.76	35.92	39.37
10.5	22.27	24.6	24.9	24.97	27.59	28.88	30.38	32.76	35.92	39.37
10.6	22.27	24.6	24.9	24.97	27.78	28.88	30.38	32.76	35.92	39.31
10.7	22.32	24.6	24.9	24.91	27.65	28.88	30.38	32.76	35.92	39.31
10.8	22.32	24.66	24.84	24.97	27.72	28.88	30.38	32.82	35.86	39.21
10.8	22.32	24.66	24.9	24.97	27.65	28.88	30.38	32.82	35.86	39.37
10.9	22.32	24.6	24.9	24.97	27.78	28.88	30.44	32.82	35.92	39.37
11.0	22.32	24.66	24.9	24.97	27.72	28.88	30.38	32.76	35.86	39.31
11.1	22.38	24.73	24.9	24.97	27.72	28.88	30.38	32.82	35.86	39.37
11.2	22.32	24.66	24.9	25.03	27.72	28.88	30.44	32.76	35.92	39.31
11.3	22.44	24.73	24.9	25.03	27.78	28.88	30.38	32.82	35.8	39.37
11.3	22.32	24.73	24.96	25.03	27.72	28.99	30.44	32.76	35.86	39.37
11.4	22.44	24.73	24.96	25.03	27.78	28.93	30.44	32.76	35.8	39.31
11.5	22.44	24.73	24.96	25.03	27.72	28.88	30.44	32.82	35.8	39.31
11.6	22.44	24.77	24.96	25.09	27.78	28.88	30.38	32.82	35.8	39.21
11.7	22.44	24.77	25.01	25.03	27.78	28.88	30.38	32.76	35.75	39.31
11.8	22.44	24.73	24.96	25.09	27.78	28.88	30.38	32.82	35.8	39.31
11.8	22.44	24.77	24.96	25.09	27.73	28.88	30.44	32.76	35.8	39.31
11.9	22.44	24.67	24.96	25.09	27.78	28.88	30.38	32.82	35.75	39.31
12.0	22.4	24.77	25.01	25.03	27.83	28.88	30.44	32.82	35.8	39.25
12.1	22.44	24.74	25.01	25.03	27.78	28.88	30.44	32.76	35.75	39.21
12.2	22.4	24.77	24.96	25.09	27.73	28.88	30.44	32.76	35.75	39.25
12.3	22.4	24.74	25.01	25.03	27.78	28.93	30.44	32.76	35.75	39.15
12.3	22.45	24.74	25.01	25.09	27.73	28.98	30.44	32.76	35.75	39.25
12.4	22.4	24.74	25.01	25.14	27.78	28.88	30.5	32.82	35.75	39.25
12.5	22.4	24.74	25.01	25.14	27.73	28.88	30.34	32.82	35.69	39.25
12.6	22.45	24.74	25.01	25.09	27.73	28.88	30.44	32.82	35.69	39.25
12.7	22.45	24.67	25.01	25.09	27.73	28.88	30.34	32.82	35.63	39.25
12.8	22.51	24.7	25.07	25.09	27.73	28.88	30.44	32.82	35.69	39.19
12.8	22.4	24.7	25.07	24.99	27.79	28.82	30.4	32.76	35.69	39.19
12.9	22.4	24.7	25.01	25.09	27.79	28.82	30.44	32.87	35.63	39.19
13.0	22.51	24.76	25.07	24.99	27.79	29.03	30.34	32.76	35.63	39.19
13.1	22.51	24.7	25.07	25.14	27.73	28.88	30.34	32.82	35.63	39.19
13.2	22.41	24.7	24.97	25.04	27.79	28.88	30.34	32.82	35.69	39.13
13.3	22.41	24.64	24.97	25.14	27.79	28.88	30.44	32.82	35.63	39.19
13.3	22.41	24.7	24.97	25.1	27.85	29.03	30.34	32.76	35.63	39.19
13.4	22.48	24.7	24.97	25.14	27.85	28.93	30.5	32.82	35.63	39.13
13.5	22.48	24.76	24.97	25.04	27.79	29.03	30.34	32.82	35.57	39.13
13.6	22.41	24.76	25.13	25.14	27.85	28.93	30.4	32.82	35.57	39.13
13.7	22.48	24.76	24.97	25.04	27.79	29.03	30.34	32.82	35.66	39.19
13.8	22.48	24.82	25.13	25.14	27.85	28.88	30.44	32.82	35.57	39.19
13.8	22.48	24.87	25.03	25.1	27.69	28.98	30.4	32.76	35.66	39.19
13.9	22.54	24.82	24.97	25.2	27.79	28.88	30.28	32.82	35.57	39.13

14.0	22.54	24.82	25.1	25.04	27.75	29.03	30.34	32.82	35.62	39.13
14.1	22.48	24.72	25.03	25.2	27.85	28.98	30.34	32.76	35.52	39.19
14.2	22.54	24.82	25.1	25.1	27.75	29.03	30.4	32.82	35.62	39.13
14.3	22.54	24.77	25.1	25.2	27.91	28.88	30.44	32.82	35.46	39.13
14.3	22.59	24.82	25.1	25.17	27.75	28.98	30.34	32.82	35.46	39.13
14.4	22.48	24.77	25.1	25.2	27.81	28.93	30.44	32.76	35.46	39.13
14.5	22.54	24.77	25.1	25.1	27.75	28.98	30.34	32.82	35.56	39.08
14.6	22.54	24.77	25.1	25.1	27.81	29.03	30.44	32.76	35.56	39.08
14.7	22.59	24.77	25.1	25.17	27.81	28.98	30.34	32.82	35.46	39.13
14.8	22.54	24.77	25.1	25.27	27.75	28.98	30.34	32.82	35.46	39.08
14.8	22.54	24.77	25.14	25.17	27.75	28.98	30.34	32.73	35.56	39.08
14.9	22.59	24.77	25.1	25.17	27.81	28.88	30.4	32.82	35.46	39.02
15.0	22.59	24.77	25.1	25.17	27.87	28.98	30.34	32.82	35.5	39.08

Table B-4. Initial Paste Temperature and Final Paste Temperature for Varying Cement Temperature Data

Starting Cement Temp. (° C)	Initial Paste Temp. (° C)	Paste Temp. @ 15 Min (° C)
15.56	20.84	23.20
18.33	22.41	24.14
21.11	23.31	25.22
23.89	23.59	25.77
26.67	23.89	26.05
29.44	25.90	27.77
32.22	25.86	27.95
37.78	26.40	28.85
43.33	30.33	32.34
48.89	33.18	35.20

Table B-5. Initial Paste Temperature and Final Paste Temperature for Varying Water Temperature Data

Starting Water Temp. (° C)	Initial Paste Temp. (° C)	Paste Temp. @ 15 Min (° C)
15.56	20.54	22.59
18.33	22.81	24.77
21.11	23.25	25.10
23.89	24.04	25.17
26.67	25.69	27.87
29.44	25.45	28.98
32.22	28.42	30.34
37.78	31.58	32.82
43.33	32.49	35.50
48.89	34.98	39.08

Table B-6. Initial Paste Temperature and Paste Temperature at 15 Minutes

Initial Paste Temp. (° C)	Paste Temp. @ 15 Min (° C)
20.54	22.59
22.81	24.77
23.25	25.10
24.04	25.17
25.69	27.87
25.45	28.98
28.42	30.34
31.58	32.82
32.49	35.50
34.98	39.08
20.84	23.20
22.41	24.14
23.31	25.22
23.59	25.77
23.89	26.05
25.90	27.77
25.86	27.95
26.40	28.85
30.33	32.34
33.18	35.20

Table B-7. Quick Heat Generation Test Results for Varying Cement Types (Cement and Water Temperature = 21.1 °C (70°F))

Elapsed Time (Min)	Cement Type							
	Type IP (°C)	Ternary (°C)	Type IPM (°C)	Type ISM (°C)	Type I (a) (°C)	Type I (b) (°C)	Type I/II (Varying Cement Temp.) (°C)	TI/II (Varying Water Temp) (°C)
0.0	21.79	21.15	25.4	22.54	26.46	26.09	23.31	23.25
0.1	21.85	21.2	25.53	22.54	26.69	26.2	23.43	23.31
0.2	21.98	21.26	25.69	22.54	26.63	26.29	23.49	23.48
0.3	22.03	21.38	25.77	22.66	26.69	26.56	23.49	23.48
0.3	22.12	21.32	25.93	22.73	26.75	26.67	23.54	23.5
0.4	22.09	21.38	25.94	22.73	26.75	26.79	23.56	23.65
0.5	22.25	21.38	26.1	22.77	26.75	26.92	23.6	23.62
0.6	22.25	21.45	26.12	22.77	26.82	27.03	23.56	23.78
0.7	22.31	21.5	26.28	22.9	26.87	27.15	23.63	23.68
0.8	22.36	21.5	26.33	22.9	26.87	27.32	23.67	23.74
0.8	22.36	21.56	26.33	22.9	26.93	27.43	23.67	23.68
0.9	22.36	21.62	26.36	22.96	26.93	27.62	23.8	23.8
1.0	22.42	21.62	26.46	23.02	26.99	27.62	23.8	23.85
1.1	22.48	21.68	26.42	22.96	26.99	27.79	23.86	23.91
1.2	22.42	21.73	26.57	23.02	26.99	27.85	23.92	23.81
1.3	22.54	21.68	26.63	23.07	27.05	27.91	23.87	23.81
1.3	22.59	21.73	26.69	23.13	27.11	28.02	23.93	23.87
1.4	22.65	21.79	26.69	23.26	27.11	28.2	23.87	23.87
1.5	22.65	21.85	26.8	23.13	27.11	28.26	23.99	23.93
1.6	22.71	21.91	26.8	23.19	27.11	28.32	23.99	23.98
1.7	22.71	21.91	26.75	23.26	27.16	28.38	23.99	24.05
1.8	22.71	21.96	26.8	23.3	27.16	28.38	23.99	23.98
1.8	22.81	21.96	26.8	23.3	27.22	28.49	24.06	24.05
1.9	22.71	22.02	26.86	23.3	27.22	28.49	24.1	24.11
2.0	22.81	22.02	26.86	23.47	27.22	28.49	24.17	24.11
2.1	22.78	22.09	26.93	23.37	27.22	28.62	24.17	24.17
2.2	22.87	22.15	26.93	23.47	27.22	28.62	24.17	24.17
2.3	22.78	22.15	26.93	23.37	27.35	28.68	24.23	24.17
2.3	22.94	22.21	26.99	23.43	27.28	28.68	24.29	24.22
2.4	22.87	22.26	27.05	23.43	27.35	28.68	24.29	24.22
2.5	22.87	22.32	26.99	23.47	27.35	28.73	24.29	24.12
2.6	22.94	22.26	26.99	23.43	27.35	28.73	24.3	24.22
2.7	22.94	22.32	27.05	23.53	27.39	28.73	24.24	24.18
2.8	22.89	22.38	26.99	23.64	27.39	28.79	24.3	24.28
2.8	22.99	22.44	27.05	23.59	27.39	28.79	24.3	24.12
2.9	23.05	22.44	27.1	23.49	27.39	28.85	24.3	24.18
3.0	23.05	22.44	27.1	23.53	27.39	28.79	24.36	24.24
3.1	23.05	22.59	27.1	23.6	27.46	28.85	24.26	24.3
3.2	22.99	22.49	27.16	23.64	27.49	28.91	24.36	24.3
3.3	23.05	22.71	27.16	23.6	27.46	28.85	24.26	24.3
3.3	23.05	22.62	27.16	23.59	27.52	28.85	24.32	24.3

3.4	22.99	22.78	27.16	23.49	27.52	28.79	24.32	24.3
3.5	22.99	22.68	27.16	23.64	27.62	28.85	24.32	24.2
3.6	23.11	22.82	27.22	23.7	27.52	28.85	24.38	24.41
3.7	23.05	22.73	27.16	23.7	27.58	28.85	24.38	24.26
3.8	23.34	22.79	27.22	23.6	27.52	28.91	24.38	24.41
3.8	23.4	22.85	27.16	23.7	27.58	28.85	24.43	24.31
3.9	23.45	22.95	27.22	23.6	27.58	29.01	24.5	24.31
4.0	23.45	22.95	27.22	23.7	27.63	28.91	24.5	24.37
4.1	23.45	23.01	27.16	23.7	27.63	28.91	24.5	24.37
4.2	23.45	22.97	27.22	23.7	27.63	28.96	24.5	24.37
4.3	23.45	23.07	27.28	23.6	27.69	28.91	24.56	24.37
4.3	23.45	23.07	27.22	23.7	27.63	28.91	24.5	24.31
4.4	23.52	23.12	27.28	23.7	27.69	28.96	24.56	24.44
4.5	23.45	23.12	27.22	23.76	27.79	28.91	24.56	24.44
4.6	23.52	23.12	27.33	23.72	27.69	28.96	24.46	24.44
4.7	23.45	23.18	27.28	23.76	27.69	29.02	24.62	24.5
4.8	23.52	23.24	27.28	23.82	27.69	29.02	24.57	24.44
4.8	23.52	23.24	27.28	23.76	27.63	29.02	24.67	24.5
4.9	23.52	23.24	27.28	23.72	27.63	28.91	24.52	24.44
5.0	23.52	23.31	27.28	23.76	27.85	29.02	24.57	24.55
5.1	23.45	23.31	27.33	23.82	27.75	28.96	24.63	24.55
5.2	23.52	23.35	27.33	23.82	27.75	28.91	24.63	24.55
5.3	23.52	23.35	27.28	23.88	27.75	29.06	24.63	24.61
5.3	23.52	23.35	27.28	23.88	27.75	28.96	24.69	24.61
5.4	23.52	23.35	27.33	23.88	27.75	28.96	24.69	24.61
5.5	23.52	23.48	27.33	23.88	27.75	28.96	24.69	24.45
5.6	23.52	23.48	27.33	23.82	27.75	28.96	24.59	24.55
5.7	23.52	23.42	27.33	23.88	27.91	29.02	24.65	24.51
5.8	23.52	23.64	27.33	23.82	27.81	28.96	24.59	24.51
5.8	23.52	23.48	27.28	23.88	27.85	29.02	24.75	24.57
5.9	23.52	23.54	27.28	23.88	27.81	29.02	24.7	24.51
6.0	23.52	23.54	27.33	23.93	27.91	29.02	24.65	24.63
6.1	23.52	23.54	27.39	24	27.87	28.96	24.65	24.63
6.2	23.67	23.59	27.33	23.93	27.87	28.96	24.7	24.63
6.3	23.58	23.64	27.39	23.93	27.81	28.96	24.7	24.63
6.3	23.67	23.65	27.39	23.93	27.97	29.02	24.7	24.63
6.4	23.64	23.69	27.33	23.93	27.87	29.18	24.66	24.68
6.5	23.58	23.65	27.39	23.93	27.97	29.02	24.76	24.68
6.6	23.52	23.75	27.33	23.93	27.87	29.02	24.66	24.63
6.7	23.61	23.65	27.39	23.93	27.97	28.96	24.66	24.58
6.8	23.61	23.75	27.39	23.93	27.87	29.12	24.66	24.58
6.8	23.67	23.71	27.39	23.93	28.02	28.96	24.66	24.53
6.9	23.67	23.81	27.39	24	27.92	28.96	24.79	24.58
7.0	23.61	23.75	27.33	24	28.02	29.02	24.79	24.58
7.1	23.67	23.81	27.33	24	27.92	29.02	24.79	24.64
7.2	23.74	23.81	27.39	24.06	28.02	29.02	24.79	24.64
7.3	23.61	23.81	27.39	24	27.92	29.02	24.79	24.7
7.3	23.67	23.81	27.39	24.06	28.09	29.02	24.84	24.64
7.4	23.67	23.87	27.39	24.06	27.92	29.08	24.74	24.7

7.5	23.67	23.87	27.39	24.06	27.92	28.96	24.9	24.64
7.6	23.67	23.87	27.45	24.06	27.87	29.12	24.8	24.64
7.7	23.67	23.87	27.39	24.12	28.02	28.96	24.8	24.64
7.8	23.67	23.93	27.45	24.12	27.92	29.02	24.86	24.7
7.8	23.67	23.93	27.43	24.06	28.02	29.08	24.86	24.7
7.9	23.67	23.93	27.45	24.06	27.99	29.02	24.76	24.7
8.0	23.67	23.93	27.49	24.06	28.09	29.08	24.8	24.7
8.1	23.67	23.93	27.39	24.12	27.99	29.18	24.76	24.77
8.2	23.67	23.98	27.39	24.06	28.09	29.02	24.92	24.82
8.3	23.67	23.93	27.39	24.06	27.99	28.96	24.82	24.82
8.3	23.67	23.98	27.43	24.17	27.99	28.96	24.76	24.82
8.4	23.67	23.98	27.39	24.06	27.99	29.02	24.76	24.82
8.5	23.61	23.93	27.55	24.12	28.15	29.02	24.88	24.77
8.6	23.67	23.98	27.55	24.06	28.05	29.18	24.88	24.82
8.7	23.61	24.04	27.55	24.12	28.09	29.02	24.88	24.82
8.8	23.67	23.98	27.45	24.12	28.05	29.08	24.88	24.82
8.8	23.74	23.98	27.49	24.12	28.15	29.02	24.88	24.82
8.9	23.67	24.04	27.45	24.17	27.99	29.12	24.88	24.82
9.0	23.67	24.04	27.55	24.17	28.15	29.02	24.88	24.82
9.1	23.74	24.11	27.39	24.17	28.05	29.08	24.93	24.88
9.2	23.74	23.98	27.49	24.17	28.15	29.08	24.93	24.88
9.3	23.67	24.04	27.45	24.17	28.11	29.18	24.88	24.88
9.3	23.67	24.11	27.55	24.17	28.21	29.08	24.93	24.88
9.4	23.67	24.11	27.49	24.29	28.05	29.12	24.99	24.88
9.5	23.74	24.04	27.55	24.12	28.21	29.08	24.99	24.78
9.6	23.74	24.04	27.52	24.12	28.05	29.08	24.99	24.94
9.7	23.74	24.11	27.55	24.23	28.15	29.08	24.93	24.78
9.8	23.74	24.11	27.45	24.17	28.15	29.02	24.89	24.78
9.8	23.67	24.04	27.55	24.17	28.21	29.08	24.99	24.84
9.9	23.74	24.04	27.55	24.17	28.11	29.08	24.99	24.84
10.0	23.67	24.11	27.55	24.29	28.21	29.08	24.99	24.84
10.1	23.8	24.11	27.52	24.23	28.11	29.18	24.95	24.84
10.2	23.74	24.17	27.55	24.23	28.15	29.08	25.05	24.9
10.3	23.74	24.17	27.49	24.23	28.11	29.08	24.95	24.84
10.3	23.74	24.17	27.55	24.23	28.21	29.08	24.95	24.9
10.4	23.74	24.11	27.45	24.23	28.11	29.18	24.95	24.84
10.5	23.71	24.11	27.55	24.23	28.21	29.08	25.02	24.9
10.6	23.8	24.17	27.49	24.23	28.11	29.08	24.95	24.9
10.7	23.77	24.11	27.49	24.29	28.21	29.08	24.95	24.9
10.8	23.67	24.17	27.45	24.23	28.11	29.08	25.02	24.84
10.8	23.77	24.17	27.49	24.29	28.11	29.08	25.07	24.9
10.9	23.67	24.17	27.55	24.23	28.26	29.12	25.07	24.9
11.0	23.83	24.17	27.62	24.23	28.21	29.08	25.07	24.9
11.1	23.67	24.17	27.55	24.29	28.26	29.02	25.07	24.9
11.2	23.74	24.22	27.62	24.23	28.26	29.08	25.02	24.9
11.3	23.67	24.17	27.55	24.29	28.22	29.12	25.02	24.9
11.3	23.83	24.22	27.62	24.29	28.26	29.12	25.13	24.96
11.4	23.83	24.22	27.62	24.35	28.11	29.12	25.13	24.96
11.5	23.83	24.22	27.55	24.23	28.26	29.08	25.07	24.96

11.6	23.74	24.22	27.55	24.29	28.32	29.18	25.07	24.96
11.7	23.77	24.28	27.55	24.17	28.26	29.08	25.07	25.01
11.8	23.83	24.17	27.62	24.29	28.16	29.02	25.13	24.96
11.8	23.9	24.22	27.55	24.23	28.26	29.08	25.13	24.96
11.9	23.77	24.17	27.62	24.29	28.26	29.18	25.13	24.96
12.0	23.77	24.22	27.62	24.29	28.26	29.08	25.13	25.01
12.1	23.83	24.17	27.62	24.35	28.16	29.02	25.13	25.01
12.2	23.83	24.22	27.62	24.29	28.26	29.08	25.19	24.96
12.3	23.83	24.31	27.62	24.35	28.22	29.02	25.19	25.01
12.3	23.83	24.22	27.55	24.35	28.32	29.08	25.19	25.01
12.4	23.83	24.28	27.62	24.29	28.22	29.08	25.25	25.01
12.5	23.83	24.22	27.62	24.35	28.32	29.02	25.25	25.01
12.6	23.83	24.31	27.62	24.35	28.32	29.12	25.19	25.01
12.7	23.83	24.22	27.62	24.35	28.26	29.02	25.25	25.01
12.8	23.83	24.38	27.55	24.4	28.32	29.18	25.19	25.07
12.8	23.83	24.28	27.55	24.29	28.32	29.14	25.19	25.07
12.9	23.9	24.28	27.62	24.29	28.22	29.18	25.25	25.01
13.0	23.83	24.22	27.62	24.29	28.32	29.02	25.3	25.07
13.1	23.83	24.38	27.55	24.4	28.32	29.12	25.15	25.07
13.2	23.93	24.28	27.62	24.35	28.32	29.08	25.25	24.97
13.3	23.83	24.31	27.55	24.35	28.32	29.12	25.15	24.97
13.3	23.83	24.22	27.62	24.4	28.38	29.02	25.2	24.97
13.4	23.83	24.38	27.55	24.35	28.22	29.18	25.2	24.97
13.5	23.83	24.38	27.67	24.4	28.32	29.08	25.15	24.97
13.6	23.9	24.38	27.62	24.35	28.22	29.12	25.2	25.13
13.7	23.93	24.38	27.62	24.35	28.44	29.02	25.2	24.97
13.8	23.83	24.38	27.67	24.4	28.38	29.12	25.2	25.13
13.8	23.93	24.28	27.62	24.35	28.38	29.08	25.26	25.03
13.9	23.9	24.38	27.67	24.4	28.28	29.02	25.26	24.97
14.0	23.93	24.31	27.62	24.35	28.38	29.02	25.2	25.1
14.1	23.9	24.44	27.62	24.4	28.28	29.18	25.2	25.03
14.2	23.93	24.38	27.62	24.4	28.38	29.08	25.26	25.1
14.3	23.83	24.38	27.62	24.4	28.28	29.12	25.32	25.1
14.3	23.93	24.44	27.55	24.4	28.38	29.02	25.32	25.1
14.4	23.99	24.44	27.62	24.35	28.44	29.08	25.16	25.1
14.5	23.99	24.44	27.62	24.46	28.38	29.02	25.32	25.1
14.6	23.99	24.44	27.67	24.46	28.28	29.24	25.32	25.1
14.7	23.93	24.38	27.62	24.35	28.38	29.08	25.32	25.1
14.8	23.93	24.44	27.62	24.4	28.28	29.08	25.22	25.1
14.8	23.87	24.44	27.55	24.46	28.32	29.08	25.28	25.14
14.9	23.93	24.44	27.62	24.46	28.38	29.18	25.22	25.1
15.0	23.93	24.44	27.62	24.46	28.38	29.08	25.22	25.1

APPENDIX C

Table C-1. AVA and Compressive Strength Data for Mixture 60TI-30C-10F

Admixture Combination	% D < 300 µm§	Spacing Factor§ (mm)	Specific Surface§ (mm-1)	Total Air§ (%)	7-Day Compressive Strength† (kPa)
AEA1-WR1	1.6	0.283	23.1	8.2	1055
AEA1-WR2	1.9	0.296	15.9	16.0	22547
AEA2-WR1	1.5	0.295	22.4	8.3	1069
AEA2-WR2	4.0	0.178	21.1	21.6	19727
AEA3-WR1	0.6	0.531	14.6	5.6	1648
AEA3-WR2	4.4	0.161	27.8	17.8	23829

§Average of two samples
†Average of three samples

Table C-2. AVA and Compressive Strength Data for Mixture 60TI-30C-10F1

Admixture Combination	% D < 300 µm§	Spacing Factor§ (mm)	Specific Surface§ (mm-1)	Total Air§ (%)	7-Day Compressive Strength† (kPa)
AEA1-WR1	3.9	0.183	26.2	5.2	1007
AEA1-WR2	3.6	0.192	17.6	13.3	15693
AEA2-WR1	4.2	0.177	27.2	5.0	1048
AEA2-WR2	3.7	0.196	20.0	15.4	18382
AEA3-WR1	1.3	0.356	17.0	4.8	1476
AEA3-WR2	3.6	0.201	20.7	13.1	17706

§Average of two samples
†Average of three samples

Table C-3. AVA and Compressive Strength Data for Mixture 50TI-30C-20G120S

Admixture Combination	% D < 300 μm[§]	Spacing Factor[§] (mm)	Specific Surface[§] (mm-1)	Total Air[§] (%)	7-Day Compressive Strength† (kPa)
AEA1-WR1	5.9	0.108	41.3	17.9	600
AEA1-WR2	4.7	0.147	23.5	23.1	12328
AEA2-WR1	5.9	0.122	36.5	17.9	655
AEA2-WR2	6.6	0.104	29.9	25.4	14507
AEA3-WR1	1.8	0.253	24.4	9.3	917
AEA3-WR2	5.9	0.114	29.7	23.7	10474

§Average of two samples
†Average of three samples

Table C-4. AVA and Compressive Strength Data for Mixture 75TIP-25C

Admixture Combination	% D < 300 μm[§]	Spacing Factor[§] (mm)	Specific Surface[§] (mm-1)	Total Air[§] (%)	7-Day Compressive Strength† (kPa)
AEA1-WR1	5.9	0.126	34.3	19.2	23278
AEA1-WR2	3.6	0.178	21.2	21.5	24781
AEA2-WR1	5.5	0.136	31.6	18.6	21788
AEA2-WR2	3.7	0.174	21.8	21.4	21574
AEA3-WR1	1.0	0.404	15.6	9.4	31110
AEA3-WR2	2.8	0.213	22.6	15.3	30634

§Average of two samples
†Average of three samples

Table C-5. AVA and Compressive Strength Data for Mixture 75TISM-25C

Admixture Combination	% D < 300 µm[§]	Spacing Factor[§] (mm)	Specific Surface[§] (mm-1)	Total Air[§] (%)	7-Day Compressive Strength† (kPa)
AEA1-WR1	6.5	0.128	30.8	20.6	13232
AEA1-WR2	1.6	0.305	13.1	20.4	19423
AEA2-WR1	7.0	0.121	28.3	23.4	13611
AEA2-WR2	1.5	0.339	13.1	18.1	19437
AEA3-WR1	2.8	0.213	24.9	12.6	20340
AEA3-WR2	2.2	0.264	17.7	16.3	26980

§Average of two samples
†Average of three samples

Table C-6. AVA and Compressive Strength Data for Mixture 75TIPM-25C

Admixture Combination	% D < 300 µm[§]	Spacing Factor[§] (mm)	Specific Surface[§] (mm-1)	Total Air[§] (%)	7-Day Compressive Strength† (kPa)
AEA1-WR1	5.2	0.150	28.5	19.0	21967
AEA1-WR2	2.4	0.259	16.6	18.7	29104
AEA2-WR1	5.3	0.152	28.9	18.4	22402
AEA2-WR2	3.0	0.230	18.2	19.2	26229
AEA3-WR1	1.7	0.298	20.2	10.0	29897
AEA3-WR2	3.2	0.194	23.4	17.3	29642

§Average of two samples
†Average of three samples

Table C-7. AVA and Compressive Strength Data for Mixture 60TI-30F-10C

Admixture Combination	% D < 300 µm§	Spacing Factor§ (mm)	Specific Surface§ (mm-1)	Total Air§ (%)	7-Day Compressive Strength† (kPa)
AEA1-WR1	0.5	0.541	14.8	5.2	22650
AEA1-WR2	2.9	0.226	22.9	13.3	23126
AEA2-WR1	0.6	0.547	15.0	5.0	23105
AEA2-WR2	4.5	0.170	28.1	15.4	20933
AEA3-WR1	0.6	0.532	15.7	4.8	21747
AEA3-WR2	2.9	0.231	22.6	13.1	22885

§Average of two samples
†Average of three samples

Table C-8. AVA and Compressive Strength Data for Mixture 60TI-30F-10F2

Admixture Combination	% D < 300 µm§	Spacing Factor§ (mm)	Specific Surface§ (mm-1)	Total Air§ (%)	7-Day Compressive Strength† (kPa)
AEA1-WR1	0.2	0.737	11.5	4.7	26532
AEA1-WR2	3.1	0.218	23.3	13.7	21664
AEA2-WR1	0.5	0.565	14.4	5.1	26242
AEA2-WR2	4.5	0.206	24.3	14.3	20657
AEA3-WR1	0.4	0.582	15.2	4.2	23960
AEA3-WR2	3.9	0.163	32.1	13.4	17644

§Average of two samples
†Average of three samples

Table C-9. AVA and Compressive Strength Data for Mixture 65TI-30F-5M

Admixture Combination	% D < 300 µm§	Spacing Factor§ (mm)	Specific Surface§ (mm-1)	Total Air§ (%)	7-Day Compressive Strength† (kPa)
AEA1-WR1	0.4	0.630	12.5	5.4	28683
AEA1-WR2	2.0	0.218	28.4	9.3	30669
AEA2-WR1	0.5	0.526	16.7	4.3	29366
AEA2-WR2	2.2	0.239	24.8	10.0	30814
AEA3-WR1	0.3	0.723	12.6	3.9	28849
AEA3-WR2	0.8	0.410	18.5	5.9	30959

§Average of two samples
†Average of three samples

Table C-10. AVA and Compressive Strength Data for Mixture 75TIP-25F

Admixture Combination	% D < 300 µm§	Spacing Factor§ (mm)	Specific Surface§ (mm-1)	Total Air§ (%)	7-Day Compressive Strength† (kPa)
AEA1-WR1	0.3	0.747	10.6	5.5	27677
AEA1-WR2	4.1	0.174	26.6	16.7	24774
AEA2-WR1	0.3	0.669	12.8	4.5	29642
AEA2-WR2	5.2	0.142	31.5	17.8	21533
AEA3-WR1	0.3	0.705	12.8	3.8	28132
AEA3-WR2	3.2	0.180	30.6	11.6	28483

§Average of two samples
†Average of three samples

APPENDIX D

Table D-1. Air Content and AVA Results for State 1

		Ahead of Paver			Behind Paver on Vibrator			Behind Paver Between Vibrator		
% Air Ahead of Paver	% Air After Paver	Spec. Sur. (in-1)	Spac. Factor (in.)	D<300 µm (%)	Spec. Surf. (in-1)	Spac. Factor (in.)	D<300 µm (%)	Spec. Sur. (in-1)	Spac. Factor (in.)	D<300 µm (%)
6.7	-	897	0.0043	4.0	515	0.0094	1.9	641	0.0085	1.9
6.6	-	900	0.0043	4.2	771	0.0061	3.0	987	0.0057	2.5
6.0	-	872	0.0053	3.0	808	0.0060	2.7	768	0.0068	2.2
5.3	-	714	0.0065	2.8	802	0.0079	1.6	621	0.0083	1.8
7.0	-	802	0.0060	3.0	771	0.0068	2.4	758	0.0062	2.7
6.4	-	650	0.0086	1.8	659	0.0083	1.7	671	0.0080	2.0
7.0	-	587	0.0077	2.4	718	0.0079	1.9	710	0.0083	2.0
6.5	5.8	766	0.0065	2.6	846	0.0066	2.3	765	0.0066	2.5

Table D-2. Air Content and AVA Results for State 2

		Ahead of Paver			Behind Paver on Vibrator			Behind Paver Between Vibrator		
% Air Ahead of Paver	% Air After Paver	Spec. Sur. (in-1)	Spac. Factor (in.)	D<300 µm (%)	Spec. Surf. (in-1)	Spac. Factor (in.)	D<300 µm (%)	Spec. Sur. (in-1)	Spac. Factor (in.)	D<300 µm (%)
5.8	-	515	0.0099	1.5	453	0.0124	1.1	582	0.0098	1.4
5.3	-	420	0.0126	1.0	606	0.0100	1.2	567	0.0114	1.1
5.5	-	439	0.0117	1.2	461	0.0143	0.7	453	0.0137	0.8
5.6	-	511	0.0099	1.4	524	0.0112	1.1	495	0.0121	1.0
5.3	-	386	0.0131	1.0	558	0.0118	0.9	647	0.0101	1.1
5.5	-	381	0.0136	0.9	423	0.0149	0.8	443	0.0138	0.9
6.0	-	408	0.0122	1.1	562	0.0108	1.3	495	0.0118	1.1
5.7	-	333	0.0141	0.9	444	0.0135	0.9	503	0.0117	1.1
6.0	-	385	0.0132	1.0	435	0.0127	1.1	381	0.0137	1.0
5.6	4.9	401	0.0124	1.1	477	0.0125	1.0	525	0.0118	1.1

Table D-3. Air Content and AVA Results for State 3

% Air Ahead of Paver	% Air After Paver	Ahead of Paver			Behind Paver on Vibrator			Behind Paver Between Vibrator		
		Spec. Sur. (in-1)	Spac. Factor (in.)	D<300 µm (%)	Spec. Surf. (in-1)	Spac. Factor (in.)	D<300 µm (%)	Spec. Sur. (in-1)	Spac. Factor (in.)	D<300 µm (%)
6.0	-	538	0.0101	1.3	481	0.0123	1.1	515	0.0107	1.5
6.5	-	546	0.0104	1.5	469	0.0128	1.1	495	0.0131	1.0
4.6	-	589	0.0146	0.7	459	0.0165	0.6	569	0.0111	1.2
6.2	-	565	0.0112	1.2	481	0.0137	0.8	564	0.0113	1.1
7.0	6.5	765	0.0072	2.2	659	0.0079	2.1	669	0.0078	2.0

Table D-4. Air Content and AVA Results for State 4

% Air Ahead of Paver	% Air After Paver	Behind Paver on Vibrator			Behind Paver Between Vibrator		
		Specific Surface (in-1)	Spacing Factor (in.)	D<300 µm (%)	Specific Surface (in-1)	Spacing Factor (in.)	D<300 µm (%)
7.3	-	463	0.0113	1.3	464	0.0110	1.3
7.0	-	583	0.0098	1.5	669	0.0078	2.0
7.0	-	567	0.0089	1.7	593	0.0102	1.2
-	-	627	0.0103	1.0	558	0.0107	1.1
-	8.0	865	0.0055	2.8	739	0.0062	2.6

Table D-5. Air Content and AVA Results for State 5

% Air Ahead of Paver	% Air After Paver	Behind Paver on Vibrator			Behind Paver Between Vibrator		
		Specific Surface (in-1)	Spacing Factor (in.)	D<300 µm (%)	Specific Surface (in-1)	Spacing Factor (in.)	D<300 µm (%)
5.9	7.4	447	0.0109	1.3	1161	0.0056	2.2
6.1	-	542	0.0107	1.1	548	0.0105	1.3
4.9	-	503	0.0138	0.7	548	0.0107	1.2

Table D-6. Air Content and AVA Results for State 6

		Behind Paver on Vibrator			Behind Paver Between Vibrator		
% Air Ahead of Paver	% Air After Paver	Specific Surface (in-1)	Spacing Factor (in.)	D<300 µm (%)	Specific Surface (in-1)	Spacing Factor (in.)	D<300 µm (%)
5.0	-	651	0.0086	1.4	521	0.0112	1.0
5.3	-	983	0.0076	1.1	804	0.0075	1.4
6.5	6.0	597	0.0097	1.3	637	0.0085	1.6
4.5	-	875	0.0083	1.0	783	0.0088	1.1

Table D-7. Air Content and AVA Results for State 7

		Behind Paver on Vibrator			Behind Paver Between Vibrator		
% Air Ahead of Paver	% Air After Paver	Specific Surface (in-1)	Spacing Factor (in.)	D<300 µm (%)	Specific Surface (in-1)	Spacing Factor (in.)	D<300 µm (%)
6.6	-	530	0.0141	0.7	581	0.0098	1.2
5.0	-	638	0.0113	0.8	519	0.0125	0.9
5.8	-	883	0.0075	1.1	928	0.0061	1.5
6.0	-	870	0.0096	0.9	821	0.0101	0.8
6.4	4.7	793	0.0102	0.8	816	0.0082	1.2
6.5	-	1001	0.0077	1.1	691	0.0105	0.9
5.4	-	665	0.0098	1.0	543	0.0106	1.1
6.5	-	743	0.0088	1.3	535	0.0111	1.0

Table D-8. Air Content and AVA Results for State 8

		Behind Paver on Vibrator			Behind Paver Between Vibrator		
% Air Ahead of Paver	% Air After Paver	Specific Surface (in-1)	Spacing Factor (in.)	D<300 µm (%)	Specific Surface (in-1)	Spacing Factor (in.)	D<300 µm (%)
4.5	-	546	0.0138	0.7	496	0.0128	0.9
5.0	-	657	0.0099	1.1	617	0.0098	1.4
4.5	3.6	899	0.0063	2.2	765	0.0076	1.7
4.4	-	1021	0.0051	2.4	711	0.0175	0.1
5.4	-	1056	0.0062	1.6	1637	0.0038	2.2

Table D-9. Air Content and AVA Results for State 9

% Air Ahead of Paver	% Air After Paver	Behind Paver on Vibrator			Behind Paver Between Vibrator		
		Specific Surface (in-1)	Spacing Factor (in.)	D<300 µm (%)	Specific Surface (in-1)	Spacing Factor (in.)	D<300 µm (%)
5.6	-	389	0.0137	0.8	1241	0.0025	4.3
5.3	-	412	0.0124	0.9	370	0.0134	0.9
8.5	-	536	0.0066	2.3	651	0.0065	2.3
4.7	-	601	0.0110	0.8	489	0.0134	0.7
5.2	3.5	388	0.0191	0.4	376	0.0170	0.5
-	-	293	0.0208	0.3	372	0.0147	0.6
-	-	765	0.0096	0.9	396	0.0149	0.7
-	-	461	0.0165	0.4	375	0.0206	0.3
-	-	370	0.0185	0.4	387	0.0175	0.5
-	-	435	0.0171	0.4	461	0.0146	0.6
-	-	335	0.0284	0.2	267	0.0272	0.2

Table D-10. Air Content and AVA Results for State 10

% Air Ahead of Paver	% Air After Paver	Behind Paver on Vibrator			Behind Paver Between Vibrator		
		Specific Surface (in-1)	Spacing Factor (in.)	D<300 µm (%)	Specific Surface (in-1)	Spacing Factor (in.)	D<300 µm (%)
7.8	-	824	0.0064	2.3	713	0.0088	1.3
6.5	-	883	0.0065	2.1	973	0.0056	2.5
7.0	-	516	0.0133	0.7	647	0.0099	1.2
7.0	-	838	0.0071	1.8	733	0.0073	2.0
8.0	-	731	0.0091	1.3	735	0.0086	1.5
7.8	-	536	0.0107	1.3	690	0.0091	1.4
9.5	-	983	0.0065	1.4	602	0.0128	0.7
7.5	-	493	0.0132	0.9	480	0.0130	1.0
8.6	-	656	0.0092	1.5	648	0.0090	1.6
8.3	-	607	0.0111	1.1	586	0.0090	1.9

Table D-11. Air Content and AVA Results for State 11

		Behind Paver on Vibrator			Behind Paver Between Vibrator		
% Air Ahead of Paver	% Air After Paver	Specific Surface (in-1)	Spacing Factor (in.)	D<300 µm (%)	Specific Surface (in-1)	Spacing Factor (in.)	D<300 µm (%)
6.5	-	494	0.0143	0.7	774	0.0089	1.2
7.5	-	696	0.0092	1.4	708	0.0083	1.6
7.0	-	954	0.0059	2.0	754	0.0086	2.1
8.1	-	786	0.0083	1.5	754	0.0097	1.2
7.8	-	824	0.0077	1.6	686	0.0079	1.8
11.3	8.0	765	0.0068	2.3	795	0.0063	2.6
10.0	-	590	0.0097	1.4	772	0.0071	2.1
9.0	-	440	0.0163	0.6	629	0.0086	1.7

Table D-12. Air Content and AVA Results for State 12

		Behind Paver on Vibrator			Behind Paver Between Vibrator		
% Air Ahead of Paver	% Air After Paver	Specific Surface (in-1)	Spacing Factor (in.)	D<300 µm (%)	Specific Surface (in-1)	Spacing Factor (in.)	D<300 µm (%)
6.7	-	660	0.0084	1.6	653	0.0100	1.0
7.3	-	798	0.0079	1.5	611	0.0086	1.6
8.5	-	756	0.0072	2.0	563	0.0101	1.4
6.6	5.1	700	0.0081	1.5	568	0.0110	1.0
6.7	-	654	0.0086	1.5	514	0.0108	1.0
6.5	-	451	0.0129	0.9	505	0.0116	1.1
7.3	-	696	0.0075	2.1	644	0.0088	1.3

Table D-13. Air Content and AVA Results for State 13

		Behind Paver on Vibrator			Behind Paver Between Vibrator		
% Air Ahead of Paver	% Air After Paver	Specific Surface (in-1)	Spacing Factor (in.)	D<300 µm (%)	Specific Surface (in-1)	Spacing Factor (in.)	D<300 µm (%)
6.5	-	568	0.0112	1.0	543	0.0113	0.9
7.5	-	1242	0.0048	1.6	1217	0.0043	2.1
5.8	-	825	0.0068	1.1	975	0.0053	2.0
5.5	-	838	0.0081	1.1	541	0.0120	0.9
5.3	-	865	0.0074	1.0	517	0.0120	0.9

Table D-14. Air Content and AVA Results for State 14

% Air Ahead of Paver	% Air After Paver	Behind Paver on Vibrator Specific Surface (in-1)	Behind Paver on Vibrator Spacing Factor (in.)	Behind Paver on Vibrator D<300 µm (%)	Behind Paver Between Vibrator Specific Surface (in-1)	Behind Paver Between Vibrator Spacing Factor (in.)	Behind Paver Between Vibrator D<300 µm (%)
4.9	-	1281	0.0046	1.9	889	0.0061	1.7
7.1	-	753	0.0087	1.3	676	0.0086	1.3
7.5	-	1018	0.0054	2.5	879	0.0061	2.1
6.1	-	1361	0.0034	3.5	1380	0.0035	3.1
5.3	-	1331	0.0047	2.0	1148	0.0054	1.6
5.8	-	892	0.0068	1.4	744	0.0045	2.8

Table D-15. Air Content and AVA Results for State 15

% Air Ahead of Paver	% Air After Paver	Behind Paver on Vibrator Specific Surface (in-1)	Behind Paver on Vibrator Spacing Factor (in.)	Behind Paver on Vibrator D<300 µm (%)	Behind Paver Between Vibrator Specific Surface (in-1)	Behind Paver Between Vibrator Spacing Factor (in.)	Behind Paver Between Vibrator D<300 µm (%)
5.2	-	475	0.0150	0.6	373	0.0170	0.5
5.0	-	445	0.0118	1.0	672	0.0090	0.9
6.1	-	495	0.0135	0.7	647	0.0098	1.1
4.5	-	468	0.0145	0.6	599	0.0135	0.6
5.8	3.8	494	0.0116	1.0	441	0.0164	0.5

Table D-16. Air Content and AVA Results for State 16

% Air Ahead of Paver	% Air After Paver	Behind Paver on Vibrator Specific Surface (in-1)	Behind Paver on Vibrator Spacing Factor (in.)	Behind Paver on Vibrator D<300 µm (%)	Behind Paver Between Vibrator Specific Surface (in-1)	Behind Paver Between Vibrator Spacing Factor (in.)	Behind Paver Between Vibrator D<300 µm (%)
7.6	-	977	0.0052	2.2	1131	0.0051	1.8
6.0	-	497	0.0120	0.9	528	0.0109	1.1
6.0	-	888	0.0091	0.9	515	0.0128	0.8
4.3	-	486	0.0128	0.9	479	0.0126	0.9
7.0	-	1048	0.0049	2.3	848	0.0062	2.2
5.5	-	595	0.0096	1.4	611	0.0092	1.5
5.8	-	401	0.0123	0.9	422	0.0138	0.7

APPENDIX E

Table E-1. Heat Signature Data for Ten Control Mixtures

Elapsed Time (min)	100TI	80TI/20C	80TI/20F	80TI/20F2	65TI/35G100S	65TI/35G120S	100TI-II	100TIP	100TISM	100TIPM	100Ternary
31	23.40	23.58	23.11	23.10	20.38	23.17	22.45	22.44	22.59	24.43	20.37
32	23.36	23.64	23.05	23.10	20.43	23.12	22.45	22.55	22.55	24.6	20.22
33	23.36	23.58	23.11	23.10	20.43	23.06	22.40	22.38	22.72	24.6	20.37
34	23.36	23.58	23.11	23.10	20.38	23.12	22.51	22.55	22.59	24.7	20.32
35	23.36	23.53	23.05	23.10	20.43	23.06	22.51	22.25	22.59	24.7	20.5
36	23.36	23.53	23.11	23.10	20.5	23.06	22.40	22.49	22.66	24.7	20.37
37	23.36	23.53	23.05	23.10	20.5	23.00	22.55	22.44	22.55	24.53	20.32
38	23.29	23.53	23.05	23.10	20.5	23.22	22.45	22.38	22.59	24.57	20.32
39	23.29	23.47	23.05	23.03	20.5	23.16	22.33	22.38	22.55	24.69	20.43
40	23.29	23.47	23.00	23.03	20.5	23.10	22.45	22.38	22.55	24.57	20.5
41	23.23	23.53	23.00	23.03	20.38	23.16	22.45	22.38	22.55	24.56	20.37
42	23.33	23.50	23.15	23.13	20.38	23.04	22.40	22.31	22.48	24.49	20.43
43	23.27	23.50	23.10	23.07	20.5	23.10	22.45	22.44	22.55	24.49	20.5
44	23.33	23.50	23.10	23.07	20.4	23.16	22.45	22.44	22.42	24.49	20.43
45	23.27	23.44	23.10	23.13	20.5	23.04	22.50	22.44	22.55	24.59	20.32
46	23.27	23.57	23.10	23.13	20.38	23.04	22.51	22.31	22.55	24.53	20.43
47	23.27	23.44	23.04	23.07	20.38	23.10	22.50	22.44	22.48	24.42	20.43
48	23.22	23.50	22.97	23.13	20.43	23.10	22.40	22.31	22.55	24.42	20.43
49	23.27	23.44	23.04	23.13	20.5	23.04	22.50	22.38	22.55	24.42	20.56
50	23.22	23.44	23.04	23.01	20.56	23.04	22.55	22.25	22.48	24.42	20.37
51	23.22	23.39	22.97	23.01	20.5	23.04	22.55	22.31	22.55	24.46	20.37
52	23.16	23.39	22.97	23.07	20.5	23.04	22.55	22.44	22.48	24.4	20.43
53	23.22	23.39	23.04	23.07	20.56	23.04	22.55	22.25	22.48	24.56	20.37
54	23.22	23.44	22.91	23.01	20.43	22.97	22.55	22.31	22.42	24.5	20.5
55	23.22	23.39	22.91	23.07	20.5	23.04	22.50	22.02	22.48	24.44	20.43
56	23.22	23.27	22.91	23.01	20.56	23.07	22.50	22.25	22.42	24.44	20.43
57	23.22	23.39	22.91	23.01	20.5	22.97	22.55	22.25	22.55	24.44	20.43
58	23.22	23.39	22.97	23.01	20.56	23.04	22.55	22.19	22.48	24.37	20.43
59	23.16	23.39	22.91	23.01	20.62	22.93	22.50	22.14	22.48	24.33	20.43
60	23.26	23.43	23.01	23.11	20.43	22.97	22.43	22.25	22.42	24.47	20.37
61	23.16	23.33	22.91	23.01	20.43	22.97	22.50	22.19	22.48	24.43	20.37
62	23.16	23.33	22.97	22.90	20.56	22.97	22.37	22.25	22.42	24.43	20.26
63	23.16	23.33	22.91	22.95	20.32	22.97	22.50	22.31	22.48	24.46	20.43
64	23.16	23.33	22.86	22.95	20.43	23.03	22.50	22.31	22.48	24.36	20.5
65	23.16	23.21	22.91	22.95	20.5	22.86	22.50	22.14	22.48	24.4	20.37
66	23.10	23.21	22.86	22.95	20.43	23.03	22.50	22.25	22.42	24.46	20.37
67	23.04	23.21	22.80	22.95	20.5	22.93	22.50	22.19	22.42	24.4	20.43
68	23.20	23.31	22.96	23.05	20.5	22.96	22.50	22.19	22.36	24.34	20.43

69	23.16	23.21	22.86	23.01	20.5	23.03	22.50	22.25	22.36	24.29	20.56
70	23.14	23.37	22.90	23.05	20.43	23.03	22.50	22.38	22.36	24.23	20.32
71	23.10	23.21	22.80	22.95	20.5	22.96	22.43	22.38	22.58	24.29	20.53
72	23.14	23.31	22.90	23.00	20.43	22.90	22.50	22.31	22.48	24.23	20.43
73	23.26	23.26	22.90	23.00	20.5	22.90	22.43	22.31	22.36	24.29	20.47
74	23.07	23.26	22.90	23.00	20.38	23.03	22.50	22.19	22.42	24.29	20.37
75	23.14	23.26	22.90	23.05	20.38	22.96	22.37	22.25	22.48	24.27	20.42
76	23.14	23.26	22.84	23.00	20.43	22.96	22.43	22.25	22.36	24.17	20.47
77	23.14	23.26	22.78	23.00	20.5	22.96	22.43	22.14	22.36	24.11	20.47
78	23.07	23.26	22.78	23.00	20.26	22.90	22.43	22.14	22.48	24.21	20.36
79	23.07	23.26	22.78	23.00	20.43	22.90	22.43	22.19	22.42	24.27	20.47
80	23.07	23.31	22.84	22.94	20.38	22.90	22.50	22.19	22.42	24.27	20.47
81	23.20	23.26	22.78	23.05	20.32	22.84	22.43	22.25	22.48	24.31	20.47
82	23.03	23.20	22.78	22.94	20.5	22.90	22.43	22.14	22.36	24.16	20.53
83	23.14	23.20	22.84	22.94	20.42	22.90	22.43	22.19	22.48	24.31	20.36
84	23.14	23.20	22.78	23.00	20.38	22.84	22.37	22.14	22.48	24.31	20.53
85	23.14	23.20	22.78	22.88	20.48	22.90	22.37	22.44	22.48	24.26	20.47
86	23.14	23.20	22.78	23.00	20.38	22.84	22.50	22.08	22.48	24.26	20.47
87	23.07	23.14	22.78	22.94	20.48	22.79	22.37	22.14	22.42	24.2	20.52
88	23.14	23.20	22.78	22.94	20.48	22.84	22.50	22.19	22.48	24.2	20.52
89	23.14	23.14	22.72	22.94	20.48	22.84	22.47	22.08	22.36	24.2	20.63
90	23.07	23.14	22.72	22.88	20.42	22.84	22.43	22.25	22.36	24.13	20.52
91	23.07	23.14	22.72	22.88	20.48	22.84	22.50	22.14	22.36	24.13	20.46
92	23.14	23.14	22.78	22.88	20.36	22.84	22.43	22.19	22.42	24.2	20.46
93	23.03	23.14	22.72	22.88	20.42	22.90	22.37	22.19	22.42	24.3	20.52
94	23.07	23.14	22.72	22.88	20.42	22.84	22.43	22.19	22.42	24.13	20.63
95	23.03	23.07	22.67	22.94	20.42	22.73	22.50	22.25	22.42	24.17	20.52
96	23.14	23.07	22.67	22.88	20.3	22.73	22.43	22.31	22.48	24.11	20.46
97	23.03	23.07	22.72	22.88	20.48	22.79	22.50	22.14	22.36	24.17	20.57
98	23.03	23.14	22.72	22.82	20.24	22.79	22.50	22.25	22.48	24.23	20.63
99	23.03	23.07	22.72	22.94	20.58	22.79	22.55	22.19	22.42	24.23	20.63
100	23.03	22.96	22.67	22.82	20.4	22.79	22.61	22.25	22.42	24.23	20.52
101	23.07	23.01	22.72	22.88	20.52	22.73	22.37	22.31	22.42	24.17	20.52
102	23.03	23.01	22.67	22.94	20.46	22.73	22.55	22.19	22.42	24.11	20.52
103	23.03	23.07	22.72	22.82	20.52	22.67	22.55	22.25	22.36	24.11	20.52
104	23.03	23.01	22.67	22.88	20.4	22.67	22.55	22.31	22.42	24.06	20.52
105	23.03	23.01	22.72	22.88	20.46	22.79	22.55	22.49	22.36	24.06	20.57
106	23.03	23.01	22.72	22.82	20.46	22.67	22.55	22.38	22.42	24.11	20.7
107	23.03	23.07	22.67	22.82	20.4	22.79	22.50	22.49	22.42	24.06	20.57
108	23.07	22.96	22.61	22.88	20.4	22.83	22.61	22.38	22.36	24.06	20.4
109	23.14	22.96	22.61	22.82	20.4	22.73	22.50	22.25	22.52	24.11	20.57
110	23.03	23.01	22.72	22.88	20.46	22.73	22.55	22.31	22.42	24.06	20.57
111	23.07	22.96	22.67	22.88	20.4	22.73	22.61	22.25	22.36	24.11	20.52
112	23.13	23.00	22.77	22.92	20.4	22.73	22.61	22.38	22.42	24.17	20.52
113	22.96	23.01	22.67	22.88	20.52	22.73	22.61	22.44	22.46	24.16	20.57
114	23.14	22.96	22.67	22.82	20.4	22.79	22.55	22.31	22.36	24.06	20.57
115	23.03	23.07	22.67	22.82	20.4	22.67	22.55	22.44	22.36	24.06	20.57
116	23.07	23.01	22.61	22.82	20.4	22.73	22.55	22.25	22.30	24.06	20.52
117	23.14	23.01	22.67	22.82	20.4	22.73	22.61	22.38	22.36	24.27	20.63

118	23.07	23.01	22.67	22.94	20.4	22.79	22.55	22.25	22.48	24.16	20.57
119	23.20	22.96	22.61	22.82	20.4	22.79	22.67	22.31	22.46	24.21	20.57
120	23.14	22.90	22.67	22.88	20.46	22.79	22.61	22.38	22.36	24.16	20.63
121	23.14	22.96	22.72	22.88	20.34	22.79	22.73	22.61	22.30	24.16	20.52
122	23.14	22.90	22.67	22.88	20.4	22.79	22.67	22.25	22.42	24.1	20.57
123	23.03	22.96	22.67	22.82	20.4	22.73	22.67	22.44	22.42	24.21	20.62
124	23.14	22.96	22.67	22.88	20.4	22.73	22.61	22.44	22.42	24.16	20.63
125	23.14	22.96	22.67	22.88	20.4	22.73	22.67	22.44	22.42	24.16	20.62
126	23.14	22.90	22.67	22.88	20.4	22.73	22.67	22.44	22.42	24.16	20.52
127	23.14	22.96	22.67	22.88	20.4	22.73	22.77	22.55	22.52	24.21	20.67
128	23.20	22.96	22.67	22.88	20.4	22.79	22.67	22.44	22.42	24.16	20.46
129	23.20	22.96	22.61	22.88	20.46	22.73	22.67	22.38	22.42	24.26	20.62
130	23.20	22.96	22.72	22.94	20.4	22.79	22.67	22.38	22.48	24.26	20.52
131	23.26	22.96	22.72	22.82	20.4	22.79	22.83	22.38	22.42	24.1	20.67
132	23.20	22.96	22.72	22.88	20.34	22.79	22.73	22.19	22.42	24.27	20.46
133	23.14	22.96	22.67	22.88	20.46	22.79	22.67	22.54	22.42	24.31	20.62
134	23.20	22.96	22.72	22.94	20.46	22.73	22.78	22.25	22.48	24.1	20.52
135	23.20	22.84	22.67	22.88	20.56	22.79	22.73	22.48	22.42	24.31	20.62
136	23.20	22.84	22.72	22.88	20.34	22.79	22.67	22.55	22.48	24.27	20.62
137	23.14	22.96	22.67	22.88	20.5	22.79	22.83	22.44	22.55	24.26	20.62
138	23.07	22.96	22.72	22.88	20.4	22.84	22.73	22.55	22.48	24.21	20.52
139	23.14	22.84	22.67	22.88	20.5	22.73	22.73	22.71	22.42	24.31	20.62
140	23.07	22.90	22.67	22.82	20.4	22.79	22.73	22.49	22.36	24.21	20.67
141	23.14	22.90	22.67	22.88	20.5	22.79	22.73	22.59	22.42	24.27	20.73
142	23.14	22.84	22.67	22.82	20.34	22.73	22.73	22.59	22.55	24.27	20.73
143	23.14	22.84	22.67	22.82	20.5	22.73	22.84	22.48	22.48	24.43	20.67
144	23.14	22.84	22.67	22.88	20.29	22.79	22.78	22.48	22.55	24.27	20.67
145	23.14	22.84	22.67	22.82	20.44	22.73	22.88	22.65	22.59	24.37	20.73
146	23.20	22.84	22.67	22.88	20.4	22.83	22.84	22.54	22.55	24.21	20.67
147	23.07	22.78	22.67	22.82	20.44	22.67	22.84	22.48	22.55	24.43	20.67
148	23.20	22.78	22.67	22.82	20.44	22.67	22.84	22.71	22.48	24.37	20.67
149	23.14	22.90	22.67	22.82	20.5	22.73	22.90	22.54	22.55	24.37	20.67
150	23.30	22.88	22.71	22.92	20.4	22.83	22.90	22.48	22.48	24.37	20.73
151	23.20	22.78	22.67	22.88	20.39	22.73	22.84	22.48	22.59	24.43	20.67
152	23.20	22.78	22.67	22.82	20.44	22.73	22.90	22.71	22.48	24.37	20.62
153	23.14	22.84	22.67	22.82	20.56	22.73	22.90	22.48	22.66	24.37	20.8
154	23.36	22.94	22.77	22.92	20.5	22.73	22.90	22.65	22.59	24.43	20.62
155	23.07	22.78	22.67	22.82	20.5	22.73	22.90	22.41	22.59	24.43	20.73
156	23.26	22.78	22.67	22.82	20.5	22.83	22.96	22.77	22.59	24.5	20.73
157	23.26	22.78	22.61	22.82	20.44	22.67	23.01	22.77	22.66	24.37	20.8
158	23.26	22.73	22.67	22.82	20.5	22.73	22.96	22.59	22.55	24.43	20.5
159	23.26	22.73	22.67	22.77	20.5	22.61	23.01	22.77	22.66	24.5	20.73
160	23.36	22.83	22.77	22.98	20.5	22.73	23.01	22.54	22.59	24.5	20.73
161	23.26	22.73	22.61	22.88	20.5	22.73	23.01	22.59	22.55	24.56	20.67
162	23.26	22.73	22.67	22.88	20.5	22.73	23.01	22.65	22.59	24.5	20.56
163	23.26	22.73	22.72	22.82	20.5	22.73	23.01	22.59	22.55	24.5	20.67
164	23.26	22.67	22.67	22.88	20.5	22.89	23.01	22.59	22.59	24.5	20.8
165	23.32	22.73	22.67	22.88	20.5	22.84	23.14	22.59	22.55	24.43	20.67
166	23.26	22.78	22.67	22.88	20.5	22.79	23.07	22.59	22.66	24.56	20.86

167	23.26	22.73	22.67	22.82	20.5	22.79	23.14	22.59	22.72	24.56	20.8
168	23.42	22.88	22.77	22.98	20.5	22.79	23.20	22.65	22.66	24.56	20.8
169	23.26	22.67	22.67	22.88	20.5	22.79	23.20	22.54	22.78	24.5	20.67
170	23.26	22.78	22.67	22.88	20.5	22.84	23.20	22.77	22.83	24.56	20.86
171	23.32	22.73	22.67	22.88	20.5	22.79	23.20	22.54	22.66	24.61	20.86
172	23.32	22.73	22.67	22.88	20.5	22.79	23.31	22.82	22.56	24.61	20.8
173	23.37	22.78	22.72	22.88	20.5	22.84	23.26	22.65	22.72	24.67	20.73
174	23.37	22.73	22.67	22.88	20.56	22.84	23.31	22.71	22.62	24.79	20.86
175	23.37	22.67	22.67	22.88	20.56	22.79	23.31	22.94	22.68	24.73	20.73
176	23.43	22.73	22.67	22.94	20.5	22.73	23.37	22.65	22.78	24.67	20.8
177	23.43	22.73	22.67	22.94	20.44	22.84	23.37	22.71	22.66	24.73	20.8
178	23.37	22.73	22.67	22.88	20.5	22.84	23.37	22.82	22.73	24.67	20.8
179	23.37	22.78	22.78	22.88	20.5	22.79	23.37	22.65	22.83	24.79	20.8
180	23.49	22.67	22.67	22.94	20.5	22.84	23.37	22.77	22.68	24.84	20.91
181	23.56	22.73	22.67	22.94	20.56	22.84	23.37	22.59	22.78	24.73	20.91
182	23.49	22.78	22.72	22.94	20.56	22.84	23.43	22.88	22.68	24.84	20.86
183	23.32	22.73	22.67	22.94	20.5	22.84	23.54	22.65	22.68	24.79	20.96
184	23.43	22.73	22.72	22.88	20.62	22.90	23.49	22.71	22.68	24.84	20.86
185	23.43	22.73	22.72	22.94	20.62	22.84	23.49	22.77	22.73	24.84	20.86
186	23.43	22.73	22.72	22.88	20.5	22.84	23.49	22.65	22.73	24.84	20.91
187	23.49	22.73	22.72	22.88	20.5	22.90	23.54	22.77	22.85	24.84	21.07
188	23.43	22.73	22.78	23.00	20.5	22.90	23.60	22.77	22.79	24.9	21.03
189	23.49	22.73	22.78	23.00	20.5	22.90	23.60	22.77	22.85	24.9	20.8
190	23.49	22.73	22.72	22.94	20.5	22.96	23.50	22.77	22.85	24.96	21.03
191	23.56	22.78	22.72	23.05	20.5	22.90	23.60	22.88	22.91	24.96	20.8
192	23.56	22.73	22.78	23.00	20.56	22.96	23.57	22.94	22.85	25.07	20.91
193	23.60	22.67	22.78	23.05	20.62	22.90	23.63	22.92	22.79	25.03	20.97
194	23.49	22.73	22.78	23.00	20.62	22.84	23.73	22.82	22.73	25.07	20.97
195	23.56	22.73	22.78	23.00	20.66	22.90	23.67	22.81	22.85	25.03	21.13
196	23.56	22.73	22.78	23.00	20.5	22.96	23.63	23.1	22.79	25.07	21.03
197	23.56	22.73	22.84	23.00	20.5	22.90	23.78	22.87	22.85	25.03	21.13
198	23.60	22.78	22.78	23.00	20.56	22.90	23.68	22.98	22.85	25.14	20.91
199	23.67	22.78	22.84	23.05	20.83	22.90	23.78	22.98	22.85	25.14	21.19
200	23.56	22.78	22.84	23.00	20.62	22.96	23.74	22.92	22.79	25.07	21.03
201	23.67	22.73	22.84	23.00	20.56	22.96	23.74	22.87	22.91	25.2	21.13
202	23.67	22.73	22.84	23.05	20.56	22.96	23.74	23.1	22.81	25.2	21.13
203	23.67	22.78	22.84	23.00	20.62	22.96	23.80	23.04	22.96	25.2	21.13
204	23.67	22.78	22.84	23.05	20.62	23.03	23.80	22.98	23.02	25.2	21.19
205	23.67	22.78	22.84	23.05	20.62	23.03	23.74	23.1	22.96	25.2	21.19
206	23.73	22.73	22.84	23.05	20.73	22.96	23.80	22.98	22.86	25.32	21.09
207	23.67	22.73	22.84	23.05	20.72	22.96	23.80	23.08	23.09	25.2	21.13
208	23.67	22.67	22.90	23.05	20.5	23.03	23.80	23.04	22.86	25.32	21.19
209	23.67	22.73	22.84	23.11	20.72	22.93	23.86	23.04	22.92	25.32	21.07
210	23.79	22.73	22.90	23.11	20.68	23.03	23.80	23.1	22.92	25.37	21.14
211	23.67	22.73	22.84	23.11	20.78	22.97	23.86	23.2	23.09	25.33	21.24
212	23.79	22.73	22.90	23.05	20.68	22.86	23.97	23.04	22.92	25.39	21.2
213	23.80	22.63	22.80	23.01	20.66	23.07	23.92	23.08	23.09	25.37	21.24
214	23.73	22.73	22.90	23.11	20.83	23.03	23.92	23.04	22.99	25.33	21.14
215	23.74	22.63	22.80	23.07	20.72	22.97	23.97	23.08	22.99	25.37	21.2

216	23.69	22.68	22.80	23.01	20.83	23.03	24.10	23.14	22.92	25.39	21.26
217	23.84	22.84	22.96	23.11	20.83	22.93	24.16	23.2	23.09	25.43	21.24
218	23.79	22.73	22.90	23.11	20.62	23.07	24.16	23.25	22.99	25.5	21.14
219	23.74	22.63	22.86	23.13	20.83	22.97	24.16	23.32	23.05	25.56	21.3
220	23.84	22.73	22.90	23.11	20.78	23.04	24.00	23.25	22.92	25.46	21.2
221	23.80	22.63	22.86	23.07	20.78	22.97	24.21	23.32	23.15	25.6	21.3
222	23.90	22.73	22.96	23.17	20.68	22.97	24.16	23.2	23.11	25.57	21.26
223	23.80	22.63	22.86	23.07	20.83	22.97	24.21	23.14	23.05	25.5	21.14
224	23.80	22.68	22.86	23.07	20.62	22.97	24.11	23.32	23.16	25.57	21.2
225	23.86	22.68	22.80	23.07	20.9	22.97	24.27	23.14	23.16	25.5	21.2
226	23.80	22.68	22.91	23.13	20.8	22.97	24.23	23.32	23.16	25.63	21.26
227	23.86	22.68	22.91	23.07	20.62	23.10	24.23	23.55	23.16	25.57	21.2
228	23.80	22.57	22.91	23.07	20.73	23.04	24.23	23.38	23.16	25.69	21.26
229	23.80	22.63	22.91	23.13	20.83	23.04	24.39	23.5	23.16	25.69	21.33
230	23.80	22.63	22.91	23.07	20.68	23.04	24.29	23.25	23.22	25.74	21.39
231	23.80	22.68	22.97	23.13	20.9	23.16	24.44	23.38	23.26	25.74	21.39
232	23.80	22.68	22.91	23.13	20.68	23.10	24.34	23.38	23.38	25.74	21.33
233	23.86	22.63	22.91	23.13	21.02	23.04	24.40	23.38	23.44	25.74	21.33
234	23.86	22.68	22.91	23.20	20.86	23.16	24.40	23.38	23.32	25.8	21.33
235	23.98	22.68	22.91	23.20	20.73	23.16	24.63	23.25	23.32	25.8	21.39
236	23.98	22.68	22.97	23.20	20.73	23.10	24.46	23.38	23.38	25.9	21.39
237	24.03	22.74	22.97	23.20	20.86	23.10	24.53	23.44	23.38	25.84	21.44
238	23.98	22.63	22.97	23.20	20.8	23.16	24.59	23.55	23.44	25.8	21.5
239	23.98	22.68	22.97	23.20	20.86	23.00	24.69	23.44	23.38	25.9	21.44
240	23.98	22.74	22.97	23.20	20.8	23.10	24.64	23.55	23.49	25.9	21.23
241	24.03	22.68	23.04	23.20	20.92	23.16	24.59	23.38	23.59	25.9	21.44
242	23.98	22.68	22.97	23.20	20.86	23.10	24.64	23.5	23.48	25.9	21.56
243	23.93	22.58	22.94	23.15	20.73	23.12	24.64	23.67	23.48	26.02	21.44
244	24.10	22.68	23.04	23.25	20.92	23.16	24.76	23.61	23.59	25.96	21.34
245	24.03	22.68	23.10	23.25	20.92	23.12	24.82	23.6	23.54	25.96	21.44
246	24.03	22.63	23.04	23.25	20.8	23.12	24.76	23.71	23.48	25.96	21.52
247	24.06	22.58	23.00	23.15	20.73	23.17	24.76	23.75	23.54	26.08	21.46
248	24.03	22.68	23.10	23.31	20.92	23.22	24.82	23.65	23.54	25.96	21.52
249	23.93	22.58	23.00	23.21	20.86	23.06	24.97	23.83	23.54	26.18	21.56
250	24.12	22.64	23.00	23.21	20.97	23.27	24.92	23.65	23.54	26.12	21.4
251	24.00	22.58	22.94	23.21	20.97	23.17	24.97	23.7	23.59	26.12	21.62
252	24.22	22.74	23.10	23.31	20.87	23.23	25.03	23.83	23.65	26.18	21.52
253	24.06	22.70	22.94	23.21	20.97	23.17	25.03	23.75	23.65	26.12	21.62
254	24.22	22.68	23.10	23.31	20.97	23.27	25.03	23.87	23.65	26.18	21.63
255	24.17	22.53	23.00	23.15	20.97	23.23	25.15	23.93	23.65	26.23	21.57
256	24.17	22.64	23.00	23.21	20.87	23.23	25.03	23.87	23.72	26.23	21.52
257	24.17	22.64	23.05	23.27	20.97	23.12	25.15	24.05	23.72	26.3	21.67
258	24.22	22.80	23.21	23.37	20.99	23.33	25.15	23.87	23.72	26.3	21.57
259	24.12	22.64	23.05	23.27	20.82	23.23	25.19	23.75	23.72	26.36	21.79
260	24.17	22.64	23.11	23.27	20.93	23.29	25.30	23.81	23.65	26.36	21.4
261	24.23	22.64	23.05	23.27	20.97	23.23	25.30	23.87	23.78	26.36	21.85
262	24.39	22.74	23.21	23.43	20.99	23.29	25.30	23.75	23.83	26.3	21.63
263	24.23	22.64	23.11	23.38	21.09	23.36	25.43	23.93	23.88	26.46	21.63
264	24.29	22.64	23.11	23.27	20.99	23.29	25.37	23.98	23.89	26.52	21.63

265	24.23	22.64	23.11	23.33	21.09	23.36	25.37	23.93	23.83	26.52	21.69
266	24.29	22.70	23.17	23.33	20.93	23.29	25.43	24.17	23.89	26.52	21.75
267	24.29	22.64	23.11	23.38	21.05	23.29	25.43	23.98	23.99	26.52	21.75
268	24.35	22.64	23.17	23.33	20.93	23.33	25.49	23.93	23.89	26.57	21.8
269	24.40	22.70	23.23	23.38	21.15	23.33	25.55	23.98	23.89	26.67	21.8
270	24.35	22.70	23.23	23.38	20.99	23.46	25.55	23.93	23.89	26.57	21.75
271	24.35	22.70	23.23	23.33	21.2	23.46	25.55	23.98	23.99	26.79	21.8
272	24.39	22.74	23.27	23.48	21.1	23.46	25.55	24.17	24.01	26.73	21.87
273	24.45	22.80	23.27	23.48	21.15	23.46	25.66	24.28	23.95	26.79	21.93
274	24.39	22.80	23.33	23.48	21.1	23.39	25.60	24.05	24.01	26.79	21.93
275	24.45	22.74	23.33	23.43	20.99	23.46	25.72	23.98	24.01	26.79	21.87
276	24.45	22.74	23.33	23.43	21.16	23.39	25.72	24.28	24.07	26.9	21.87
277	24.45	22.68	23.33	23.43	20.99	23.46	25.72	24.34	24.07	26.85	21.87
278	24.56	22.68	23.27	23.48	21.1	23.49	25.78	23.93	24.12	26.96	21.87
279	24.45	22.74	23.27	23.43	21.05	23.56	25.83	24.11	24.12	26.85	21.87
280	24.45	22.68	23.27	23.48	21.16	23.49	25.83	24.17	24.12	26.85	21.99
281	24.33	22.68	23.33	23.43	21.16	23.49	26.00	24.4	24.12	26.96	21.93
282	24.60	22.84	23.37	23.58	21.16	23.56	25.90	24.22	24.31	27.03	22.05
283	24.66	22.84	23.48	23.64	21.1	23.56	25.96	24.22	24.12	26.96	21.99
284	24.66	22.78	23.37	23.58	21.29	23.60	25.96	24.05	24.24	27.14	21.93
285	24.66	22.73	23.43	23.53	21.16	23.56	26.12	24.28	24.31	27.09	21.99
286	24.66	22.73	23.43	23.53	21.1	23.56	25.96	24.11	24.24	27.03	22.1
287	24.66	22.84	23.43	23.64	21.23	23.60	26.07	24.34	24.36	27.14	22.1
288	24.66	22.90	23.37	23.64	21.23	23.60	26.07	24.34	24.36	27.14	22.1
289	24.73	22.84	23.43	23.64	21.16	23.49	26.23	24.34	24.36	27.2	22.1
290	24.60	22.78	23.37	23.58	21.29	23.67	26.19	24.34	24.42	27.14	22.1
291	24.73	22.84	23.43	23.58	21.29	23.56	26.19	24.32	24.48	27.2	22.05
292	24.66	22.78	23.43	23.58	21.16	23.67	26.19	24.46	24.42	27.2	22.16
293	24.66	22.84	23.43	23.58	21.29	23.60	26.25	24.5	24.48	27.2	22.1
294	24.66	22.78	23.43	23.58	21.34	23.67	26.31	24.34	24.44	27.26	22.16
295	24.73	22.78	23.43	23.64	21.34	23.60	26.36	24.56	24.59	27.32	22.1
296	24.60	22.78	23.48	23.64	21.46	23.60	26.42	24.46	24.54	27.32	22.16
297	24.66	22.78	23.48	23.58	21.29	23.60	26.36	24.5	24.59	27.32	22.28
298	24.73	22.78	23.48	23.58	21.4	23.67	26.49	24.46	24.55	27.32	22.28
299	24.84	22.78	23.48	23.70	21.4	23.67	26.49	24.5	24.65	27.38	22.5
300	24.79	22.78	23.48	23.58	21.29	23.77	26.42	24.51	24.61	27.32	22.33
301	24.90	22.78	23.54	23.70	21.4	23.67	26.55	24.46	24.71	27.38	22.28
302	24.79	22.84	23.54	23.76	21.34	23.73	26.55	24.51	24.67	27.49	22.28
303	24.96	22.73	23.48	23.70	21.46	23.79	26.66	24.64	24.67	27.49	22.56
304	25.00	22.88	23.64	23.86	21.34	23.83	26.72	24.64	24.72	27.49	22.28
305	24.90	22.84	23.54	23.70	21.4	23.73	26.72	24.74	24.79	27.55	22.4
306	24.96	22.84	23.48	23.76	21.34	23.67	26.72	24.57	24.72	27.55	22.46
307	24.90	22.84	23.54	23.76	21.52	23.79	26.72	24.67	24.72	27.55	22.46
308	25.00	22.94	23.70	23.86	21.52	23.83	26.78	24.75	24.85	27.62	22.33
309	24.96	22.84	23.72	23.81	21.58	23.79	26.89	24.7	24.91	27.62	22.62
310	24.90	22.90	23.60	23.76	21.46	23.79	26.89	24.64	24.91	27.55	22.46
311	25.02	22.90	23.60	23.81	21.56	23.79	26.89	24.81	24.85	27.67	22.62
312	25.12	23.00	23.82	23.91	21.34	23.79	26.79	24.81	24.91	27.73	22.46
313	25.08	22.90	23.67	23.88	21.29	23.84	26.95	24.87	24.97	27.67	22.5

314	25.02	22.96	23.72	23.81	21.4	23.84	26.95	24.98	25.08	27.67	22.52
315	25.19	22.90	23.72	23.88	21.5	23.84	27.02	24.87	25.02	27.73	22.62
316	25.19	22.90	23.72	23.88	21.52	23.90	26.97	24.93	24.92	27.79	22.62
317	25.13	22.90	23.72	23.88	21.52	23.90	27.07	24.87	25.02	27.73	22.62
318	25.13	22.96	23.78	23.88	21.52	23.90	27.03	24.98	25.04	27.85	22.52
319	25.13	22.96	23.72	23.88	21.58	23.90	27.13	24.98	25.04	27.79	22.73
320	25.13	22.90	23.78	23.88	21.52	23.90	27.15	25.1	25.04	27.9	22.63
321	25.08	22.90	23.84	23.88	21.62	23.90	27.21	24.87	24.98	27.85	22.79
322	25.19	23.07	23.84	23.88	21.52	23.96	27.15	25.1	25.10	27.85	22.69
323	25.19	23.01	23.84	23.94	21.62	23.90	27.21	24.87	25.10	27.96	22.81
324	25.32	22.96	23.90	23.88	21.75	23.96	27.26	25.1	25.15	28.02	22.69
325	25.32	23.07	23.84	23.94	21.68	23.96	27.32	25.1	25.15	27.96	22.81
326	25.32	22.96	23.90	24.00	21.69	24.02	27.32	25.22	25.10	27.96	22.75
327	25.32	23.14	23.90	24.00	21.79	24.02	27.32	25.22	25.15	28.08	22.75
328	25.37	23.01	23.90	24.06	21.79	24.02	27.38	25.17	25.21	28.15	22.81
329	25.49	23.01	23.90	24.06	21.62	24.02	27.38	25.28	25.34	28.08	22.75
330	25.43	23.07	23.90	24.00	21.63	24.08	27.45	25.28	25.28	28.15	22.81
331	25.43	23.14	23.90	24.06	21.73	23.92	27.56	25.17	25.34	28.15	22.86
332	25.49	23.07	23.96	24.06	21.69	24.13	27.56	25.34	25.34	28.2	22.86
333	25.49	23.07	23.96	24.06	21.68	24.20	27.56	25.28	25.45	28.26	22.86
334	25.55	23.14	23.96	24.11	21.63	24.13	27.46	25.34	25.34	28.2	22.99
335	25.39	22.97	23.91	24.01	21.63	24.03	27.62	25.17	25.45	28.32	22.86
336	25.55	23.14	24.01	24.11	21.75	24.13	27.58	25.57	25.39	28.22	23.1
337	25.60	23.07	24.01	24.11	21.82	24.03	27.58	25.34	25.51	28.32	22.92
338	25.55	23.14	24.07	24.17	21.75	24.13	27.63	25.4	25.45	28.16	22.99
339	25.50	23.04	24.03	24.07	21.82	24.10	27.63	25.4	25.45	28.43	23.1
340	25.60	23.20	24.07	24.23	21.87	24.16	27.63	25.4	25.57	28.38	22.99
341	25.50	23.10	23.97	24.07	21.82	24.10	27.69	25.22	25.57	28.43	23.1
342	25.66	23.26	24.13	24.23	21.75	24.16	27.69	25.57	25.51	28.33	23.1
343	25.62	23.04	24.10	24.07	21.87	24.22	27.87	25.46	25.63	28.43	23.16
344	25.56	23.16	24.03	24.13	21.82	24.27	27.87	25.34	25.51	28.33	23.22
345	25.62	23.10	24.03	24.24	21.87	24.16	27.81	25.46	25.68	28.39	23.16
346	25.68	23.16	24.10	24.19	21.82	24.22	27.99	25.46	25.68	28.33	23.22
347	25.62	23.21	24.14	24.24	21.99	24.27	27.92	25.57	25.67	28.33	23.1
348	25.75	23.10	24.14	24.24	21.82	24.33	27.99	25.34	25.78	28.39	23.28
349	25.75	23.16	24.14	24.19	21.87	24.27	27.99	25.51	25.78	28.51	23.22
350	25.80	23.21	24.14	24.30	22.05	24.33	27.99	25.46	25.84	28.39	23.22
351	25.80	23.16	24.14	24.30	21.87	24.33	28.05	25.7	26.01	28.51	23.28
352	25.80	23.21	24.21	24.30	21.93	24.33	28.16	25.73	25.84	28.51	23.22
353	25.80	23.21	24.14	24.24	21.87	24.29	28.16	25.84	26.01	28.51	23.28
354	25.80	23.21	24.21	24.37	21.99	24.39	28.16	25.93	26.01	28.51	23.28
355	25.92	23.21	24.21	24.37	22.1	24.23	28.16	25.7	25.94	28.66	23.39
356	26.03	23.33	24.27	24.37	21.99	24.29	28.28	26.2	26.01	28.56	23.33
357	25.88	23.17	24.11	24.33	21.99	24.29	28.22	26.26	26.01	28.66	23.39
358	26.03	23.27	24.27	24.37	21.99	24.35	28.22	25.84	26.07	28.66	23.39
359	25.93	23.23	24.23	24.33	22.1	24.35	28.34	25.97	25.94	28.66	23.45
360	25.88	23.23	24.23	24.33	22.05	24.40	28.34	26.03	26.07	28.66	23.52
361	25.93	23.23	24.23	24.38	22.1	24.40	28.39	26.08	26.12	28.85	23.45
362	25.99	23.23	24.28	24.33	21.99	24.46	28.45	26.08	26.12	28.66	23.52

363	25.99	23.23	24.23	24.38	22.05	24.46	28.45	26.2	26.22	28.79	23.52
364	26.05	23.17	24.28	24.38	22.16	24.53	28.45	26.08	26.01	28.85	23.57
365	26.05	23.23	24.28	24.44	22.22	24.46	28.62	26.03	26.22	28.79	23.52
366	26.16	23.29	24.23	24.44	22.05	24.46	28.68	26.03	26.22	28.85	23.63
367	26.16	23.40	24.34	24.50	22.1	24.53	28.62	26.44	26.22	28.85	23.63
368	26.16	23.34	24.34	24.44	22.22	24.53	28.62	26.5	26.34	28.91	23.52
369	26.29	23.29	24.40	24.50	22.16	24.59	28.72	26.2	26.40	28.91	23.63
370	26.16	23.34	24.34	24.56	22.16	24.59	28.62	26.08	26.34	28.81	23.75
371	26.16	23.34	24.40	24.56	22.1	24.59	28.84	26.2	26.40	28.91	23.69
372	26.22	23.40	24.40	24.61	22.16	24.59	28.84	26.56	26.34	28.81	23.81
373	26.22	23.40	24.40	24.56	22.22	24.64	28.89	26.26	26.34	28.96	23.69
374	26.16	23.40	24.53	24.61	22.22	24.70	28.84	26.26	26.40	28.92	23.75
375	26.29	23.40	24.46	24.56	22.1	24.70	28.89	26.37	26.40	28.96	23.75
376	26.41	23.40	24.46	24.61	22.28	24.64	28.89	26.2	26.40	28.92	23.81
377	26.46	23.40	24.57	24.67	22.4	24.70	28.89	26.37	26.45	29.02	23.81
378	26.41	23.40	24.64	24.61	22.22	24.64	28.89	26.44	26.45	28.92	23.86
379	26.46	23.47	24.53	24.67	22.4	24.76	28.95	26.2	26.51	29.08	23.81
380	26.52	23.47	24.57	24.73	22.28	24.76	28.95	26.44	26.51	28.98	23.92
381	26.46	23.47	24.57	24.73	22.4	24.70	29.17	26.61	26.57	28.98	23.92
382	26.52	23.53	24.70	24.73	22.35	24.76	29.01	26.56	26.51	29.04	23.98
383	26.52	23.47	24.64	24.80	22.35	24.70	29.17	26.9	26.64	29.04	23.92
384	26.58	23.53	24.64	24.80	22.4	24.86	29.17	26.46	26.57	29.04	23.86
385	26.64	23.58	24.64	24.67	22.35	24.86	29.22	26.61	26.64	29.04	23.92
386	26.52	23.47	24.64	24.73	22.35	24.80	29.22	26.67	26.57	29.04	24.09
387	26.64	23.53	24.70	24.73	22.4	24.92	29.22	26.5	26.64	29.04	23.98
388	26.74	23.57	24.67	24.83	22.4	25.08	29.22	26.61	26.57	29.15	23.98
389	26.68	23.63	24.80	24.83	22.46	24.86	29.22	26.79	26.80	29.09	24.09
390	26.74	23.57	24.80	24.90	22.46	25.02	29.34	26.61	26.64	29.09	24.09
391	26.74	23.57	24.80	24.90	22.52	25.02	29.22	27.03	26.80	29.09	24.09
392	26.95	23.67	24.90	25.06	22.4	25.08	29.28	26.84	26.75	29.05	24.05
393	26.79	23.63	24.86	24.83	22.46	25.08	29.34	26.9	26.91	29.15	24.09
394	26.84	23.73	24.96	25.00	22.58	25.02	29.41	26.74	26.80	29.05	24.22
395	26.95	23.73	24.96	25.11	22.58	25.08	29.34	26.9	26.91	29.05	24.16
396	26.95	23.67	24.90	25.06	22.58	25.08	29.41	26.74	26.81	29.12	24.22
397	26.89	23.78	24.90	25.00	22.58	25.08	29.41	26.97	26.91	29.18	24.22
398	26.95	23.60	24.96	25.06	22.52	25.02	29.41	27.32	26.91	29.12	24.16
399	26.95	23.73	24.90	25.06	22.46	25.19	29.41	26.9	26.97	29.18	24.28
400	27.08	23.78	24.96	25.11	22.69	25.23	29.52	26.87	27.03	29.18	24.28
401	27.02	23.73	24.96	25.06	22.52	25.13	29.58	26.9	27.03	29.18	24.28
402	27.02	23.67	24.96	25.06	22.52	25.23	29.52	27.22	27.03	29.18	24.22
403	27.08	23.67	25.01	25.11	22.69	25.23	29.52	27.26	27.03	29.12	24.39
404	27.12	23.83	25.11	25.16	22.63	25.23	29.58	27.16	27.03	29.23	24.39
405	27.19	23.78	25.01	25.11	22.52	25.23	29.64	27.03	27.14	29.18	24.33
406	27.05	23.83	25.06	25.27	22.63	25.29	29.58	27.04	27.14	29.12	24.39
407	27.23	23.88	25.11	25.27	22.69	25.29	29.80	27.43	27.03	29.23	24.45
408	27.29	23.88	25.11	25.27	22.69	25.29	29.58	27.22	27.14	29.29	24.51
409	27.29	23.88	25.06	25.33	22.75	25.29	29.80	27.5	27.20	29.29	24.39
410	27.23	23.88	25.17	25.27	22.75	25.35	29.64	27.16	27.20	29.29	24.51
411	27.35	23.88	25.11	25.33	22.75	25.42	29.74	27.27	27.20	29.35	24.51

412	27.35	23.94	25.11	25.33	22.81	25.35	29.80	27.4	27.31	29.35	24.57
413	27.29	23.94	25.17	25.33	22.69	25.42	29.80	27.4	27.27	29.23	24.57
414	27.41	23.88	25.17	25.39	22.86	25.47	29.70	27.22	27.17	29.35	24.57
415	27.41	24.00	25.23	25.44	22.81	25.53	29.85	27.75	27.31	29.35	24.62
416	27.41	24.00	25.23	25.33	22.92	25.47	29.91	27.63	27.31	29.25	24.62
417	27.52	23.88	25.29	25.44	22.69	25.53	29.91	27.46	27.38	29.41	24.62
418	27.47	23.94	25.23	25.39	22.81	25.53	29.85	27.69	27.31	29.37	24.57
419	27.47	24.00	25.29	25.44	22.92	25.47	29.97	27.51	27.38	29.25	24.69
420	27.47	24.00	25.29	25.39	22.86	25.47	29.91	27.57	27.31	29.31	24.69
421	27.65	23.94	25.34	25.44	22.86	25.53	29.97	27.57	27.38	29.31	24.62
422	27.65	23.94	25.34	25.50	22.92	25.59	29.97	27.92	27.38	29.42	24.75
423	27.65	24.06	25.29	25.50	22.99	25.53	30.04	27.8	27.38	29.31	24.75
424	27.71	24.00	25.34	25.50	22.92	25.65	30.04	27.75	27.38	29.37	24.52
425	27.76	24.00	25.34	25.56	22.81	25.65	30.08	27.86	27.44	29.31	24.75
426	27.76	24.00	25.34	25.56	22.86	25.75	30.08	27.75	27.44	29.37	24.81
427	27.76	24.00	25.40	25.50	22.99	25.70	30.04	27.75	27.50	29.37	24.81
428	27.82	24.06	25.47	25.56	22.99	25.80	30.04	27.92	27.56	29.37	24.81
429	27.88	24.00	25.47	25.56	22.92	25.70	30.14	27.69	27.50	29.42	24.86
430	27.98	24.16	25.57	25.73	23.11	25.86	30.20	27.86	27.50	29.42	24.86
431	27.94	24.12	25.53	25.63	22.92	25.86	30.14	27.92	27.56	29.42	24.92
432	27.98	24.16	25.69	25.73	23.05	25.92	30.05	27.92	27.44	29.42	24.86
433	27.94	24.12	25.53	25.63	22.92	25.82	30.20	28.16	27.66	29.42	24.98
434	28.15	24.27	25.57	25.77	22.99	25.98	30.20	28.22	27.71	29.37	24.92
435	28.09	24.22	25.63	25.73	22.99	25.98	30.20	27.99	27.66	29.48	24.98
436	28.09	24.27	25.63	25.84	23.06	25.98	30.26	28.16	27.66	29.42	24.92
437	28.11	24.12	25.53	25.67	23.11	26.05	30.31	28.16	27.71	29.55	24.98
438	28.21	24.22	25.63	25.84	23.11	26.10	30.20	28.45	27.66	29.48	24.88
439	28.27	24.33	25.69	25.84	23.05	26.10	30.31	28.45	27.83	29.48	25.09
440	28.27	24.33	25.69	25.84	23.16	26.16	30.31	28.04	27.71	29.55	25.04
441	28.27	24.33	25.69	25.90	23.11	26.22	30.26	28.33	27.71	29.61	25.04
442	28.27	24.40	25.80	25.84	23.16	26.22	30.31	28.33	27.77	29.55	24.99
443	28.39	24.33	25.74	25.96	23.16	26.33	30.31	28.27	27.77	29.48	25.15
444	28.27	24.40	25.86	25.96	23.28	26.28	30.31	28.27	27.71	29.45	25.05
445	28.34	24.46	25.80	25.96	23.11	26.33	30.37	28.52	27.87	29.66	25.05
446	28.45	24.46	25.80	25.96	23.11	26.39	30.37	28.45	27.77	29.51	25.12
447	28.39	24.46	25.92	26.02	23.28	26.45	30.37	28.45	27.93	29.55	25.18
448	28.57	24.51	25.92	26.02	23.16	26.51	30.43	28.39	27.93	29.45	25.12
449	28.51	24.46	25.86	26.07	23.22	26.51	30.43	28.33	27.93	29.61	25.18
450	28.62	24.51	25.86	26.13	23.12	26.56	30.43	28.39	27.93	29.61	25.12
451	28.57	24.57	25.97	26.02	23.28	26.52	30.53	28.52	27.93	29.55	25.24
452	28.57	24.57	25.92	26.13	23.45	26.69	30.59	28.57	27.93	29.55	25.24
453	28.57	24.57	25.97	26.13	23.45	26.62	30.53	28.57	27.99	29.61	25.29
454	28.74	24.51	26.03	26.19	23.24	26.69	30.59	28.8	28.04	29.61	25.29
455	28.58	24.53	25.87	26.16	23.39	26.75	30.53	28.69	28.14	29.55	25.35
456	28.74	24.57	25.97	26.26	23.24	26.86	30.53	28.53	28.04	29.55	25.24
457	28.85	24.57	26.03	26.26	23.35	26.86	30.59	28.7	28.14	29.61	25.29
458	28.74	24.57	26.10	26.26	23.18	26.92	30.53	28.59	27.99	29.55	25.29
459	28.85	24.63	26.10	26.30	23.24	26.92	30.59	28.65	28.14	29.55	25.19
460	28.85	24.69	26.10	26.30	23.35	26.98	30.53	28.76	28.21	29.61	25.31

461	28.85	24.74	26.16	26.37	23.42	27.09	30.59	28.7	28.14	29.61	25.31
462	28.74	24.74	26.16	26.30	23.42	27.04	30.53	28.82	28.21	29.55	25.31
463	28.85	24.74	26.21	26.30	23.53	27.09	30.75	28.65	28.21	29.55	25.37
464	28.98	24.74	26.21	26.37	23.48	27.22	30.59	29.12	28.21	29.55	25.42
465	29.04	24.80	26.21	26.43	23.35	27.22	30.63	28.59	28.27	29.61	25.37
466	28.98	24.80	26.21	26.43	23.59	27.22	30.63	28.82	28.21	29.55	25.37
467	29.04	24.74	26.27	26.37	23.53	27.28	30.69	28.88	28.27	29.61	25.42
468	28.98	24.86	26.27	26.49	23.59	27.33	30.69	28.72	28.33	29.55	25.48
469	28.98	24.80	26.33	26.43	23.53	27.39	30.75	28.82	28.33	29.66	25.42
470	28.98	24.86	26.33	26.43	23.71	27.43	30.63	28.89	28.38	29.48	25.48
471	29.10	24.80	26.33	26.49	23.55	27.49	30.69	28.96	28.38	29.55	25.48
472	29.10	24.86	26.39	26.60	23.61	27.55	30.69	28.89	28.38	29.55	25.48
473	29.10	24.93	26.33	26.54	23.43	27.61	30.78	29.08	28.44	29.61	25.61
474	29.14	25.03	26.55	26.70	23.67	27.61	30.69	29.13	28.33	29.61	25.54
475	29.25	24.96	26.49	26.70	23.55	27.55	30.78	29.19	28.44	29.61	25.61
476	29.14	25.03	26.49	26.70	23.43	27.61	30.75	28.96	28.38	29.61	25.54
477	29.14	25.03	26.49	26.70	23.67	27.61	30.78	29.08	28.50	29.61	25.66
478	29.20	25.09	26.60	26.70	23.55	27.67	30.78	28.78	28.44	29.61	25.72
479	29.20	25.03	26.49	26.76	23.61	27.67	30.72	29.08	28.50	29.61	25.66
480	29.20	25.14	26.60	26.82	23.67	27.67	30.78	29.02	28.44	29.66	25.66
481	29.25	25.09	26.55	26.76	23.72	27.72	30.78	28.89	28.50	29.66	25.66
482	29.25	25.03	26.66	26.82	23.61	27.82	30.78	28.96	28.50	29.66	25.72
483	29.20	25.14	26.66	26.82	23.72	27.72	30.84	28.96	28.56	29.61	25.72
484	29.25	25.09	26.66	26.82	23.78	27.82	30.89	29.13	28.50	29.61	25.68
485	29.14	25.14	26.66	26.82	23.85	27.82	30.84	29.13	28.56	29.66	25.68
486	29.30	25.24	26.76	26.98	23.96	27.77	30.89	29.19	28.62	29.61	25.74
487	29.14	25.14	26.72	26.82	23.96	27.77	30.84	29.19	28.56	29.61	25.68
488	29.35	25.30	26.82	26.92	23.78	27.88	30.84	29.13	28.67	29.61	25.8
489	29.24	25.30	26.89	26.98	23.96	27.82	30.89	28.96	28.67	29.66	25.8
490	29.18	25.36	26.89	26.98	23.85	27.82	30.89	29.19	28.67	29.66	25.8
491	29.30	25.36	26.89	27.03	23.78	27.88	30.89	29.25	28.62	29.72	25.8
492	29.30	25.36	26.89	27.03	24.02	27.98	30.89	29.31	28.80	29.66	25.8
493	29.41	25.42	26.94	27.03	23.96	27.88	30.89	29.49	28.73	29.66	25.85
494	29.24	25.36	26.94	27.10	24.14	28.05	30.84	29.6	28.67	29.66	25.81
495	29.30	25.42	26.94	27.16	23.96	27.88	30.89	29.55	28.73	29.72	25.91
496	29.34	25.52	27.10	27.32	24.04	27.98	30.84	29.13	28.67	29.72	25.81
497	29.30	25.42	27.00	27.10	23.92	27.98	30.89	29.25	28.73	29.56	25.97
498	29.45	25.52	27.16	27.26	23.86	27.98	30.89	29.72	28.86	29.68	25.81
499	29.30	25.42	27.12	27.22	24.09	27.98	30.89	29.42	28.80	29.56	25.94
500	29.28	25.57	27.22	27.37	24.04	27.98	30.89	28.89	28.76	29.68	25.81
501	29.28	25.57	27.33	27.43	24.09	27.98	30.89	29.25	28.70	29.68	25.97
502	29.28	25.63	27.33	27.37	24.21	28.05	30.89	29.13	28.87	29.62	25.94
503	29.40	25.57	27.33	27.37	24.09	28.11	30.89	29.76	28.76	29.68	25.99
504	29.34	25.69	27.39	27.43	24.09	27.98	30.89	29.55	28.87	29.58	25.87
505	29.28	25.57	27.33	27.43	24.09	27.98	30.95	29.41	28.91	29.58	25.99
506	29.28	25.63	27.45	27.49	24.11	28.05	30.84	29.41	28.87	29.52	25.99
507	29.28	25.69	27.39	27.55	24.27	27.98	30.95	29.52	28.87	29.58	26.11
508	29.22	25.69	27.52	27.55	24.17	27.98	30.95	29.65	28.87	29.64	26.05
509	29.34	25.75	27.45	27.60	24.27	28.05	31.01	29.76	28.81	29.58	25.99

510	29.28	25.75	27.57	27.60	24.35	27.98	30.95	29.42	28.87	29.64	26.05
511	29.22	25.80	27.57	27.66	24.29	27.98	30.95	29.41	28.87	29.58	26.05
512	29.34	25.87	27.57	27.66	24.47	27.98	31.01	29.6	28.93	29.69	26.11
513	29.22	25.87	27.63	27.66	24.51	27.98	30.95	29.72	28.81	29.64	26.11
514	29.22	25.80	27.75	27.73	24.41	28.05	31.01	29.36	28.81	29.64	26.17
515	29.28	25.93	27.69	27.73	24.52	28.05	31.01	29.52	28.93	29.64	26.17
516	29.15	25.93	27.75	27.85	24.58	27.98	31.01	29.36	28.87	29.48	26.17
517	29.22	25.99	27.75	27.85	24.58	27.98	30.95	29.29	29.04	29.64	26.11
518	29.15	25.93	27.86	27.85	24.52	28.05	30.92	29.76	28.93	29.59	26.22
519	29.22	25.93	27.86	27.90	24.64	27.98	30.86	29.29	28.93	29.59	26.17
520	29.15	26.05	27.92	27.90	24.7	27.98	30.92	29.46	28.93	29.48	26.17
521	29.15	26.05	27.92	27.96	24.7	27.98	30.92	29.46	29.14	29.65	26.17
522	29.15	25.99	27.98	28.02	24.82	28.05	30.92	29.59	29.09	29.59	26.11
523	29.15	26.10	27.98	27.96	24.94	27.98	31.01	29.52	28.97	29.59	26.17
524	28.92	26.10	28.03	28.08	24.88	27.98	30.86	29.72	29.03	29.54	26.22
525	29.10	26.16	28.03	28.08	24.88	28.05	30.92	29.7	28.99	29.59	26.22
526	29.22	26.16	28.09	28.13	25.05	27.98	30.92	29.65	29.04	29.59	26.17
527	29.10	26.22	28.16	28.19	25	28.05	30.98	29.41	29.03	29.54	26.32
528	29.22	26.16	28.16	28.25	25.05	27.98	30.92	29.41	28.99	29.54	26.17
529	29.10	26.22	28.28	28.19	25.17	28.05	30.92	29.51	29.09	29.59	26.38
530	28.98	26.22	28.22	28.25	25.23	27.98	30.92	29.7	28.99	29.49	26.28
531	29.15	26.10	28.28	28.25	25.05	27.98	30.92	29.94	28.99	29.59	26.32
532	29.10	26.22	28.33	28.25	25.17	27.98	30.80	29.76	29.09	29.49	26.28
533	28.92	26.33	28.33	28.37	25.34	27.98	30.86	29.59	29.09	29.49	26.38
534	29.04	26.33	28.33	28.32	25.17	27.98	30.86	29.65	29.04	29.49	26.38
535	29.10	26.28	28.33	28.49	25.28	27.98	30.86	29.51	29.09	29.55	26.38
536	29.04	26.40	28.51	28.49	25.41	27.98	30.86	29.59	29.04	29.49	26.22
537	29.10	26.33	28.45	28.43	25.34	27.88	30.92	29.92	29.04	29.45	26.44
538	29.15	26.40	28.51	28.49	25.41	27.88	30.92	29.59	29.04	29.39	26.4
539	28.92	26.46	28.45	28.55	25.51	27.88	30.95	29.75	29.14	29.39	26.44
540	28.98	26.46	28.51	28.61	25.58	27.82	30.89	29.69	29.04	29.39	26.34
541	28.88	26.47	28.41	28.51	25.62	27.95	30.95	29.62	29.10	29.39	26.44
542	28.82	26.47	28.46	28.56	25.47	28.05	30.89	30.09	29.10	29.39	26.5
543	28.77	26.42	28.46	28.62	25.74	27.95	30.80	29.62	29.10	29.45	26.44
544	28.82	26.47	28.46	28.56	25.7	27.95	30.86	29.75	29.10	29.45	26.5
545	28.88	26.47	28.46	28.62	25.86	27.95	30.95	29.28	29.16	29.39	26.38
546	28.98	26.69	28.69	28.78	25.8	27.88	30.80	29.51	29.16	29.45	26.44
547	28.77	26.59	28.52	28.62	25.91	27.88	30.95	29.39	29.23	29.39	26.44
548	28.82	26.53	28.52	28.62	25.81	27.82	30.80	29.75	29.10	29.45	26.44
549	28.82	26.65	28.59	28.75	25.74	27.88	30.80	29.69	29.10	29.39	26.44
550	28.88	26.65	28.65	28.68	25.87	27.88	30.89	29.75	29.00	29.39	26.44
551	28.88	26.76	28.59	28.75	25.86	27.82	30.89	29.75	29.23	29.39	26.5
552	28.88	26.71	28.59	28.80	25.94	27.82	30.80	29.86	29.16	29.39	26.5
553	28.71	26.59	28.59	28.75	25.97	27.88	30.84	29.92	29.29	29.39	26.5
554	28.77	26.76	28.65	28.80	25.97	27.88	30.86	29.69	29.06	29.34	26.57
555	28.88	26.76	28.65	28.80	26.04	27.77	30.75	29.8	29.16	29.39	26.57
556	28.77	26.71	28.65	28.80	25.91	27.88	30.86	29.62	29.19	29.34	26.5
557	28.71	26.76	28.65	28.86	26.15	27.82	30.89	29.69	29.23	29.34	26.57
558	28.65	26.76	28.59	28.86	26.1	27.92	30.75	29.69	29.13	29.28	26.57

559	28.59	26.95	28.65	28.86	26.04	27.92	30.80	29.86	29.13	29.34	26.61
560	28.65	26.89	28.65	28.92	26.04	27.87	30.75	29.69	29.13	29.28	26.57
561	28.65	26.89	28.65	28.92	25.91	27.92	30.75	29.72	29.13	29.34	26.5
562	28.75	26.92	28.75	28.96	26.1	27.82	30.75	29.66	29.19	29.28	26.57
563	28.57	27.05	28.75	29.02	25.97	27.82	30.80	29.75	29.06	29.34	26.61
564	28.75	26.99	28.75	29.02	26.04	27.87	30.63	30.04	29.30	29.28	26.5
565	28.75	27.05	28.75	29.02	25.97	27.77	30.80	29.61	29.19	29.34	26.57
566	28.54	27.00	28.65	28.92	26.21	27.87	30.75	29.79	29.19	29.22	26.61
567	28.59	26.95	28.70	28.92	26.15	27.77	30.69	29.79	29.13	29.34	26.68
568	28.69	27.10	28.75	29.02	26.21	27.77	30.65	29.79	29.13	29.28	26.57
569	28.71	27.06	28.65	28.98	26.04	27.87	30.69	29.89	29.24	29.28	26.61
570	28.81	27.10	28.69	28.96	26.04	27.87	30.69	29.79	29.24	29.22	26.51
571	28.59	27.12	28.59	28.98	26.33	27.71	30.75	29.89	29.24	29.22	26.68
572	28.54	27.12	28.52	28.98	26.15	27.87	30.65	30.14	29.24	29.28	26.68
573	28.64	27.22	28.75	29.08	26.1	27.71	30.75	30.08	29.24	29.22	26.61
574	28.64	27.28	28.62	29.08	25.97	27.77	30.59	30.14	29.24	29.11	26.68
575	28.41	27.18	28.65	28.98	26.1	27.77	30.69	29.61	29.30	29.22	26.74
576	28.75	27.22	28.75	29.08	26.15	27.87	30.53	29.96	29.30	29.16	26.51
577	28.47	27.29	28.52	28.98	26.04	27.82	30.53	29.95	29.24	29.28	26.74
578	28.41	27.29	28.59	29.03	26.1	27.77	30.53	30.06	29.24	29.22	26.58
579	28.54	27.29	28.65	29.03	26.21	27.71	30.59	29.95	29.24	29.16	26.61
580	28.57	27.45	28.75	29.13	26.21	27.71	30.53	29.85	29.19	29.16	26.64
581	28.54	27.35	28.52	29.03	26.15	27.71	30.65	30.12	29.24	29.28	26.58
582	28.47	27.29	28.59	29.03	26.05	27.71	30.53	29.76	29.24	29.16	26.47
583	28.41	27.42	28.52	29.03	26.1	27.71	30.53	29.89	29.13	29.16	26.51
584	28.41	27.35	28.65	29.03	26.15	27.71	30.53	29.95	29.30	29.11	26.64
585	28.47	27.35	28.59	28.98	26.1	27.77	30.47	30	29.36	29.16	26.51
586	28.35	27.47	28.52	29.03	26.21	27.65	30.53	29.95	29.19	29.11	26.58
587	28.29	27.42	28.46	28.98	26.15	27.61	30.41	29.95	29.24	29.16	26.64
588	28.29	27.47	28.52	28.98	26.05	27.77	30.47	29.9	29.24	29.16	26.64
589	28.35	27.53	28.52	29.09	25.97	27.71	30.53	30.29	29.19	29.22	26.58
590	28.35	27.53	28.52	29.03	25.94	27.77	30.47	30	29.30	29.16	26.58
591	28.25	27.43	28.36	28.88	26.15	27.61	30.47	29.89	29.30	29.11	26.58
592	28.35	27.59	28.52	29.03	26.05	27.71	30.47	30.35	29.24	29.11	26.7
593	28.41	27.53	28.46	29.03	26.05	27.61	30.47	29.95	29.24	29.05	26.7
594	28.29	27.65	28.46	29.03	25.94	27.77	30.47	29.71	29.19	29.11	26.58
595	28.37	27.55	28.36	28.93	26	27.61	30.41	30.12	29.19	29.11	26.64
596	28.29	27.76	28.46	29.03	25.81	27.61	30.41	29.71	29.24	29.05	26.7
597	28.08	27.61	28.36	28.93	26	27.55	30.41	29.89	29.19	29.05	26.64
598	28.29	27.71	28.46	29.03	25.94	27.55	30.41	29.76	29.24	29.11	26.75
599	28.19	27.55	28.36	28.99	26	27.67	30.41	29.82	29.24	29.05	26.58
600	28.19	27.61	28.36	28.93	25.87	27.61	30.36	29.76	29.30	29.05	26.58
601	28.14	27.66	28.36	28.93	25.94	27.67	30.36	29.95	29.24	28.98	26.64
602	28.14	27.72	28.31	28.93	25.94	27.61	30.30	30.12	29.30	28.98	26.7
603	28.08	27.78	28.36	28.93	26	27.55	30.36	29.89	29.30	28.98	26.7
604	28.14	27.72	28.36	28.93	25.81	27.61	30.36	29.76	29.13	28.92	26.7
605	28.08	27.78	28.31	28.93	25.94	27.61	30.41	29.95	29.30	29.05	26.64
606	28.02	27.85	28.31	28.99	26	27.67	30.30	29.82	29.19	28.98	26.75
607	28.14	27.78	28.36	28.93	26	27.61	30.30	29.99	29.24	28.98	26.7

608	28.08	27.78	28.25	28.88	25.81	27.61	30.36	29.92	29.19	28.92	26.7
609	28.19	27.85	28.25	28.88	25.94	27.67	30.24	29.99	29.24	28.92	26.64
610	27.96	27.85	28.19	28.93	25.87	27.61	30.30	29.99	29.24	28.92	26.58
611	28.02	27.89	28.31	28.93	25.81	27.61	30.24	29.86	29.24	28.87	26.7
612	28.14	27.89	28.31	28.99	25.81	27.55	30.30	29.81	29.14	28.92	26.7
613	28.08	27.96	28.25	28.93	25.87	27.61	30.24	29.92	29.14	28.87	26.7
614	28.02	27.89	28.19	28.93	25.87	27.61	30.24	29.99	29.09	28.81	26.75
615	28.19	27.89	28.25	28.88	25.7	27.55	30.24	29.81	29.19	28.81	26.7
616	28.02	27.96	28.19	28.88	25.58	27.55	30.18	29.86	29.09	28.87	26.64
617	27.96	28.02	28.19	28.93	25.64	27.61	30.18	29.75	29.20	28.87	26.58
618	27.96	28.02	28.25	28.88	25.81	27.61	30.13	29.69	29.14	28.81	26.64
619	27.96	27.96	28.19	28.88	25.58	27.55	30.18	29.75	29.09	28.92	26.7
620	28.02	28.02	28.13	28.88	25.81	27.55	30.18	29.75	28.99	28.87	26.75
621	28.02	27.96	28.19	28.88	25.64	27.55	30.18	29.86	29.14	28.75	26.75
622	27.96	27.96	28.19	28.88	25.7	27.49	30.07	29.92	29.09	28.75	26.54
623	27.96	28.08	28.08	28.88	25.58	27.55	30.07	29.69	29.04	28.81	26.75
624	27.96	28.02	28.13	28.88	25.64	27.55	30.18	29.99	29.14	28.91	26.6
625	27.85	28.02	28.08	28.76	25.58	27.55	30.13	29.81	29.04	28.97	26.6
626	27.85	28.08	28.08	28.82	25.7	27.49	30.01	29.69	29.04	28.81	26.6
627	28.02	28.08	28.08	28.82	25.64	27.49	30.01	29.52	29.04	28.91	26.64
628	27.85	28.02	28.08	28.76	25.58	27.49	30.07	29.63	29.04	28.79	26.6
629	27.85	28.02	28.08	28.76	25.64	27.49	30.07	29.92	29.04	28.85	26.6
630	27.91	28.08	28.02	28.70	25.64	27.49	30.04	30.05	29.10	28.79	26.65
631	27.85	28.13	28.02	28.76	25.81	27.49	29.97	29.69	29.10	28.79	26.54
632	27.72	28.19	28.02	28.70	25.64	27.55	29.97	29.75	29.10	28.85	26.65
633	27.78	28.08	27.96	28.70	25.64	27.49	30.01	29.81	29.04	28.73	26.54
634	27.78	28.08	28.02	28.70	25.67	27.49	29.91	29.69	29.04	28.73	26.6
635	27.72	28.08	27.96	28.70	25.52	27.43	29.85	29.58	29.04	28.73	26.65
636	27.85	28.13	28.02	28.65	25.6	27.49	29.85	29.81	29.10	28.78	26.6
637	27.72	28.13	27.96	28.70	25.42	27.49	29.91	29.69	29.10	28.83	26.65
638	27.67	28.13	27.89	28.70	25.42	27.38	29.75	29.69	29.00	28.72	26.65
639	27.72	28.08	27.89	28.70	25.47	27.49	29.85	29.92	28.94	28.78	26.65
640	27.72	28.02	27.89	28.65	25.31	27.43	29.85	29.86	29.00	28.78	26.65
641	27.78	28.02	27.89	28.58	25.48	27.38	29.75	29.81	28.94	28.78	26.6
642	27.67	28.13	27.83	28.65	25.42	27.43	29.80	29.81	28.94	28.72	26.65
643	27.67	28.19	27.83	28.65	25.31	27.43	29.70	29.86	28.94	28.65	26.65
644	27.67	28.19	27.89	28.65	25.48	27.43	29.70	29.63	28.94	28.72	26.54
645	27.85	28.19	27.83	28.58	25.6	27.43	29.70	29.63	29.00	28.59	26.6
646	27.67	28.25	27.83	28.58	25.42	27.43	29.70	29.69	28.94	28.65	26.54
647	27.72	28.25	27.78	28.58	25.48	27.43	29.70	29.63	28.89	28.65	26.54
648	27.67	28.13	27.72	28.58	25.31	27.43	29.64	29.63	28.94	28.65	26.6
649	27.72	28.13	27.83	28.52	25.37	27.28	29.64	29.58	28.94	28.69	26.6
650	27.61	28.13	27.78	28.58	25.37	27.33	29.64	29.63	29.00	28.69	26.54
651	27.67	28.19	27.78	28.52	25.31	27.33	29.64	29.69	28.94	28.69	26.54
652	27.55	28.19	27.78	28.52	25.31	27.38	29.64	29.52	28.94	28.64	26.54
653	27.45	28.15	27.62	28.42	25.18	27.33	29.64	29.63	28.89	28.69	26.6
654	27.39	28.15	27.68	28.42	25.18	27.33	29.58	29.52	28.94	28.64	26.48
655	27.62	28.09	27.68	28.42	25.25	27.28	29.58	29.39	28.89	28.69	26.54
656	27.67	28.13	27.72	28.46	25.25	27.28	29.54	29.33	28.89	28.64	26.54

657	27.62	28.03	27.62	28.36	25.14	27.23	29.60	29.33	28.94	28.64	26.54
658	27.51	28.09	27.56	28.48	25.18	27.33	29.54	29.46	28.89	28.64	26.6
659	27.45	28.09	27.62	28.42	25.31	27.28	29.54	29.46	28.94	28.64	26.6
660	27.57	28.03	27.56	28.42	25.31	27.12	29.54	29.63	28.89	28.69	26.54
661	27.52	27.99	27.46	28.21	25.18	27.33	29.54	29.39	28.79	28.58	26.48
662	27.57	28.21	27.56	28.36	25.25	27.18	29.54	29.28	28.84	28.52	26.48
663	27.57	28.09	27.62	28.31	25.31	27.18	29.54	29.28	28.94	28.64	26.54
664	27.29	27.99	27.46	28.26	25.07	27.18	29.42	29.46	28.96	28.58	26.6
665	27.39	28.09	27.56	28.36	25.31	27.18	29.42	29.46	28.84	28.58	26.54
666	27.35	27.99	27.46	28.21	25.07	27.23	29.48	29.39	28.73	28.52	26.54
667	27.35	27.93	27.52	28.21	25.18	27.23	29.42	29.28	28.90	28.52	26.54
668	27.29	27.99	27.40	28.21	25.14	27.23	29.36	29.39	28.84	28.58	26.48
669	27.29	28.05	27.46	28.21	25.14	27.29	29.54	29.28	28.90	28.58	26.54
670	27.29	27.99	27.46	28.26	25.18	27.18	29.48	29.33	28.69	28.52	26.42
671	27.35	28.11	27.40	28.26	25.18	27.23	29.36	29.16	28.84	28.52	26.42
672	27.29	27.93	27.46	28.21	25.14	27.23	29.42	29.46	28.74	28.46	26.54
673	27.29	28.05	27.40	28.26	25.18	27.23	29.36	29.16	28.74	28.41	26.42
674	27.23	27.99	27.40	28.21	25.01	27.23	29.36	29.52	28.69	28.46	26.54
675	27.23	28.05	27.40	28.26	25.18	27.13	29.31	29.33	28.74	28.46	26.54
676	27.41	28.05	27.40	28.21	25.07	27.13	29.31	29.05	28.69	28.41	26.54
677	27.35	28.05	27.40	28.15	25.01	27.13	29.36	29.52	28.74	28.35	26.44
678	27.35	28.05	27.40	28.21	25.14	27.13	29.24	29.06	28.69	28.46	26.38
679	27.25	27.89	27.25	28.11	25.07	27.13	29.21	29.22	28.69	28.46	26.54
680	27.31	27.95	27.25	28.11	25.07	27.13	29.26	29	28.69	28.41	26.38
681	27.37	28.07	27.36	28.11	24.95	27.19	29.24	29.36	28.63	28.41	26.38
682	27.42	28.07	27.30	28.11	25.01	27.19	29.21	29.23	28.63	28.41	26.44
683	27.19	28.01	27.36	28.05	24.95	27.19	29.14	29.23	28.74	28.41	26.44
684	27.19	27.95	27.25	28.05	25.01	27.08	29.14	29.06	28.69	28.29	26.34
685	27.25	27.95	27.30	28.11	25.01	27.13	29.08	29.23	28.56	28.29	26.34
686	27.31	27.95	27.19	28.11	25.01	27.13	29.14	29.18	28.63	28.41	26.34
687	27.31	28.01	27.25	28.11	25.01	27.08	29.14	29.12	28.69	28.41	26.4
688	27.37	28.01	27.25	27.99	25.14	27.19	28.98	29.48	28.74	28.41	26.4
689	27.19	27.95	27.25	28.05	24.8	27.08	29.08	29	28.69	28.35	26.34
690	27.31	28.01	27.25	27.99	24.85	27.08	28.92	29.06	28.63	28.35	26.34
691	27.37	27.89	27.19	28.05	25.14	27.13	28.98	29.06	28.63	28.29	26.4
692	27.31	27.95	27.13	28.05	24.85	27.13	28.98	29.06	28.59	28.35	26.34
693	27.19	27.89	27.25	28.05	24.74	27.08	28.98	29.18	28.53	28.29	26.4
694	27.37	27.89	27.13	27.93	24.8	27.08	28.92	28.9	28.53	28.29	26.4
695	27.19	27.89	27.19	27.99	24.98	27.13	28.92	29.06	28.53	28.35	26.4
696	27.31	27.89	27.19	27.99	24.94	27.08	28.98	28.96	28.46	28.22	26.36
697	27.25	27.89	27.25	27.99	24.75	27.08	28.87	28.96	28.53	28.29	26.18
698	27.25	27.83	27.13	28.05	24.64	26.92	28.92	28.9	28.53	28.29	26.24
699	27.19	27.83	27.19	27.93	24.75	26.98	28.81	28.9	28.46	28.16	26.24
700	27.25	27.89	27.13	27.99	24.88	27.02	28.92	28.9	28.59	28.22	26.31
701	27.25	27.83	27.19	27.99	24.75	26.98	28.81	28.9	28.53	28.29	26.31
702	27.09	27.79	27.03	27.83	24.64	26.92	28.92	29.02	28.59	28.22	26.31
703	27.15	27.68	27.03	27.83	24.75	26.92	28.81	28.79	28.53	28.11	26.31
704	27.13	27.83	27.13	27.93	24.75	26.98	28.87	28.85	28.46	28.16	26.26
705	27.03	27.73	26.92	27.83	24.75	26.98	28.81	28.96	28.46	28.22	26.36

706	27.03	27.68	26.97	27.83	24.82	26.98	28.81	29.08	28.53	28.16	26.31
707	26.92	27.68	26.97	27.83	24.71	26.88	28.87	28.73	28.46	28.16	26.21
708	26.98	27.68	26.97	27.77	24.61	26.92	28.81	28.67	28.36	28.16	26.15
709	27.15	27.68	26.97	27.77	24.55	26.88	28.81	28.73	28.53	28.22	26.26
710	27.09	27.73	26.97	27.77	24.78	26.88	28.71	28.67	28.43	28.16	26.11
711	26.99	27.58	26.87	27.67	24.84	26.82	28.65	28.96	28.43	28.22	26.15
712	26.98	27.68	26.92	27.72	24.78	26.88	28.71	28.45	28.36	28.11	26.11
713	26.93	27.58	26.87	27.67	24.55	26.88	28.65	28.73	28.30	28.05	26.11
714	26.88	27.58	26.75	27.67	24.66	26.88	28.71	28.62	28.30	28.11	26.16
715	27.05	27.46	26.82	27.73	24.61	26.88	28.65	28.96	28.36	28.05	26.16
716	26.93	27.52	26.82	27.62	24.56	26.88	28.59	28.62	28.24	28.11	26.16
717	26.82	27.58	26.82	27.67	24.55	26.88	28.59	28.55	28.24	27.99	26.11
718	26.93	27.46	26.82	27.62	24.66	26.88	28.65	28.67	28.36	28.11	26.11
719	26.93	27.58	26.87	27.62	24.45	26.88	28.59	28.52	28.24	27.99	26.16
720	26.82	27.58	26.75	27.62	24.68	26.75	28.54	28.39	28.30	28.05	26.06
721	26.75	27.52	26.82	27.67	24.45	26.93	28.59	28.27	28.23	27.99	26.16
722	26.75	27.52	26.82	27.62	24.52	26.82	28.59	28.33	28.24	27.99	26.06
723	26.64	27.52	26.82	27.55	24.62	26.82	28.59	28.45	28.29	27.99	26.06
724	26.88	27.46	26.82	27.62	24.58	26.88	28.54	28.27	28.34	27.99	26.01
725	26.82	27.46	26.75	27.62	24.41	26.75	28.54	28.52	28.29	27.93	26.06
726	26.93	27.46	26.82	27.55	24.41	26.88	28.49	28.52	28.29	28.03	26.06
727	26.75	27.52	26.75	27.55	24.46	26.93	28.54	28.45	28.17	27.98	25.96
728	26.82	27.52	26.75	27.55	24.64	26.88	28.44	28.52	28.23	27.88	25.96
729	26.69	27.52	26.82	27.62	24.46	26.72	28.38	28.16	28.17	27.98	25.91
730	26.88	27.46	26.75	27.49	24.64	26.78	28.49	28.22	28.23	27.88	25.96
731	27.05	27.46	26.69	27.55	24.58	26.72	28.44	28.04	28.17	27.92	26.02
732	26.82	27.46	26.69	27.55	24.25	26.65	28.44	28.52	28.17	27.98	25.96
733	26.72	27.29	26.72	27.45	24.64	26.72	28.32	28.1	28.17	27.98	25.91
734	26.72	27.36	26.59	27.52	24.25	26.78	28.32	28.45	28.17	27.98	25.96
735	26.78	27.36	26.65	27.39	24.36	26.72	28.32	28.16	28.17	27.98	25.96
736	26.83	27.29	26.59	27.45	24.31	26.72	28.25	28.39	28.06	27.92	25.96
737	26.72	27.29	26.59	27.45	24.19	26.72	28.25	28.04	28.11	27.92	25.96
738	26.78	27.29	26.59	27.45	24.42	26.72	28.25	28.57	28.06	27.86	25.86
739	26.78	27.29	26.59	27.39	24.21	26.72	28.35	28.16	28.06	27.86	25.82
740	26.59	27.29	26.59	27.39	24.21	26.72	28.25	28.45	28.06	27.98	25.86
741	26.59	27.29	26.59	27.45	24.15	26.72	28.29	27.92	28.00	27.86	25.93
742	26.72	27.18	26.59	27.39	24.32	26.72	28.29	28.16	27.93	27.92	25.93
743	26.65	27.29	26.59	27.39	24.21	26.72	28.24	27.92	28.06	27.86	25.82
744	26.65	27.29	26.53	27.39	24.26	26.78	28.29	28.39	28.00	27.8	25.72
745	26.72	27.29	26.59	27.39	24.39	26.62	28.24	28.33	28.00	27.8	25.72
746	26.89	27.36	26.59	27.39	24.21	26.65	28.24	28.22	28.00	27.92	25.72
747	26.78	27.25	26.59	27.39	24.32	26.55	28.18	28.04	28.00	27.9	25.77
748	26.59	27.18	26.59	27.39	24.39	26.62	28.12	28.1	27.93	27.78	25.77
749	26.68	27.15	26.49	27.29	24.21	26.62	28.18	28.04	27.93	27.85	25.66
750	26.72	27.25	26.59	27.33	24.16	26.55	28.12	28.04	27.87	27.85	25.77
751	26.68	27.19	26.43	27.23	24.23	26.55	28.12	28.16	27.93	27.85	25.77
752	26.44	27.19	26.43	27.35	24.35	26.62	28.06	28.16	27.82	27.85	25.83
753	26.55	27.15	26.37	27.29	24.23	26.55	28.01	28.27	27.93	27.72	25.77
754	26.68	27.08	26.43	27.23	24.05	26.62	28.06	27.99	27.82	27.78	25.83

755	26.49	27.15	26.37	27.23	24.23	26.49	28.01	27.86	27.82	27.78	25.77
756	26.44	27.08	26.43	27.23	24.25	26.49	28.01	27.92	27.82	27.78	25.77
757	26.55	27.08	26.32	27.18	24.19	26.49	27.95	28.04	27.82	27.72	25.72
758	26.44	26.96	26.32	27.18	24.02	26.65	28.01	27.86	27.82	27.78	25.67
759	26.44	27.08	26.32	27.18	24.13	26.49	27.95	28.1	27.82	27.72	25.77
760	26.49	27.02	26.37	27.12	24.25	26.59	27.95	27.86	27.82	27.78	25.56
761	26.32	27.02	26.32	27.12	24.19	26.54	27.89	27.86	27.76	27.78	25.62
762	26.59	27.12	26.42	27.22	23.96	26.54	27.82	27.8	27.76	27.72	25.56
763	26.49	26.96	26.26	27.12	24.19	26.48	27.89	27.92	27.76	27.72	25.62
764	26.59	27.06	26.42	27.28	24.02	26.48	27.89	27.8	27.76	27.72	25.62
765	26.54	27.01	26.36	27.16	24.07	26.54	27.82	28.04	27.82	27.72	25.56
766	26.48	27.01	26.42	27.16	24.13	26.54	27.71	27.92	27.70	27.66	25.62
767	26.42	27.01	26.30	27.16	24.19	26.48	27.77	27.86	27.70	27.6	25.56
768	26.59	27.01	26.30	27.22	24.07	26.42	27.82	27.63	27.70	27.6	25.56
769	26.42	26.95	26.30	27.16	24.19	26.42	27.77	27.8	27.64	27.6	25.62
770	26.48	26.95	26.24	27.05	23.97	26.42	27.71	27.75	27.64	27.6	25.62
771	26.42	26.89	26.30	27.05	24.19	26.42	27.65	27.69	27.64	27.6	25.5
772	26.31	26.89	26.24	27.05	23.92	26.42	27.65	27.75	27.64	27.6	25.56
773	26.36	26.89	26.30	27.10	23.92	26.42	27.71	27.46	27.58	27.6	25.5
774	26.31	26.83	26.19	27.10	23.92	26.36	27.71	27.8	27.64	27.55	25.5
775	26.36	26.77	26.24	27.05	23.92	26.31	27.65	27.75	27.64	27.55	25.5
776	26.36	26.83	26.19	26.99	23.86	26.36	27.59	27.46	27.58	27.55	25.5
777	26.25	26.72	26.19	26.99	23.97	26.36	27.65	27.69	27.58	27.6	25.43
778	26.25	26.83	26.19	26.93	23.92	26.31	27.59	27.69	27.58	27.55	25.43
779	26.42	26.77	26.19	27.05	24.03	26.36	27.59	27.63	27.53	27.55	25.38
780	26.25	26.83	26.19	26.93	23.73	26.36	27.59	27.57	27.58	27.6	25.38
781	26.25	26.77	26.12	26.93	23.86	26.31	27.53	27.57	27.53	27.55	25.48
782	26.31	26.72	26.06	26.93	23.92	26.31	27.53	27.51	27.58	27.55	25.38
783	26.42	26.65	26.06	26.93	23.97	26.31	27.53	27.51	27.53	27.55	25.48
784	26.25	26.65	26.12	26.86	23.86	26.31	27.48	27.36	27.47	27.49	25.38
785	26.25	26.65	26.06	26.99	23.86	26.31	27.48	27.4	27.47	27.49	25.48
786	26.31	26.72	26.06	26.86	23.97	26.25	27.48	27.59	27.47	27.43	25.32
787	26.25	26.59	26.06	26.86	23.8	26.31	27.48	27.36	27.41	27.43	25.42
788	26.19	26.65	26.06	26.86	23.97	26.25	27.42	27.3	27.41	27.49	25.32
789	26.19	26.65	26.00	26.86	23.86	26.25	27.42	27.33	27.47	27.37	25.42
790	26.25	26.65	26.06	26.86	23.97	26.25	27.42	27.23	27.47	27.43	25.42
791	26.12	26.65	25.95	26.80	23.73	26.25	27.36	27.3	27.41	27.37	25.36
792	26.19	26.59	26.00	26.80	23.86	26.25	27.36	27.3	27.47	27.37	25.36
793	26.19	26.59	26.00	26.80	23.77	26.25	27.36	27.17	27.41	27.43	25.36
794	26.12	26.53	26.00	26.75	23.8	26.19	27.29	27.17	27.41	27.37	25.36
795	26.19	26.53	25.95	26.75	23.96	26.19	27.36	27.17	27.41	27.37	25.3
796	26.06	26.42	25.95	26.75	23.67	26.25	27.36	27.12	27.34	27.32	25.3
797	26.06	26.59	25.95	26.75	23.89	26.12	27.29	27.47	27.34	27.32	25.36
798	26.12	26.53	25.89	26.75	23.67	26.12	27.29	27.02	27.34	27.37	25.24
799	26.06	26.53	25.89	26.69	23.66	26.12	27.29	27.41	27.29	27.25	25.24
800	26.06	26.53	25.89	26.69	23.73	26.06	27.25	27.26	27.29	27.32	25.19
801	26.06	26.48	25.95	26.75	23.72	26.12	27.29	27.02	27.29	27.25	25.13
802	26.12	26.42	25.89	26.63	23.77	26.12	27.29	26.96	27.23	27.19	25.19
803	26.01	26.53	25.89	26.69	23.72	26.19	27.25	27.13	27.23	27.19	25.24

804	26.06	26.42	25.83	26.69	23.77	26.06	27.25	26.84	27.23	27.19	25.13
805	26.06	26.48	25.83	26.69	23.77	26.06	27.18	26.73	27.17	27.19	25.19
806	26.01	26.48	25.77	26.63	23.83	26.06	27.12	26.79	27.23	27.19	25.13
807	26.06	26.48	25.83	26.63	23.77	26.12	27.25	26.6	27.17	27.19	25.16
808	26.06	26.42	25.83	26.63	23.83	26.06	27.25	27.26	27.17	27.25	25.24
809	26.06	26.48	25.83	26.57	23.72	26.06	27.18	26.79	27.17	27.19	25.1
810	26.01	26.36	25.77	26.57	23.6	26.06	27.18	26.9	27.17	27.19	25.06
811	26.06	26.36	25.77	26.57	23.72	26.01	27.18	26.96	27.11	27.19	25.16
812	26.01	26.36	25.77	26.57	23.77	26.12	27.12	27.02	27.06	27.19	25.16
813	26.01	26.36	25.71	26.63	23.66	26.06	27.12	26.96	27.06	27.13	25.16
814	26.01	26.42	25.71	26.52	23.66	26.01	27.06	27.03	27.11	27.13	25.1
815	26.01	26.36	25.77	26.57	23.49	26.06	27.12	26.9	27.11	27.13	25.1
816	26.01	26.36	25.77	26.57	23.6	25.95	27.06	26.8	27.06	27.02	25.16
817	26.01	26.36	25.71	26.57	23.66	26.06	27.06	26.79	27.06	27.23	24.99
818	25.95	26.36	25.71	26.52	23.54	25.95	27.01	26.69	27.06	27.02	25.05
819	25.95	26.42	25.71	26.57	23.52	26.01	27.06	26.63	27.11	27.08	25.15
820	25.95	26.30	25.71	26.52	23.6	26.01	26.89	26.86	27.06	27.08	25.09
821	25.95	26.30	25.66	26.57	23.64	25.95	27.01	26.79	27.06	27.13	24.97
822	25.95	26.36	25.66	26.52	23.49	26.01	26.95	26.84	27.00	27.02	25.03
823	25.89	26.30	25.71	26.52	23.59	25.89	26.95	26.74	27.00	27.02	25.03
824	25.83	26.36	25.66	26.57	23.76	25.95	26.95	26.5	27.00	27.08	25.03
825	25.95	26.30	25.66	26.52	23.82	26.01	26.89	26.69	26.94	27.02	25.03
826	25.89	26.30	25.66	26.52	23.59	25.89	26.83	26.97	26.94	26.96	24.92
827	25.89	26.30	25.60	26.46	23.64	25.89	26.83	26.63	26.88	27.02	24.85
828	25.89	26.19	25.66	26.52	23.59	25.95	26.89	26.63	26.94	26.96	24.97
829	25.89	26.25	25.66	26.46	23.52	25.95	26.83	26.57	26.94	26.96	24.92
830	25.89	26.19	25.66	26.40	23.52	25.89	26.77	26.57	26.94	26.96	24.92
831	25.83	26.30	25.66	26.46	23.56	25.95	26.83	26.57	26.88	27.02	25.01
832	25.89	26.30	25.66	26.46	23.73	25.89	26.83	26.59	26.88	27.02	24.89
833	25.83	26.25	25.66	26.46	23.5	25.83	26.77	26.69	26.88	26.96	24.89
834	25.89	26.25	25.66	26.46	23.73	25.89	26.77	26.76	26.88	26.96	24.89
835	25.83	26.25	25.66	26.46	23.33	25.89	26.77	26.47	26.88	26.96	24.93
836	25.83	26.19	25.53	26.40	23.5	25.83	26.72	26.34	26.81	26.9	24.83
837	25.83	26.12	25.60	26.40	23.5	25.83	26.72	26.53	26.88	26.9	24.93
838	25.83	26.12	25.53	26.33	23.45	25.78	26.65	26.47	26.81	26.9	24.93
839	25.78	26.19	25.66	26.28	23.45	25.83	26.65	26.47	26.81	26.9	24.87
840	25.83	26.12	25.60	26.33	23.62	25.78	26.65	26.34	26.81	26.96	24.82
841	25.78	26.12	25.53	26.33	23.33	25.83	26.72	26.7	26.81	26.84	24.82
842	25.72	26.12	25.47	26.28	23.33	25.78	26.65	26.29	26.81	26.9	24.82
843	25.78	26.12	25.53	26.33	23.49	25.83	26.65	26.34	26.81	26.9	24.82
844	25.83	26.06	25.47	26.28	23.49	25.83	26.65	26.4	26.77	26.96	24.76
845	25.72	26.06	25.42	26.28	23.6	25.78	26.59	26.34	26.77	26.9	24.76
846	25.66	26.06	25.47	26.22	23.3	25.78	26.53	26.4	26.77	26.9	24.82
847	25.72	26.06	25.53	26.28	23.46	25.83	26.48	26.34	26.64	26.9	24.69
848	25.66	26.01	25.42	26.28	23.43	25.72	26.59	26.17	26.77	26.9	24.63
849	25.66	26.06	25.36	26.22	23.59	25.66	26.48	26.34	26.64	26.84	24.69
850	25.66	26.01	25.42	26.28	23.52	25.72	26.53	26.13	26.70	26.79	24.63
851	25.66	26.01	25.42	26.22	23.46	25.72	26.48	26.29	26.70	26.84	24.63
852	25.66	25.95	25.42	26.16	23.52	25.60	26.48	26.13	26.54	26.74	24.63

853	25.66	25.95	25.36	26.22	23.52	25.66	26.53	26.34	26.70	26.8	24.73
854	25.60	25.89	25.36	26.16	23.4	25.66	26.48	26.3	26.54	26.69	24.63
855	25.55	26.01	25.36	26.16	23.35	25.66	26.53	26.13	26.64	26.74	24.62
856	25.60	25.95	25.36	26.16	23.4	25.66	26.48	26.24	26.48	26.69	24.62
857	25.55	25.95	25.42	26.10	23.29	25.60	26.42	26.01	26.54	26.74	24.62
858	25.60	25.89	25.42	26.04	23.52	25.66	26.42	26.3	26.54	26.63	24.56
859	25.60	25.89	25.36	26.10	23.35	25.66	26.42	26.01	26.54	26.8	24.56
860	25.66	25.89	25.30	25.99	23.17	25.60	26.36	26.13	26.48	26.53	24.45
861	25.55	25.89	25.30	26.04	23.46	25.55	26.36	26.24	26.48	26.74	24.56
862	25.55	25.89	25.30	26.04	23.23	25.60	26.36	26.24	26.48	26.59	24.56
863	25.48	25.89	25.30	26.10	23.23	25.55	26.36	26.07	26.54	26.59	24.59
864	25.55	25.83	25.24	26.04	23.35	25.48	26.36	26.13	26.48	26.64	24.5
865	25.55	25.83	25.30	26.04	23.39	25.55	26.42	25.9	26.27	26.64	24.39
866	25.48	25.89	25.24	26.04	23.35	25.48	26.36	26.3	26.33	26.64	24.45
867	25.48	25.83	25.24	25.99	23.45	25.55	26.36	26.13	26.38	26.53	24.48
868	25.55	25.83	25.24	26.04	23.26	25.55	26.36	25.91	26.38	26.59	24.45
869	25.42	25.83	25.24	25.99	23.33	25.60	26.30	26.01	26.27	26.59	24.42
870	25.48	25.83	25.24	25.99	23.15	25.60	26.26	25.91	26.33	26.53	24.48
871	25.36	25.83	25.24	26.04	23.15	25.48	26.30	26.03	26.33	26.53	24.36
872	25.48	25.77	25.24	25.99	23.09	25.48	26.20	25.97	26.38	26.53	24.36
873	25.48	25.83	25.19	25.93	23.26	25.48	26.30	25.86	26.27	26.53	24.36
874	25.48	25.83	25.19	25.93	23.22	25.48	26.26	25.81	26.38	26.53	24.36
875	25.48	25.77	25.19	25.93	23.25	25.48	26.26	26.33	26.33	26.46	24.3
876	25.48	25.77	25.19	25.99	23.09	25.48	26.20	25.91	26.33	26.53	24.36
877	25.36	25.72	25.19	26.04	23.09	25.55	26.15	25.64	26.27	26.53	24.36
878	25.42	25.77	25.19	25.99	23.33	25.42	26.20	25.81	26.27	26.46	24.36
879	25.48	25.77	25.19	25.99	23.31	25.48	26.15	25.81	26.21	26.4	24.36
880	25.42	25.77	25.19	25.99	23.03	25.48	26.15	25.91	26.33	26.53	24.3
881	25.36	25.77	25.19	25.93	23.42	25.48	26.09	25.91	26.21	26.46	24.25
882	25.36	25.77	25.13	25.93	23.31	25.36	26.20	25.7	26.15	26.46	24.3
883	25.42	25.72	25.19	25.93	23.19	25.48	26.05	25.74	26.21	26.53	24.36
884	25.36	25.77	25.07	25.93	23.31	25.42	25.99	25.64	26.27	26.4	24.3
885	25.36	25.77	25.07	25.87	23.25	25.48	26.05	25.8	26.27	26.46	24.25
886	25.42	25.72	25.19	25.93	23.19	25.48	25.99	25.7	26.21	26.46	24.13
887	25.36	25.72	25.13	25.80	23.31	25.42	25.99	25.5	26.10	26.4	24.19
888	25.36	25.77	25.13	25.87	23.19	25.42	26.05	25.74	26.21	26.3	24.25
889	25.36	25.72	25.13	25.87	23.13	25.32	25.99	25.8	26.15	26.4	24.13
890	25.36	25.72	25.07	25.87	23.25	25.36	25.99	25.4	26.15	26.3	24.19
891	25.36	25.72	25.07	25.87	23.25	25.32	25.99	25.8	26.10	26.46	24.25
892	25.36	25.72	25.07	25.87	23.08	25.36	25.99	25.87	26.15	26.3	24.19
893	25.26	25.67	24.97	25.77	23.13	25.32	25.99	25.74	26.15	26.19	24.19
894	25.36	25.72	25.07	25.87	23.13	25.32	25.99	25.53	26.10	26.25	24.02
895	25.20	25.62	24.97	25.77	23.08	25.38	25.92	25.63	26.04	26.25	24.02
896	25.36	25.72	25.07	25.87	23.19	25.32	25.92	25.57	26.10	26.3	24.07
897	25.26	25.67	25.03	25.83	23.02	25.32	25.92	25.63	25.97	26.3	24.11
898	25.20	25.62	24.97	25.77	23.13	25.38	25.86	25.46	25.97	26.25	23.89
899	25.26	25.62	24.97	25.70	23.31	25.26	25.92	25.5	26.07	26.3	24.16
900	25.20	25.62	24.97	25.70	23.08	25.32	25.92	25.4	25.97	26.25	23.95
901	25.26	25.67	24.97	25.70	23.13	25.32	25.86	25.63	26.07	26.25	24.11

902	25.26	25.62	25.03	25.77	22.96	25.22	25.86	25.46	25.97	26.25	24.11
903	25.26	25.62	24.97	25.70	23.13	25.16	25.92	25.53	26.01	26.25	24.05
904	25.26	25.62	24.97	25.70	22.96	25.28	25.86	25.4	25.95	26.25	23.99
905	25.20	25.62	24.97	25.77	23.02	25.16	25.81	25.53	26.01	26.3	23.99
906	25.22	25.52	24.87	25.60	23.08	25.22	25.92	25.4	26.01	26.25	24.05
907	25.16	25.46	24.80	25.60	23.02	25.16	25.81	25.28	25.95	26.19	23.99
908	25.16	25.52	24.80	25.60	23.02	25.10	25.81	25.34	25.90	26.25	23.99
909	25.10	25.52	24.87	25.60	22.93	25.10	25.75	25.17	25.90	26.25	23.99
910	25.16	25.52	24.87	25.60	22.9	25.22	25.81	25.4	25.90	26.03	23.99
911	25.10	25.46	24.93	25.60	22.93	25.16	25.75	25.28	25.90	26.15	23.93
912	25.10	25.46	24.87	25.67	22.9	25.22	25.75	25.46	25.90	26.09	23.99
913	25.05	25.52	24.87	25.60	23.05	25.22	25.75	25.17	25.94	26.09	23.99
914	25.05	25.46	24.80	25.60	22.93	25.22	25.69	25.46	25.90	26.05	23.88
915	25.10	25.46	24.80	25.67	23.12	25.22	25.69	25.53	25.94	26.15	23.82
916	25.10	25.46	24.87	25.60	22.88	25.16	25.63	25.28	25.78	26.05	23.82
917	25.16	25.46	24.87	25.56	23.05	25.16	25.73	25.34	25.94	26.09	23.82
918	25.05	25.52	24.80	25.60	22.88	25.10	25.69	25.46	25.84	26.05	23.88
919	25.05	25.52	24.80	25.60	23.05	25.16	25.73	25.28	25.82	25.99	23.82
920	25.10	25.52	24.80	25.56	22.88	25.10	25.57	25.23	25.82	26.05	23.88
921	25.05	25.46	24.74	25.56	22.88	25.10	25.73	25.28	25.82	26.05	23.82
922	25.05	25.46	24.80	25.56	23.05	25.05	25.67	25.28	25.82	26.05	23.82
923	25.05	25.46	24.80	25.49	22.82	25.16	25.62	25.17	25.71	26.05	23.76
924	25.10	25.46	24.80	25.56	22.93	25.10	25.62	25.23	25.77	25.99	23.76
925	25.05	25.46	24.74	25.49	22.93	25.10	25.67	25.4	25.77	25.99	23.76
926	25.05	25.40	24.80	25.56	22.82	25.16	25.56	25.01	25.64	25.99	23.82
927	24.99	25.40	24.80	25.49	22.88	24.99	25.62	25.01	25.71	25.93	23.76
928	25.05	25.40	24.74	25.49	22.82	24.99	25.56	24.94	25.64	25.93	23.7
929	25.05	25.46	24.80	25.56	22.93	25.05	25.62	25.11	25.71	25.99	23.76
930	24.99	25.40	24.74	25.43	22.93	25.05	25.56	25.13	25.71	25.87	23.7
931	24.99	25.40	24.74	25.43	22.82	24.99	25.60	25.18	25.64	25.93	23.63
932	24.99	25.33	24.74	25.43	22.93	24.99	25.50	24.94	25.58	25.99	23.7
933	24.93	25.40	24.69	25.37	22.88	24.93	25.60	25.07	25.64	25.99	23.63
934	24.99	25.40	24.69	25.37	22.88	24.99	25.43	25.24	25.53	25.93	23.7
935	24.87	25.33	24.63	25.37	22.76	24.99	25.53	25.13	25.58	25.99	23.76
936	24.93	25.33	24.63	25.37	22.82	24.92	25.38	24.9	25.58	25.99	23.7
937	24.87	25.33	24.63	25.37	22.88	24.99	25.60	24.9	25.53	25.99	23.63
938	24.87	25.33	24.63	25.32	22.76	25.09	25.53	24.9	25.53	25.99	23.63
939	24.87	25.28	24.63	25.32	22.82	24.93	25.42	24.94	25.57	25.99	23.7
940	24.97	25.38	24.67	25.42	22.7	25.03	25.48	25.13	25.57	25.83	23.58
941	24.82	25.28	24.57	25.32	22.88	24.97	25.42	24.77	25.51	25.93	23.58
942	24.97	25.38	24.67	25.36	22.88	24.92	25.48	25.07	25.51	25.77	23.58
943	24.75	25.22	24.63	25.32	22.7	24.97	25.42	24.9	25.57	25.89	23.63
944	24.92	25.32	24.61	25.36	22.7	24.85	25.42	24.77	25.51	25.77	23.58
945	24.92	25.32	24.61	25.30	22.82	24.92	25.48	24.9	25.45	25.93	23.58
946	24.79	25.26	24.56	25.30	22.7	24.92	25.36	24.54	25.39	25.77	23.58
947	24.85	25.26	24.61	25.36	22.82	24.85	25.42	24.71	25.45	25.77	23.52
948	24.85	25.26	24.56	25.30	22.82	24.85	25.36	24.54	25.45	25.66	23.58
949	24.85	25.26	24.56	25.30	22.76	24.85	25.36	24.83	25.51	25.87	23.58
950	24.85	25.26	24.56	25.24	22.76	24.89	25.25	24.77	25.39	25.87	23.58

951	24.92	25.20	24.56	25.30	22.65	24.79	25.30	24.71	25.39	25.82	23.58
952	24.73	25.32	24.50	25.24	22.82	24.95	25.30	24.66	25.39	25.82	23.58
953	24.79	25.20	24.50	25.30	22.88	24.85	25.25	25.01	25.39	25.87	23.58
954	24.89	25.30	24.60	25.40	22.88	24.95	25.19	24.54	25.34	25.72	23.58
955	24.79	25.20	24.56	25.17	22.76	24.79	25.19	24.77	25.44	25.76	23.52
956	24.89	25.30	24.66	25.34	22.7	24.89	25.19	24.8	25.34	25.76	23.46
957	24.68	25.20	24.50	25.24	22.7	24.89	25.29	24.77	25.38	25.82	23.52
958	24.89	25.36	24.60	25.27	22.7	24.83	25.29	24.61	25.31	25.6	23.52
959	24.79	25.20	24.50	25.17	22.82	24.89	25.23	24.77	25.38	25.7	23.52
960	24.83	25.30	24.54	25.23	22.76	24.83	25.17	24.9	25.31	25.7	23.46
961	24.78	25.30	24.54	25.23	22.82	24.78	25.23	25.01	25.31	25.76	23.46
962	24.83	25.25	24.60	25.23	22.82	24.83	25.23	24.71	25.31	25.7	23.46
963	24.78	25.19	24.54	25.27	22.7	24.83	25.17	24.83	25.41	25.63	23.46
964	24.78	25.25	24.54	25.16	22.93	24.72	25.10	24.66	25.25	25.7	23.35
965	24.83	25.25	24.54	25.23	22.76	24.78	25.17	24.66	25.30	25.7	23.52
966	24.78	25.13	24.54	25.16	22.82	24.72	25.10	24.77	25.24	25.7	23.3
967	24.78	25.25	24.47	25.23	22.65	24.72	25.17	24.66	25.24	25.58	23.46
968	24.78	25.13	24.47	25.16	22.65	24.78	25.10	24.66	25.24	25.7	23.36
969	24.78	25.13	24.47	25.10	22.65	24.72	25.10	24.6	25.24	25.58	23.36
970	24.72	25.13	24.36	25.16	22.65	24.78	24.99	24.77	25.12	25.58	23.36
971	24.66	25.13	24.36	25.10	22.76	24.72	25.10	24.6	25.18	25.58	23.25
972	24.66	25.07	24.36	25.10	22.76	24.72	25.05	24.42	25.12	25.63	23.3
973	24.66	25.07	24.36	25.04	22.7	24.72	25.15	24.54	25.12	25.58	23.36
974	24.66	25.07	24.30	25.04	22.7	24.66	25.05	24.83	25.07	25.58	23.3
975	24.60	25.00	24.36	25.04	22.76	24.66	25.03	24.54	25.12	25.52	23.25
976	24.60	25.07	24.36	24.99	22.76	24.76	25.09	24.54	25.07	25.52	23.3
977	24.60	25.07	24.36	25.04	22.76	24.70	25.03	24.42	25.07	25.52	23.3
978	24.54	25.07	24.30	25.04	22.66	24.70	25.03	24.54	25.07	25.52	23.3
979	24.60	25.07	24.30	24.93	22.7	24.70	25.03	24.54	25.11	25.52	23.3
980	24.64	24.99	24.34	25.09	22.6	24.76	24.97	24.48	25.01	25.46	23.3
981	24.59	25.05	24.34	25.09	22.72	24.64	25.07	24.37	25.05	25.46	23.3
982	24.59	25.10	24.34	25.03	22.55	24.59	24.92	24.37	25.11	25.4	23.3
983	24.59	25.10	24.40	25.03	22.66	24.64	25.02	24.42	25.11	25.4	23.13
984	24.59	25.05	24.28	25.03	22.6	24.64	25.02	24.37	25.05	25.52	23.25
985	24.59	24.99	24.28	25.03	22.72	24.64	24.96	24.37	25.05	25.46	23.3
986	24.53	25.05	24.28	24.97	22.66	24.59	24.96	24.54	25.05	25.4	23.25
987	24.46	24.99	24.28	25.03	22.66	24.46	24.96	24.42	24.99	25.46	23.25
988	24.46	24.99	24.28	25.03	22.55	24.59	24.90	24.24	24.99	25.4	23.19
989	24.53	24.93	24.28	24.91	22.72	24.53	24.96	24.6	24.92	25.4	23.13
990	24.46	24.93	24.28	24.86	22.6	24.53	24.96	24.37	24.99	25.4	23.25
991	24.46	24.99	24.17	24.91	22.55	24.59	24.84	24.37	24.87	25.4	23.13
992	24.46	24.93	24.17	24.86	22.6	24.56	24.84	24.48	24.87	25.4	23.19
993	24.46	24.93	24.17	24.91	22.72	24.46	24.84	24.48	24.81	25.4	23.23
994	24.40	24.87	24.17	24.86	22.66	24.63	24.84	24.24	24.81	25.34	23.29
995	24.40	24.87	24.17	24.80	22.66	24.56	24.79	23.95	24.97	25.4	23.29
996	24.45	25.03	24.27	24.96	22.6	24.50	24.84	24.3	24.87	25.4	23.23
997	24.35	24.87	24.17	24.80	22.6	24.50	24.83	24.13	24.85	25.4	23.23
998	24.50	24.97	24.21	24.83	22.55	24.50	24.79	24.13	24.91	25.4	23.12
999	24.45	24.97	24.27	24.90	22.6	24.50	24.89	24.18	24.85	25.4	23.23

1000	24.39	24.92	24.14	24.90	22.66	24.60	24.83	24.18	24.89	25.4	23.17
1001	24.39	24.97	24.21	24.83	22.55	24.50	24.76	24.24	24.84	25.4	23.17
1002	24.39	24.92	24.14	24.90	22.6	24.55	24.76	24.18	24.89	25.4	23.17
1003	24.39	24.86	24.14	24.77	22.55	24.55	24.83	24.13	24.89	25.34	23.12
1004	24.55	24.96	24.24	24.93	22.6	24.55	24.76	24.18	24.78	25.34	23.12
1005	24.39	24.86	24.10	24.77	22.59	24.43	24.76	24.13	24.84	25.4	23.12
1006	24.49	24.96	24.20	24.87	22.59	24.49	24.76	24.13	24.78	25.29	23.12
1007	24.43	24.90	24.20	24.87	22.59	24.49	24.76	24.24	24.72	25.29	23.12
1008	24.43	24.90	24.13	24.81	22.76	24.43	24.70	24.18	24.72	25.24	23.05
1009	24.37	24.96	24.13	24.81	22.7	24.43	24.76	23.95	24.72	25.34	22.99
1010	24.37	24.90	24.20	24.87	22.65	24.37	24.64	24.13	24.76	25.24	23.05
1011	24.37	24.84	24.07	24.76	22.59	24.43	24.70	24.01	24.76	25.29	22.99
1012	24.37	24.84	24.07	24.76	22.59	24.43	24.64	24.18	24.66	25.19	22.99
1013	24.32	24.84	24.07	24.81	22.65	24.37	24.80	24.13	24.82	25.29	23.05
1014	24.26	24.73	24.07	24.76	22.53	24.43	24.64	24.18	24.76	25.24	22.99
1015	24.32	24.79	24.01	24.70	22.59	24.32	24.74	23.84	24.76	25.29	22.99
1016	24.26	24.79	24.01	24.76	22.59	24.47	24.69	24.13	24.76	25.24	22.93
1017	24.32	24.73	23.96	24.76	22.7	24.26	24.69	24.07	24.76	25.19	22.97
1018	24.26	24.73	23.96	24.64	22.46	24.42	24.73	23.95	24.64	25.19	22.93
1019	24.26	24.79	24.01	24.64	22.46	24.36	24.67	23.9	24.64	25.17	23.03
1020	24.30	24.89	24.06	24.80	22.59	24.42	24.67	23.71	24.71	25.19	22.87
1021	24.20	24.73	24.01	24.70	22.46	24.36	24.73	24.13	24.74	25.13	22.97
1022	24.30	24.83	24.06	24.68	22.53	24.36	24.67	24.01	24.64	25.13	22.87
1023	24.30	24.76	24.00	24.68	22.46	24.30	24.61	23.9	24.68	25.13	22.97
1024	24.23	24.76	24.06	24.68	22.65	24.36	24.61	24.07	24.74	25.13	22.92
1025	24.30	24.76	24.06	24.68	22.46	24.36	24.61	24.07	24.74	25.19	22.92
1026	24.23	24.76	24.06	24.63	22.41	24.36	24.56	23.9	24.68	25.13	22.86
1027	24.23	24.83	24.00	24.63	22.46	24.23	24.56	23.95	24.62	25.07	22.8
1028	24.18	24.76	24.00	24.63	22.53	24.30	24.66	23.9	24.74	25.13	22.92
1029	24.23	24.76	24.00	24.63	22.62	24.30	24.66	23.95	24.62	25.07	23.03
1030	24.18	24.70	24.00	24.68	22.53	24.18	24.56	23.9	24.68	25.13	22.92
1031	24.12	24.70	24.00	24.57	22.45	24.23	24.53	23.95	24.57	25.07	22.97
1032	24.23	24.70	24.00	24.57	22.41	24.33	24.60	23.95	24.52	24.97	22.86
1033	24.18	24.70	24.00	24.57	22.51	24.18	24.60	23.95	24.68	25.07	22.86
1034	24.12	24.64	24.00	24.57	22.29	24.33	24.53	23.48	24.62	24.97	22.8
1035	24.12	24.64	23.94	24.57	22.45	24.28	24.66	23.77	24.62	25.07	23.02
1036	24.16	24.74	24.04	24.67	22.56	24.28	24.60	23.9	24.62	25.07	22.86
1037	24.06	24.59	23.94	24.63	22.56	24.32	24.53	23.9	24.57	25	22.86
1038	24.16	24.69	24.04	24.67	22.45	24.38	24.47	23.9	24.35	25	22.8
1039	24.16	24.69	23.92	24.60	22.56	24.26	24.57	23.84	24.49	25	22.89
1040	24.10	24.63	23.92	24.49	22.56	24.32	24.53	23.9	24.48	24.97	22.92
1041	24.20	24.79	24.08	24.59	22.56	24.20	24.57	23.9	24.42	25	22.89
1042	24.20	24.73	24.02	24.59	22.51	24.20	24.57	23.9	24.45	25.07	22.83
1043	24.20	24.79	24.02	24.59	22.56	24.20	24.46	23.71	24.45	25.07	22.83
1044	24.20	24.73	23.97	24.59	22.51	24.20	24.57	23.9	24.45	25.07	22.73
1045	24.20	24.67	23.90	24.59	22.56	24.20	24.57	23.71	24.52	25	22.83
1046	24.20	24.67	23.97	24.53	22.51	24.20	24.57	23.77	24.52	24.96	22.83
1047	24.14	24.67	23.84	24.53	22.61	24.30	24.57	23.66	24.58	24.96	22.83
1048	24.09	24.61	23.90	24.53	22.39	24.30	24.52	23.84	24.52	25	22.78

1049	24.09	24.67	23.90	24.47	22.51	24.20	24.52	23.84	24.52	24.96	22.78
1050	24.14	24.61	23.90	24.47	22.39	24.30	24.36	23.77	24.45	24.96	22.78
1051	24.19	24.66	24.00	24.57	22.49	24.24	24.57	23.84	24.48	25.06	22.78
1052	24.24	24.66	23.94	24.57	22.33	24.30	24.52	23.84	24.42	24.96	22.72
1053	24.09	24.61	23.84	24.47	22.36	24.19	24.46	23.77	24.48	24.96	22.72
1054	24.24	24.71	24.00	24.51	22.55	24.19	24.46	23.71	24.42	24.96	22.78
1055	24.19	24.66	23.88	24.51	22.43	24.24	24.46	23.66	24.35	24.83	22.72
1056	24.19	24.66	24.00	24.51	22.39	24.19	24.18	23.66	24.42	24.83	22.72
1057	24.13	24.60	23.94	24.46	22.43	24.19	24.38	23.84	24.48	24.93	22.72
1058	24.19	24.60	23.94	24.51	22.36	24.34	24.37	23.77	24.53	24.89	22.6
1059	24.13	24.66	23.88	24.46	22.36	24.24	24.24	23.31	24.38	24.89	22.66
1060	24.19	24.53	23.88	24.46	22.36	24.29	24.34	23.95	24.38	24.83	22.6
1061	24.13	24.66	23.88	24.46	22.36	24.29	24.34	23.76	24.38	24.83	22.66
1062	24.23	24.70	23.98	24.50	22.36	24.34	24.34	23.54	24.38	24.83	22.66
1063	24.07	24.53	23.83	24.46	22.36	24.29	24.40	23.81	24.38	24.89	22.66
1064	24.23	24.63	23.98	24.56	22.36	24.29	24.40	23.81	24.32	24.83	22.6
1065	24.23	24.70	23.87	24.61	22.36	24.29	24.34	23.47	24.28	24.83	22.6
1066	24.17	24.63	23.93	24.56	22.36	24.29	24.40	23.47	24.28	24.89	22.66
1067	24.17	24.63	23.98	24.50	22.43	24.23	24.34	23.41	24.33	24.89	22.66
1068	24.23	24.63	23.93	24.50	22.32	24.17	24.40	23.76	24.28	24.89	22.55
1069	24.17	24.63	23.93	24.44	22.43	24.13	24.30	23.81	24.28	24.77	22.6
1070	24.23	24.63	23.93	24.44	22.43	24.23	24.19	23.81	24.28	24.77	22.55
1071	24.10	24.63	23.87	24.50	22.32	24.17	24.30	23.64	24.28	24.77	22.6
1072	24.17	24.57	23.93	24.44	22.36	24.17	24.37	23.64	24.28	24.77	22.55
1073	24.00	24.53	23.77	24.34	22.32	24.17	24.30	23.64	24.28	24.77	22.55
1074	24.17	24.57	23.93	24.50	22.43	24.23	24.30	23.64	24.33	24.83	22.49
1075	24.17	24.57	23.87	24.44	22.32	23.89	24.37	23.64	24.33	24.77	22.55
1076	24.10	24.63	23.81	24.44	22.19	23.92	24.30	23.58	24.33	24.72	22.55
1077	24.10	24.57	23.81	24.38	22.32	23.96	24.20	23.52	24.28	24.72	22.6
1078	24.17	24.57	23.81	24.44	22.32	23.96	24.20	23.47	24.33	24.77	22.55
1079	23.83	24.36	23.71	24.38	22.32	24.00	24.20	23.28	24.18	24.77	22.43
1080	23.86	24.50	23.80	24.33	22.19	24.06	24.27	23.41	24.28	24.67	22.49
1081	23.84	24.54	23.84	24.32	22.13	24.00	24.27	23.87	24.28	24.73	22.43
1082	23.84	24.48	23.71	24.28	22.13	24.00	24.27	23.64	24.33	24.67	22.36
1083	23.94	24.58	23.76	24.26	22.19	24.00	24.10	23.76	24.18	24.67	22.49
1084	23.94	24.53	23.76	24.24	22.25	24.00	24.17	23.52	24.28	24.62	22.49
1085	23.94	24.58	23.76	24.26	22.13	24.06	24.23	23.47	24.23	24.83	22.36
1086	24.00	24.58	23.70	24.29	22.25	24.17	24.23	23.35	24.23	24.62	22.43
1087	24.00	24.53	23.81	24.27	22.19	24.12	24.23	23.47	24.18	24.72	22.49
1088	24.00	24.53	23.81	24.27	22.25	24.02	24.17	23.76	24.18	24.62	22.43
1089	24.00	24.58	23.76	24.29	22.13	24.07	24.17	23.35	24.23	24.56	22.52
1090	24.00	24.58	23.81	24.29	22.13	24.02	24.23	23.62	24.18	24.56	22.36
1091	24.00	24.58	23.81	24.29	22.13	24.02	24.17	23.57	24.18	24.62	22.43
1092	23.96	24.48	23.71	24.22	22.08	24.07	24.17	23.47	24.18	24.62	22.46
1093	23.96	24.54	23.71	24.25	22.25	24.02	24.23	23.62	24.23	24.62	22.46
1094	23.96	24.54	23.66	24.25	22.19	24.07	24.23	23.8	24.18	24.56	22.46
1095	24.02	24.48	23.71	24.25	22.13	24.02	24.28	23.38	24.23	24.62	22.46
1096	23.96	24.48	23.77	24.22	22.02	24.03	24.23	23.51	24.18	24.62	22.43
1097	23.96	24.54	23.71	24.25	22.08	23.97	24.13	23.51	24.08	24.56	22.41

1098	24.02	24.60	23.77	24.31	22.19	24.03	24.23	23.62	24.12	24.56	22.46
1099	23.96	24.60	23.77	24.28	22.19	24.03	24.17	23.68	24.08	24.62	22.35
1100	23.92	24.44	23.67	24.18	22.08	24.03	24.23	23.57	24.18	24.56	22.41
1101	23.92	24.44	23.67	24.18	22.18	24.03	24.18	23.33	24.02	24.56	22.35
1102	23.92	24.50	23.67	24.21	22.08	23.99	24.23	23.57	24.18	24.62	22.32
1103	23.92	24.50	23.67	24.21	22.08	23.93	24.07	23.38	24.08	24.62	22.35
1104	23.97	24.50	23.67	24.24	22.12	23.87	24.07	23.45	24.18	24.56	22.46
1105	23.97	24.50	23.74	24.24	22.18	23.87	24.13	23.68	24.12	24.56	22.41
1106	23.87	24.40	23.57	24.14	22.12	23.93	24.13	23.27	24.12	24.62	22.35
1107	23.87	24.40	23.57	24.14	22.23	23.93	24.07	23.51	24.05	24.56	22.41
1108	23.76	24.40	23.64	24.08	22.08	23.93	24.13	23.57	24.05	24.4	22.35
1109	23.87	24.40	23.64	24.14	22.18	23.93	24.13	23.45	24.05	24.5	22.35
1110	23.76	24.40	23.57	24.08	22.29	24.06	24.07	23.38	23.99	24.46	22.35
1111	23.87	24.40	23.57	24.14	22.23	23.93	24.13	23.57	23.99	24.46	22.35
1112	23.87	24.40	23.70	24.14	22.12	23.93	24.13	23.57	24.12	24.46	22.29
1113	23.93	24.40	23.70	24.17	22.18	23.99	24.13	23.55	23.99	24.52	22.23
1114	23.87	24.40	23.64	24.14	21.96	23.93	24.07	23.62	23.99	24.4	22.29
1115	23.82	24.40	23.64	24.11	22.06	23.99	23.97	23.45	23.99	24.46	22.23
1116	23.93	24.40	23.64	24.17	22.06	23.83	24.07	23.38	24.15	24.46	22.23
1117	23.87	24.40	23.64	24.14	22.12	23.99	23.97	23.33	24.15	24.46	22.29
1118	23.87	24.40	23.70	24.14	22.06	23.99	24.13	23.38	24.15	24.4	22.35
1119	23.87	24.40	23.70	24.14	22.12	23.87	23.97	23.33	24.09	24.4	22.23
1120	23.72	24.30	23.54	24.01	22.06	23.83	24.07	23.62	24.09	24.46	22.29
1121	23.93	24.40	23.70	24.17	22	23.93	23.97	23.62	24.04	24.4	22.23
1122	23.93	24.40	23.64	24.17	22.12	23.89	24.00	23.45	24.04	24.36	22.29
1123	23.82	24.40	23.75	24.11	22	23.83	24.13	23.38	24.04	24.3	22.29
1124	23.83	24.30	23.54	24.07	22.12	23.83	24.00	23.33	23.98	24.36	22.17
1125	23.87	24.40	23.75	24.14	22.06	23.83	24.00	23.33	24.04	24.3	22.23
1126	23.77	24.30	23.60	24.04	22.18	23.83	24.00	23.45	24.09	24.36	22.17
1127	23.83	24.36	23.54	24.10	22.06	23.89	23.94	23.51	24.04	24.3	22.17
1128	23.72	24.30	23.60	24.01	22.12	23.83	24.00	23.33	24.04	24.36	22.17
1129	23.77	24.30	23.60	24.04	22.12	23.83	24.00	23.27	23.98	24.36	22.23
1130	23.77	24.30	23.60	24.04	22.18	23.83	24.00	23.17	24.04	24.3	22.17
1131	23.77	24.30	23.65	24.04	22.06	23.83	24.00	23.38	23.98	24.3	22.17
1132	23.83	24.30	23.60	24.07	22.06	23.83	24.00	23.23	23.98	24.3	22.17
1133	23.83	24.30	23.60	24.07	22	23.89	24.00	23.17	24.04	24.3	22.23
1134	23.89	24.36	23.54	24.13	22.12	23.73	24.04	23.23	23.92	24.3	22.23
1135	23.83	24.30	23.60	24.07	22.06	23.89	23.99	23.23	23.92	24.3	22.17
1136	23.83	24.30	23.54	24.07	22.12	23.79	23.99	23.41	24.09	24.24	22.17
1137	23.83	24.42	23.60	24.13	22.06	23.89	24.04	23.11	23.98	24.27	22.17
1138	23.73	24.20	23.50	23.97	22	23.79	23.99	23.23	23.98	24.17	22.17
1139	23.83	24.30	23.54	24.07	22.18	23.83	24.04	23.11	23.98	24.17	22.17
1140	23.67	24.26	23.50	23.97	22	23.73	23.93	23.17	23.92	24.24	22.12
1141	23.83	24.30	23.60	24.07	21.95	23.83	23.99	23.23	23.92	24.27	22.12
1142	23.73	24.20	23.50	23.97	22.12	23.83	23.99	23.28	23.98	24.13	22.17
1143	23.77	24.36	23.60	24.07	22.12	23.83	23.93	23.28	23.94	24.27	22.17
1144	23.67	24.20	23.44	23.94	22	23.83	23.99	23.28	23.82	24.34	22.12
1145	23.77	24.30	23.60	24.04	22.06	23.77	23.93	23.28	23.88	24.27	22.12
1146	23.77	24.30	23.54	24.04	22	23.77	23.93	23.41	23.82	24.17	22.06

1147	23.83	24.30	23.54	24.07	22.06	23.77	23.99	23.35	23.88	24.23	22.17
1148	23.72	24.30	23.54	24.01	22	23.77	23.93	23.11	23.82	24.17	22.12
1149	23.72	24.30	23.60	24.01	22.06	23.77	23.87	23.35	23.82	24.13	22.12
1150	23.72	24.30	23.60	24.01	22	23.72	23.93	23.23	23.82	24.13	22.06
1151	23.72	24.24	23.54	23.98	21.95	23.77	23.87	23.11	23.78	24.23	22
1152	23.66	24.24	23.54	23.95	22	23.72	23.93	23.28	23.82	24.06	22.17
1153	23.72	24.30	23.54	24.01	22.12	23.87	23.93	22.94	23.78	24.13	22.06
1154	23.66	24.30	23.47	23.98	22.12	23.82	23.93	23.05	23.82	24.17	22.06
1155	23.66	24.24	23.41	23.95	22	23.82	23.93	23.28	23.78	24.17	22.12
1156	23.66	24.30	23.47	23.98	22.06	23.76	23.99	23.35	23.78	24.17	22.12
1157	23.82	24.34	23.51	24.08	21.95	23.82	23.99	23.28	23.72	24.06	22.12
1158	23.76	24.34	23.51	24.05	22	23.76	23.93	23.05	23.78	24.13	22.06
1159	23.76	24.34	23.57	24.05	22.12	23.87	23.93	23.11	23.78	24.13	22.12
1160	23.76	24.28	23.51	24.02	21.88	23.76	23.93	23.17	23.78	24.13	22.12
1161	23.76	24.40	23.51	24.08	22.12	23.70	23.77	23.11	23.78	24.17	22.06
1162	23.70	24.28	23.51	23.99	21.88	23.82	23.83	23.17	23.78	24.06	22
1163	23.76	24.28	23.51	24.02	22.06	23.76	23.89	23.17	23.72	24.17	22.06
1164	23.70	24.28	23.46	23.99	21.95	23.82	23.83	23.23	23.72	24.06	22.06
1165	23.70	24.28	23.46	23.99	22.06	23.82	23.83	23.23	23.78	24.13	22.12
1166	23.70	24.28	23.57	23.99	21.95	23.70	23.83	23.17	23.72	24.13	22
1167	23.76	24.28	23.51	24.02	22.06	23.70	23.83	22.88	23.72	24.13	22
1168	23.76	24.28	23.51	24.02	22	23.76	23.83	23.33	23.72	24.06	22
1169	23.70	24.34	23.46	24.02	21.88	23.76	23.67	23.1	23.68	24.06	22
1170	23.70	24.28	23.51	23.99	22	23.76	23.83	23.04	23.84	24.13	22
1171	23.70	24.28	23.46	23.99	21.88	23.70	23.79	23.04	23.72	24.06	22
1172	23.64	24.28	23.40	23.96	22	23.70	23.83	23.27	23.72	24.17	22.06
1173	23.76	24.28	23.46	24.02	21.88	23.70	23.73	23.15	23.72	24.06	22.06
1174	23.70	24.28	23.51	23.99	22	23.76	23.73	23.04	23.78	24.13	22.12
1175	23.76	24.28	23.46	24.02	21.88	23.70	23.79	23.1	23.78	24.06	22.06
1176	23.70	24.28	23.40	23.99	22	23.82	23.73	23.04	23.72	24	22.12
1177	23.70	24.28	23.51	23.99	21.95	23.82	23.73	23.1	23.62	24.13	22.06
1178	23.70	24.23	23.46	23.97	22	23.76	23.79	23.04	23.62	24.06	22.02
1179	23.70	24.23	23.51	23.97	22	23.76	23.79	23.27	23.62	24.13	22.02
1180	23.70	24.28	23.46	23.99	21.95	23.72	23.79	23.1	23.68	24.13	22.09
1181	23.76	24.28	23.46	24.02	21.88	23.66	23.67	23.14	23.68	24.06	22.12
1182	23.70	24.28	23.51	23.99	21.95	23.66	23.73	23.15	23.62	23.96	22.02
1183	23.64	24.23	23.46	23.94	21.95	23.66	23.73	23.1	23.62	24.06	22.07
1184	23.60	24.18	23.41	23.89	21.82	23.77	23.79	23.15	23.62	24.03	22.03
1185	23.60	24.18	23.41	23.89	21.95	23.66	23.79	23.14	23.62	24.06	22
1186	23.66	24.18	23.36	23.92	22.06	23.66	23.73	23.15	23.62	24.06	22
1187	23.66	24.18	23.36	23.92	21.88	23.66	23.69	23.08	23.56	23.9	22.17
1188	23.66	24.18	23.36	23.92	21.88	23.62	23.73	23.08	23.62	23.96	21.91
1189	23.60	24.13	23.36	23.87	22.06	23.66	23.79	23.02	23.62	23.96	21.97
1190	23.66	24.18	23.36	23.92	22.02	23.56	23.73	23.1	23.56	23.96	22.1
1191	23.60	24.18	23.41	23.89	22.02	23.66	23.79	23.14	23.56	24.13	22.1
1192	23.37	24.08	23.26	23.73	22.09	23.62	23.79	23.02	23.62	23.96	22.03
1193	23.60	24.24	23.41	23.92	21.93	23.62	23.73	22.95	23.56	23.96	22
1194	23.50	24.14	23.26	23.82	22.02	23.62	23.73	23.04	23.61	23.96	22
1195	23.54	24.24	23.41	23.89	22.13	23.62	23.63	22.95	23.56	24.06	22

1196	23.56	24.08	23.37	23.82	21.92	23.56	23.63	23.15	23.66	23.9	21.9
1197	23.50	24.14	23.37	23.82	21.93	23.62	23.69	22.84	23.56	23.9	22.01
1198	23.50	24.14	23.37	23.82	22.06	23.62	23.57	22.85	23.66	23.96	21.95
1199	23.56	24.14	23.31	23.85	22.12	23.56	23.63	23.2	23.62	23.9	21.95
1200	23.56	24.14	23.31	23.85	21.92	23.62	23.63	22.8	23.66	23.96	21.95
1201	23.56	24.14	23.31	23.85	21.92	23.56	23.63	22.95	23.66	23.9	21.95
1202	23.62	24.20	23.37	23.91	21.8	23.62	23.63	22.98	23.66	23.96	21.95
1203	23.50	24.08	23.31	23.79	21.97	23.62	23.69	22.92	23.61	23.96	22.01
1204	23.50	24.14	23.37	23.82	22.03	23.56	23.63	22.8	23.55	23.96	21.91
1205	23.56	24.08	23.31	23.82	21.94	23.56	23.57	22.9	23.61	23.9	21.91
1206	23.56	24.14	23.31	23.85	21.94	23.57	23.63	22.98	23.61	23.96	21.91
1207	23.50	24.08	23.37	23.79	22	23.50	23.63	22.9	23.66	23.96	21.97
1208	23.50	24.08	23.37	23.79	21.78	23.62	23.63	22.9	23.55	23.96	21.97
1209	23.56	24.14	23.37	23.85	21.96	23.62	23.63	23.14	23.61	23.9	21.97
1210	23.52	24.04	23.21	23.78	21.84	23.67	23.51	22.95	23.61	23.96	21.91
1211	23.62	24.14	23.31	23.88	21.96	23.67	23.63	22.84	23.61	23.9	21.91
1212	23.50	24.14	23.37	23.82	22.01	23.62	23.67	22.84	23.55	23.96	21.87
1213	23.56	24.14	23.31	23.85	21.96	23.67	23.63	22.95	23.66	23.9	21.91
1214	23.50	24.14	23.31	23.82	21.9	23.46	23.67	22.9	23.61	23.86	21.85
1215	23.62	24.14	23.31	23.88	22.01	23.46	23.57	22.78	23.55	23.8	21.85
1216	23.56	24.14	23.31	23.85	21.8	23.52	23.73	22.9	23.55	23.86	21.85
1217	23.56	24.08	23.31	23.82	21.86	23.57	23.51	22.84	23.61	23.8	21.85
1218	23.46	24.04	23.21	23.75	21.86	23.52	23.67	22.78	23.49	23.86	21.8
1219	23.46	24.04	23.27	23.75	21.91	23.52	23.67	22.9	23.55	23.86	21.8
1220	23.46	24.04	23.27	23.75	21.97	23.52	23.56	22.84	23.49	23.8	21.85
1221	23.52	24.04	23.27	23.78	21.97	23.46	23.67	22.78	23.49	23.86	21.95
1222	23.46	24.04	23.27	23.75	21.91	23.46	23.61	22.9	23.55	23.74	21.78
1223	23.52	24.04	23.27	23.78	21.86	23.52	23.61	22.78	23.59	23.86	21.84
1224	23.46	24.04	23.27	23.75	21.7	23.46	23.61	23.02	23.59	23.76	21.84
1225	23.46	23.98	23.21	23.72	21.86	23.46	23.61	22.78	23.52	23.86	21.84
1226	23.46	24.10	23.16	23.78	21.86	23.52	23.61	22.95	23.52	23.7	21.78
1227	23.46	24.04	23.27	23.75	21.8	23.46	23.56	22.84	23.46	23.7	21.84
1228	23.46	23.98	23.21	23.72	21.8	23.46	23.61	22.78	23.52	23.7	21.84
1229	23.46	23.98	23.21	23.72	21.97	23.40	23.56	22.61	23.59	23.76	21.71
1230	23.40	23.98	23.27	23.69	21.8	23.52	23.56	22.67	23.46	23.76	21.71
1231	23.46	23.98	23.21	23.72	21.8	23.56	23.56	22.95	23.52	23.76	21.76
1232	23.40	23.98	23.21	23.69	21.8	23.46	23.56	22.67	23.56	23.76	21.81
1233	23.40	23.98	23.21	23.69	21.84	23.50	23.61	22.67	23.56	23.76	21.81
1234	23.40	23.98	23.16	23.69	21.84	23.40	23.56	22.78	23.56	23.76	21.76
1235	23.37	24.08	23.26	23.73	21.73	23.56	23.50	22.82	23.51	23.7	21.86
1236	23.27	23.93	23.27	23.60	21.78	23.46	23.56	22.72	23.51	23.76	21.8
1237	23.44	24.08	23.31	23.76	21.84	23.62	23.50	22.82	23.51	23.7	21.74
1238	23.34	23.98	23.21	23.66	21.73	23.50	23.50	22.65	23.51	23.7	21.74
1239	23.44	24.08	23.26	23.76	21.78	23.56	23.56	22.59	23.51	23.7	21.68
1240	23.34	23.93	23.21	23.64	21.84	23.37	23.50	22.71	23.45	23.7	21.68
1241	23.44	24.08	23.20	23.76	21.73	23.50	23.54	22.71	23.39	23.7	21.74
1242	23.50	24.03	23.26	23.77	21.73	23.44	23.47	22.54	23.45	23.7	21.78
1243	23.44	24.03	23.26	23.74	21.87	23.37	23.47	22.71	23.45	23.7	21.73
1244	23.37	24.03	23.20	23.70	21.94	23.44	23.54	22.82	23.39	23.64	21.73

1245	23.44	24.03	23.20	23.74	21.76	23.44	23.54	22.59	23.39	23.7	21.76
1246	23.50	24.03	23.20	23.77	21.7	23.50	23.47	22.65	23.45	23.7	21.82
1247	23.44	24.03	23.20	23.74	21.8	23.50	23.47	22.54	23.33	23.64	21.82
1248	23.44	24.08	23.26	23.76	21.86	23.44	23.47	22.65	23.49	23.7	21.7
1249	23.37	24.03	23.26	23.70	21.86	23.37	23.47	22.71	23.45	23.64	21.76
1250	23.44	23.97	23.20	23.71	21.8	23.44	23.57	22.59	23.43	23.59	21.7
1251	23.37	23.97	23.20	23.67	21.74	23.44	23.57	22.65	23.33	23.64	21.8
1252	23.37	23.90	23.26	23.64	21.63	23.37	23.51	22.65	23.49	23.59	21.74
1253	23.37	23.97	23.20	23.67	21.68	23.37	23.51	22.59	23.43	23.64	21.74
1254	23.33	24.03	23.14	23.68	21.78	23.37	23.51	22.65	23.49	23.64	21.63
1255	23.37	23.90	23.20	23.64	21.73	23.44	23.46	22.65	23.43	23.7	21.73
1256	23.37	23.97	23.14	23.67	21.84	23.37	23.46	22.65	23.43	23.64	21.77
1257	23.37	23.97	23.20	23.67	21.82	23.33	23.46	22.59	23.43	23.59	21.66
1258	23.37	23.97	23.14	23.67	21.82	23.33	23.51	22.65	23.38	23.53	21.66
1259	23.37	23.90	23.14	23.64	21.82	23.33	23.51	22.71	23.43	23.64	21.66
1260	23.37	23.90	23.20	23.64	21.76	23.43	23.46	22.72	23.38	23.53	21.6
1261	23.33	23.84	23.14	23.59	21.76	23.47	23.46	22.55	23.43	23.53	21.64
1262	23.33	23.90	23.08	23.62	21.7	23.43	23.46	22.65	23.43	23.59	21.64
1263	23.33	23.90	23.20	23.62	21.8	23.36	23.34	22.94	23.49	23.69	21.64
1264	23.43	24.07	23.24	23.75	21.8	23.36	23.40	22.61	23.38	23.53	21.59
1265	23.36	23.94	23.24	23.65	21.69	23.30	23.40	22.61	23.38	23.63	21.59
1266	23.36	23.94	23.18	23.65	21.69	23.36	23.56	22.9	23.38	23.59	21.59
1267	23.43	23.94	23.18	23.69	21.79	23.36	23.40	22.55	23.38	23.53	21.69
1268	23.43	23.89	23.12	23.66	21.73	23.36	23.50	22.61	23.48	23.53	21.69
1269	23.30	23.94	23.12	23.62	21.66	23.53	23.34	22.55	23.38	23.59	21.56
1270	23.36	23.89	23.12	23.63	21.66	23.40	23.56	22.49	23.42	23.59	21.56
1271	23.36	23.94	23.12	23.65	21.6	23.40	23.44	22.54	23.32	23.63	21.6
1272	23.30	23.89	23.12	23.60	21.66	23.40	23.38	22.55	23.42	23.53	21.66
1273	23.40	23.93	23.17	23.67	21.65	23.40	23.50	22.88	23.32	23.57	21.55
1274	23.40	23.93	23.17	23.67	21.59	23.29	23.44	22.49	23.48	23.47	21.66
1275	23.34	23.93	23.17	23.64	21.65	23.40	23.44	22.65	23.42	23.57	21.49
1276	23.29	23.99	23.11	23.64	21.53	23.34	23.44	22.54	23.36	23.53	21.6
1277	23.40	23.87	23.17	23.64	21.65	23.34	23.33	22.59	23.36	23.57	21.55
1278	23.40	23.93	23.17	23.67	21.59	23.40	23.44	22.59	23.42	23.47	21.55
1279	23.40	23.87	23.11	23.64	21.69	23.29	23.44	22.65	23.32	23.57	21.53
1280	23.40	23.93	23.11	23.67	21.69	23.29	23.38	22.48	23.42	23.47	21.59
1281	23.34	23.93	23.11	23.64	21.56	23.34	23.38	22.59	23.42	23.57	21.59
1282	23.23	23.87	23.17	23.55	21.56	23.29	23.44	22.59	23.29	23.47	21.53
1283	23.29	23.87	23.11	23.58	21.66	23.29	23.38	22.65	23.42	23.57	21.47
1284	23.34	23.93	23.11	23.64	21.66	23.34	23.33	22.65	23.42	23.57	21.53
1285	23.29	23.87	23.11	23.58	21.55	23.39	23.38	22.54	23.36	23.63	21.53
1286	23.29	23.87	23.11	23.58	21.55	23.23	23.37	22.65	23.36	23.51	21.47
1287	23.23	23.87	23.05	23.55	21.79	23.33	23.38	22.59	23.36	23.51	21.5
1288	23.23	23.87	23.11	23.55	21.66	23.29	23.43	22.54	23.36	23.41	21.63
1289	23.39	23.97	23.15	23.68	21.6	23.39	23.38	22.59	23.29	23.57	21.45
1290	23.23	23.81	23.05	23.52	21.6	23.33	23.43	22.71	23.29	23.46	21.57
1291	23.33	23.86	23.15	23.60	21.65	23.39	23.33	22.59	23.29	23.51	21.6
1292	23.23	23.81	23.05	23.52	21.65	23.39	23.37	22.59	23.29	23.57	21.45
1293	23.44	23.91	23.21	23.68	21.7	23.33	23.37	22.54	23.29	23.57	21.49

1294	23.33	23.86	23.15	23.60	21.59	23.33	23.48	22.48	23.29	23.51	21.55
1295	23.39	23.86	23.15	23.63	21.59	23.39	23.37	22.71	23.29	23.51	21.49
1296	23.33	23.91	23.08	23.62	21.53	23.33	23.37	22.77	23.25	23.46	21.55
1297	23.33	23.91	23.15	23.62	21.47	23.33	23.27	22.48	23.29	23.4	21.49
1298	23.33	23.86	23.08	23.60	21.47	23.27	23.37	22.77	23.29	23.46	21.55
1299	23.33	23.86	23.15	23.60	21.52	23.33	23.37	22.71	23.29	23.51	21.49
1300	23.27	23.86	23.08	23.57	21.57	23.27	23.48	22.54	23.29	23.46	21.43
1301	23.39	23.86	23.15	23.63	21.57	23.33	23.31	22.48	23.36	23.56	21.49
1302	23.27	23.86	23.08	23.57	21.57	23.33	23.31	22.41	23.29	23.4	21.55
1303	23.33	23.80	23.08	23.57	21.62	23.27	23.37	22.29	23.25	23.5	21.49
1304	23.27	23.91	23.03	23.59	21.52	23.27	23.37	22.59	23.29	23.46	21.55
1305	23.21	23.86	23.08	23.54	21.55	23.37	23.37	22.64	23.36	23.5	21.49
1306	23.33	23.80	23.03	23.57	21.55	23.27	23.31	22.54	23.36	23.4	21.49
1307	23.27	23.80	22.97	23.54	21.62	23.37	23.37	22.48	23.19	23.5	21.49
1308	23.27	23.86	23.03	23.57	21.49	23.27	23.37	22.48	23.29	23.43	21.49
1309	23.43	23.90	23.13	23.67	21.49	23.43	23.37	22.29	23.19	23.5	21.55
1310	23.21	23.80	23.08	23.51	21.49	23.27	23.31	22.54	23.19	23.37	21.49
1311	23.31	23.84	23.13	23.58	21.55	23.31	23.31	22.35	23.19	23.43	21.49
1312	23.27	23.80	23.03	23.54	21.55	23.37	23.37	22.24	23.19	23.37	21.43
1313	23.37	23.90	23.13	23.64	21.67	23.31	23.37	22.41	23.19	23.37	21.43
1314	23.27	23.80	23.08	23.54	21.55	23.31	23.31	22.54	23.26	23.43	21.49
1315	23.31	23.84	23.13	23.58	21.62	23.31	23.37	22.41	23.19	23.37	21.43
1316	23.31	23.84	23.07	23.58	21.55	23.21	23.31	22.41	23.19	23.37	21.37
1317	23.31	23.90	23.13	23.61	21.49	23.31	23.31	22.65	23.19	23.37	21.37
1318	23.37	23.90	23.13	23.64	21.49	23.31	23.31	22.41	23.19	23.37	21.32
1319	23.26	23.96	23.07	23.61	21.55	23.26	23.31	22.29	23.32	23.37	21.37
1320	23.16	23.74	22.97	23.45	21.49	23.26	23.31	22.41	23.26	23.37	21.32

Table E-2. Model Input Parameters for the Control Mixtures

Mix Design	C_3S	C_2S	C_3A	C_4AF	FACaO	S	SF	M
100TI	48.1	20.4	12.2	7.6	0	0	0	0
80TI/20C	38.5	16.4	9.7	6.1	27.24	0	0	0
80TI/20F	38.5	16.4	9.7	6.1	3.78	0	0	0
80TI/20F2	38.5	16.4	9.7	6.1	13.26	0	0	0
65TI/35G100S	31.3	13.3	7.9	4.9	0	1.42	0	0
65TI/35G120S	31.3	13.3	7.9	4.9	0	0.5	0	0
100TI-II	58.7	15.1	5.7	9.5	0	0	0	0
80TI-II/20G120S	46.9	12.1	4.6	7.6	0	0.5	0	0
100TIP	42.1	13.3	5.5	7.8	10.9	0	0	0
100TISM	46.9	12.1	4.6	7.6	0	0.5	0	0
100TIPM	56.1	11.5	6.9	7.6	0	0	7	0
100Ternary	42.2	8.7	5.2	5.7	0	0.5	5	0

Table E-3. Model Input Parameters for Mixtures Containing Type I PC and 20% FA

Mix Design	C_3S	C_2S	C_3A	C_4AF	FACaO	S	SF	M
60TI/20C/20F	28.9	12.3	7.3	4.6	15.51	0	0	0
60TI/20C/20F2	28.9	12.3	7.3	4.6	20.25	0	0	0
75TI/20C/5SF	36.1	15.3	9.1	5.7	27.24	0	5	0
77TI/20C/3SF	37.1	15.7	9.4	5.9	27.24	0	3	0
60TI/20C/20G100S	28.9	12.3	7.3	4.6	27.24	1.42	0	0
60TI/20C/20G120S	28.9	12.3	7.3	4.6	27.24	0.5	0	0
75TI/20C/5M	36.1	15.3	9.1	5.7	27.24	0	0	5
60TI/20F/20F2	28.9	12.3	7.3	4.6	8.52	0	0	0
75TI/20F/5SF	36.1	15.3	9.1	5.7	3.78	0	5	0
77TI/20F/3SF	37.1	15.7	9.4	5.9	3.78	0	3	0
60TI/20F/20G100S	28.9	12.3	7.3	4.6	3.78	1.42	0	0
60TI/20F/20G120S	28.9	12.3	7.3	4.6	3.78	0.5	0	0
75TI/20F/5M	36.1	15.3	9.1	5.7	3.78	0	0	5
75TI/20F2/5SF	36.1	15.3	9.1	5.7	13.26	0	5	0
77TI/20F2/3SF	37.1	15.7	9.4	5.9	13.26	0	3	0
60TI/20F2/20G100S	28.9	12.3	7.3	4.6	13.26	1.42	0	0
60TI/20F2/20G120S	28.9	12.3	7.3	4.6	13.26	0.5	0	0
75TI/20F2/5M	36.2	15.4	9.2	5.7	13.26	0	0	5

Table E-4. Model Input Parameters for Mixtures Containing Type I PC and 30% FA

Mix Design	C_3S	C_2S	C_3A	C_4AF	FACaO	S	SF	M
60TI/30F/10C	28.9	12.3	7.3	4.6	9.645	0	0	0
60TI/30F2/10C	28.9	12.3	7.3	4.6	6.15	0	0	0
60TI/30C/10F	28.9	12.3	7.3	4.6	21.375	0	0	0
60TI/30C/10F2	28.9	12.3	7.3	4.6	23.745	0	0	0
65TI/30C/5SF	31.3	13.3	7.9	4.9	27.24	0	5	0
67TI/30C/3SF	32.2	13.7	8.1	5.1	27.24	0	3	0
50TI/30C/20G100S	24.1	10.2	6.1	3.8	27.24	1.42	0	0
50TI/30C/20G120S	24.1	10.2	6.1	3.8	27.24	0.5	0	0
65TI/30C/5M	31.3	13.3	7.9	4.9	27.24	0	0	5
60TI/30F/10F2	28.9	12.3	7.3	4.6	6.15	0	0	0
65TI/30F/5SF	31.3	13.3	7.9	4.9	3.78	0	5	0
67TI/30F/3SF	32.2	13.7	8.1	5.1	3.78	0	3	0
50TI/30F/20G100S	24.1	10.2	6.1	3.8	3.78	0	0	0
50TI/30F/20G120S	24.1	10.2	6.1	3.8	3.78	0	0	0
65TI/30F/5M	31.3	13.3	7.9	4.9	3.78	0	0	5
65TI/30F2/5SF	31.3	13.3	7.9	4.9	13.26	0	5	0
67TI/30F2/3SF	32.2	13.7	8.1	5.1	13.26	0	3	0
50TI/30F2/20G100S	24.1	10.2	6.1	3.8	13.26	1.42	0	0
50TI/30F2/20G120S	24.1	10.2	6.1	3.8	13.26	0.5	0	0
65TI/30F2/5M	31.3	13.3	7.9	4.9	13.26	0	0	5

Table E-5. Model Input Parameters for Mixtures Containing Type I PC and 35% GGBFS or Type I PC and Metakaolin

Mix Design	C_3S	C_2S	C_3A	C_4AF	FACaO	S	SF	M
50TI/35G100S/15C	24.1	10.2	6.1	3.8	27.24	1.42	0	0
50TI/35G100S/15F	24.1	10.2	6.1	3.8	3.78	1.42	0	0
50TI/35G100S/15F2	24.1	10.2	6.1	3.8	13.26	1.42	0	0
60TI/35G100S/5SF	28.9	12.3	7.3	4.6	0	1.42	5	0
62TI/35G100S/3SF	29.8	12.7	7.5	4.7	0	1.42	3	0
60TI/35G100S/5M	28.9	12.3	7.3	4.6	0	1.42	0	5
50TI/35G120S/15C	24.1	10.2	6.1	3.8	27.24	0.5	0	0
50TI/35G120S/15F	24.1	10.2	6.1	3.8	3.78	0.5	0	0
50TI/35G120S/15F2	24.1	10.2	6.1	3.8	13.26	0.5	0	0
60TI/35G120S/5SF	28.9	12.3	7.3	4.6	0	0.5	5	0
62TI/35G120S/3SF	29.8	12.7	7.5	4.7	0	0.5	3	0
60TI/35G120S/5M	28.9	12.3	7.3	4.6	0	0.5	0	5
90TI/5M/5SF	43.3	18.4	10.9	6.8	0	0	5	5
92TI/5M/3SF	44.3	18.8	11.2	7.0	0	0	3	5

Table E-6. Model Input Parameters for Mixtures Containing Type I/II PC

Mix Design	C_3S	C_2S	C_3A	C_4AF	FACaO	S	SF	M
68TI-II/17G120S/15C	39.9	10.3	3.9	6.5	27.24	0.5	0	0
68TI-II/17G120S/15F	39.9	10.3	3.9	6.5	3.78	0.5	0	0
68TI-II/17G120S/15F2	39.9	10.3	3.9	6.5	13.26	0.5	0	0
76TI-II/19G120S/5SF	44.6	11.5	4.4	7.2	0	0.5	5	0
78TI-II/19G120S/3SF	45.7	11.8	4.5	7.4	0	0.5	3	0
64TI-II/20G100S/16G120S	37.5	9.7	3.7	6.1	0	1.01	0	0
76TI-II/19G120S/5M	44.6	11.5	4.4	7.2	0	0.5	0	5
60TI-II/25C/15G120S	35.2	9.1	3.4	5.7	27.24	0.5	0	0
60TI-II/25F/15G120S	35.2	9.1	3.4	5.7	3.78	0.5	0	0
60TI-II/25F2/15G120S	35.2	9.1	3.4	5.7	13.26	0.5	0	0
52TI-II/35G100S/13G120S	30.5	7.8	3.0	5.0	0	1.17	0	0

Table E-7. Model Input Parameters for Mixtures Containing Type IP PC

Mix Design	C_3S	C_2S	C_3A	C_4AF	FACaO	S	SF	M
85TIP/15C	34.0	10.7	4.4	6.3	16.88	0	0	0
85TIP/15F	34.0	10.7	4.4	6.3	8.30	0	0	0
85TIP/15F2	34.0	10.7	4.4	6.3	11.76	0	0	0
95TIP/5SF	38.0	12.0	4.9	7.0	10.9	0	5	0
97TIP/3SF	38.8	12.2	5.0	7.2	10.9	0	3	0
80TIP/20G100S	32.0	10.1	4.1	5.9	10.9	1.42	0	0
80TIP/20G120S	32.0	10.1	4.1	5.9	10.9	0.5	0	0
95TIP/5M	38.0	12.0	4.9	7.0	10.9	0	0	5
75TIP/25C	30.0	9.4	3.9	5.6	18.91	0	0	0
75TIP/25F	30.0	9.4	3.9	5.6	7.41	0	0	0
75TIP/25F2	30.0	9.4	3.9	5.6	12.06	0	0	0
65TIP/35G100S	26.0	8.2	3.4	4.8	10.9	1.42	0	0
65TIP/35G120S	26.0	8.2	3.4	4.8	10.9	0.5	0	0
90TIP/5M/5SF	36.0	11.3	4.7	6.7	10.9	0	5	5
92TIP/5M/3SF	36.8	11.6	4.8	6.8	10.9	0	3	5

Table E-8. Model Input Parameters for Mixtures Containing Type ISM PC

Mix Design	C_3S	C_2S	C_3A	C_4AF	FACaO	S	SF	M
85TISM/15C	39.9	10.3	3.9	6.5	27.24	0.5	0	0
85TISM/15F	39.9	10.3	3.9	6.5	3.78	0.5	0	0
85TISM/15F2	39.9	10.3	3.9	6.5	13.26	0.5	0	0
95TISM/5SF	44.6	11.5	4.4	7.2	0	0.5	5	0
97TISM/3SF	45.5	11.7	4.4	7.4	0	0.5	3	0
80TISM/20G100S	37.5	9.7	3.7	6.1	0	1.01	0	0
80TISM/20G120S	37.5	9.7	3.7	6.1	0	0.5	0	0
95TISM/5M	44.6	11.5	4.4	7.2	0	0.5	0	5
75TISM/25C	35.2	9.1	3.4	5.7	27.24	0.5	0	0
75TISM/25F	35.2	9.1	3.4	5.7	3.78	0.5	0	0
75TISM/25F2	35.2	9.1	3.4	5.7	13.26	0.5	0	0
65TISM/35G100S	30.5	7.8	3.0	5.0	0	1.17	0	0
65TISM/35G120S	30.5	7.8	3.0	5.0	0	0.5	0	0
90TISM/5M/5SF	42.2	10.9	4.1	6.9	0	0.5	5	5
92TISM/5M/3SF	43.2	11.1	4.2	7.0	0	0.5	3	5

Table E-9. Model Input Parameters for Mixtures Containing Type IPM PC

Mix Design	C_3S	C_2S	C_3A	C_4AF	FACaO	S	SF	M
85TIPM/15C	47.7	9.8	5.8	6.5	27.24	0	5.95	0
85TIPM/15F	47.7	9.8	5.8	6.5	3.78	0	5.95	0
85TIPM/15F2	47.7	9.8	5.8	6.5	13.26	0	5.95	0
95TIPM/5SF	53.3	11.0	6.5	7.2	0	0	11.65	0
97TIPM/3SF	54.4	11.2	6.7	7.4	0	0	9.79	0
80TIPM/20G100S	44.9	9.2	5.5	6.1	0	1.42	5.6	0
80TIPM/20G120S	44.9	9.2	5.5	6.1	0	0.5	5.6	0
95TIPM/5M	53.3	11.0	6.5	7.2	0	0	6.65	5
75TIPM/25C	42.1	8.6	5.2	5.7	27.24	0	5.25	0
75TIPM/25F	42.1	8.6	5.2	5.7	3.78	0	5.25	0
75TIPM/25F2	42.1	8.6	5.2	5.7	13.26	0	5.25	0
65TIPM/35G100S	36.5	7.5	4.5	5.0	0	1.42	4.55	0
65TIPM/35G120S	36.5	7.5	4.5	5.0	0	0.5	4.55	0
90TIPM/5M/5SF	50.5	10.4	6.2	6.9	0	0	11.3	5
92TIPM/5M/3SF	51.6	10.6	6.3	7.0	0	0	9.44	5