STATE OF FLORIDA
DEPARTMENT OF TRANSPORTATION

STATE MATERIALS OFFICE
STRUCTURAL MATERIALS LABORATORY
5007 NE 39th Avenue
Gainesville, Florida 32609
(352) 955-6600

REPORT OF CHANGES TO CEMENT SPECIFICATIONS AASHTO M 85 AND ASTM C150 SUBSEQUENT TO HARMONIZATION

Authors: *Christopher C. Ferraro*
Charles A. Ishee

Approved: *Michael Bergin*

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BACKGROUND

The purpose of this report is to provide an overview of the current status of the national specifications for Portland cement and the changes resulting from harmonization. Recently, a Joint American Society for Testing and Materials (ASTM)/American Association Of State Highway And Transportation Officials (AASHTO) Harmonizing Task Group (JAAHTG) was formed to harmonize the cement specifications in the United States. As a result of their efforts, the standard specifications for cement ASTM C 150 and AASHTO M 85 have undergone significant revisions. Following these specification changes, the early-age heat of hydration of Type II Portland cement produced in the State of Florida (which previously used AASHTO M 85 for the specification of cement)[1] has increased. The increase in the heat of hydration of Type II cements has resulted in adverse performance characteristics of some concrete being produced in the state. Some of the performance issues observed by engineers and inspectorsinclude higher than expected temperature readings obtained in concrete structures, and an increase in the cracking of concrete structures relative to past performance.Therefore, it may be necessary for the Florida Department of Transportation (FDOT) to make revisions to Specification 921, Portland Cement and Blended Cement, to mitigate the adverse effects of Type II cements produced in Florida.

THE RELATIONSHIP BETWEEN HEAT OF HYDRATION AND CLINKER COMPONENTS

As part of the harmonization of the AASHTO and ASTM cement specifications, the decision was made to investigate the usefulness of relating standard test properties to the heat of hydration of hydraulic cements [2]. Therefore, an analysis was performed on the historical data of cement provided to the Cement and Concrete Reference Laboratory (CCRL). The data was supplied by the U.S. Army corps of Engineers who developed a linear equation (equation 1) that relates the proportion of the clinker compounds of cement to seven-day heat of hydration [2].

The CCRL data was obtained via the testing on the CCRL proficiency samples that are sent out twice a year to laboratories for accreditation purposes. Typically, there are approximately 230 laboratories that participate in the X-ray fluorescence testing as per ASTM C 114. In addition, there are typically 20 laboratories that participate in heat of hydration testing as per ASTM C 186. Therefore, each of the data points provided by CCRL laboratories should not be considered a single laboratory test, but the average of a series of tests.

$$7 \text{ Day HH} = A1\ C_3S + A2\ C_3A + C \qquad (1)$$

Where:
C_3S = Percentage of Tricalcium Silicate
C_3A = Percentage Tricalcium Aluminate
7 Day HH = Heat of Hydration at 7 Days (ASTM C 186)
A1, A2 and C are numeric constants used to create a best fit equation.

CHANGES IN THE CEMENT SPECIFICATIONS

The harmonization of the ASTM and AASHTO cement specifications has resulted in several changes as documented by Tennis and Melander [3]. One change to the specifications that is of significant importance is the limit of C_3S for Type II cements. Prior to the recent specification change, AASHTO M 85 specified a maximum of 58% C_3S and ASTM C 150 had an optional requirement of a maximum of 58% C_3S for Type II cements with moderate heat of hydration[4,5]. Subsequent to the harmonization of the AASHTO and ASTM Specifications, the decision was made to remove the limit for the maximum percentage of 58% C_3S for Type II cements. Per the new/harmonized Portland cement specifications, the Type II cements no longer have a maximum limit on C_3S. The current cement specifications (AASHTO M 85 and ASTM C 150) incorporate a new type of cement, Type II(MH) that utilizes the heat index equation based upon the combined percentages of C_3S and C_3A which were was adopted from equation (2) [1, 3].

$$C_3S + 4.75\ C_3A \leq 100 \quad (2)$$

Where:
C_3S = Percentage of Tricalcium Silicate
C_3A = Percentage Tricalcium Aluminate
$C_3S + 4.75\ C_3A$ = Heat index [2, 5]

As per note 4 in current ASTM C150 and AASHTO M85 specifications, "*The limit on the sum, C_3S+4.75 C_3A, in Table 1 Provides control on the heat of hydration and is consistent with a Test Method C186 7-day heat of hydration limit of 335KJ/kg (80cal/g)*" [6,7].

The data used from the CCRL laboratory testing to formulate note 4 in ASTM C150 and AASHTO M85 is presented in figure 1[2]. The Y-axis value is the 7 day heat of hydration, and the X-axis value is the heat index as per ASTM C150/AASHTO M85. "Line 1" denotes the 7 day heat of hydration limit and "Line

2" denotes the line for the vertical x-intercept which corresponds to a heat index of 100. The dashed oval denotes a visible space between Line 2 and the best fit line of the data obtained by Poole[2]. From this figure it is evident that a cement which has a heat index of 100 per equation 2 is not consistent with a Test Method C186 7-day heat of hydration limit of 335KJ/kg (80cal/g).

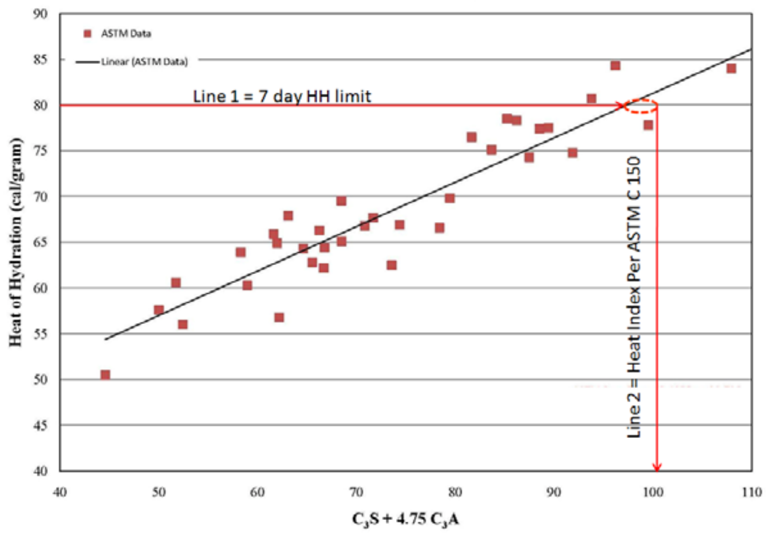

Figure 1 -Data used to formulate note 4 in ASTM C150 and AASHTO M 85[2].

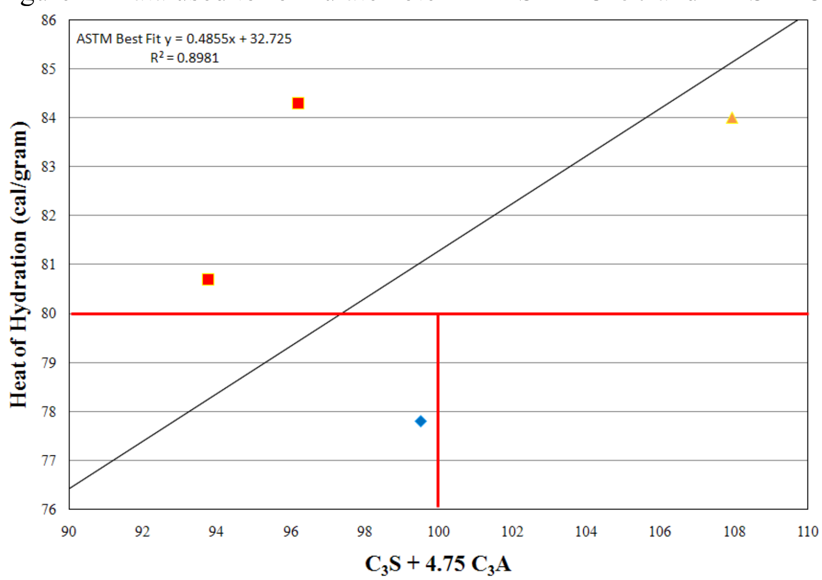

Figure 2 -Data used to formulate note 4 in ASTM C150 and AASHTO M 85[2].

The best fit linear equation derived from the data in figure 1shows that a cement specimen, which has a heat index of 100, would have a 7 day heat of hydration of approximately 81.25. Figure 2 is a close-up view of the CCRL data which had a 7 day heat of hydration above 76 cal/g and a heat index above 90. From the data used to formulate note 4, only four of the 38 data points, were near the point of intersection for the 7 day heat of hydration limit, and the specified heat index of 100. Two of the data points have a heat index of less than 100 and a measured seven-day heat of hydration above the 80 cal/g "limit" as described by note 4 in ASTM C150 and AASHTO M 85.

Following a review of the data in Figures 1 and 2, the idea that a cement specimen with a heat index of 100 would be limited to a 7 day heat of hydration 80 is erroneous. The research shows that it would have been more appropriate to use a statistical analysis of the data to create the limit of the heat index per note 4 in ASTM C150 / AASHTO M85.

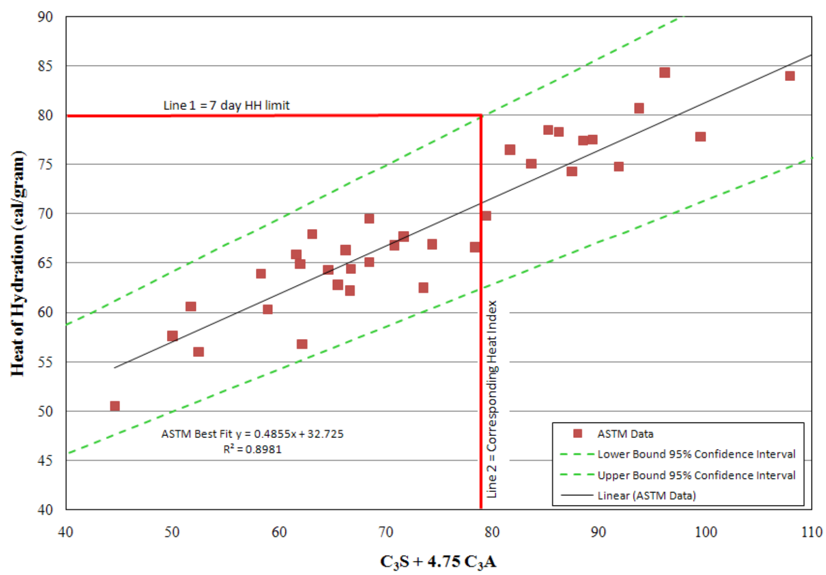

Figure 3 – Data used to formulate Note 4 in ASTM C150 and AASHTO M 85[2] with 95% confidence intervals.

Figure 3 is a reproduction of Figure 1 with the incorporation of the 95% confidence intervals for the best fit data within. With the incorporation of the confidence interval as indicated by Figure 3, the use of "Line 1" to denote the 7 day heat of hydration limit and "Line 2" to denote the vertical line intersection the x-intercept, the corresponding heat index is drastically reduced. The use of confidence intervals would ensure that approximately 97.5% of all cements with a 7 day heat of hydration would be below 80 in the event the heat index is reduced to 79 as opposed to 100 as denoted by Note 4 in ASTM C150/AASHTO M85.

CHANGES IN TYPE II CEMENT PRODUCTION AS A RESULT OF HARMONIZATION

A survey of compound composition data for 37 cements produced in the State of Florida from October 2009 to February 2010 was performed. The averaged data, that was combined with the historical data reported by Gebhardt, Mather and Hime [8,9], and is provided in Table 1. The historical data indicates that the C_3S and the C_3A of Type II (as well as early strength and early heat of hydration) can be attributed to a change in the ASTM C150 specification which increased the limits on C_3S and C_3A sometime in the early 1960's [10]. The data obtained from the cements produced in the State of Florida in 2009-2010 indicates that the C_3S in Type II has again increased, which can be attributed to the most recent specification change.

Table 1 - Summary of Data for Type II/III Cements

Type II Cements			Type III Cements		
Year	C_3S %	C_3A %	Year	C_3S %	C_3A %
1948*	40.9	5.6	1948*	59.2	9.3
1994*	54.9	7.1	1994*	51.7	10.4
2010**	56.7	7.0	2010**	57.9	7.2

* Historical data reported by Gebhardt as well as Mather and Hime
** Data obtained from cement producer data to the FDOT for January / February 2010

Historically, the majority of the limits put on cements were for the purposes of specifying low-heat cements based on chemical composition and fineness. However, the chemical composition of the cements has gradually changed over the past 60 years. A side-by-side comparison of Type II and Type III cements provided in Table 1 indicates that the significant compositional differences of Type II and Type III cements, produced between 1940 and today, no longer exist. The most recent data indicates that there is little difference between the C_3S and C_3A compositions for the Type II and Type III cements produced in Florida. A review of the cement producers in the State of Florida who produce both Type II and Type III cements revealed that the chemical compositions are essentially the same with the exception that Type III cements have more gypsum added. Type III cements are ground finer than Type II cements.

Currently, the majority of the physical requirements (time of set, air content of mortar, autoclave expansion, etc.) for cement, per the ASTM C 150 and AASHTO M 85 Specification, are the same regardless of cement type. Therefore, Type II cement could also qualify as a Type III cement (or viceversa) in the event the minimum strength requirements (of 1740 psi at 1 day and 3480 psi at 3 days) for Type III cement were met and the maximum fineness requirements (430 m^2/kg) Type II cement were met.

A survey of mill certification data was performed for (all) of the cements produced in Florida in January and February of 2010. The resultant data, which includes compound composition, heat index, 1 day strength, 3 day strength, and fineness data is summarized in Table 2. As per the new / harmonized requirements for Portland cement, all of the cement in Table 2 qualifies as Type I/II. Following a review of ASTM C 150 and AASHTO M 85, the data indicates that each of the Type II cements listed in Table 2 qualify as Type III (high early strength) per the cement specifications. Therefore, under the current data provided by the producers in the State of Florida, it is possible for the Portland cements listed in Table 2 to be classified as Type I, Type II, Type II(MH) or Type III.

Table 2 - Summary of Data for Type II Cements Reported for January / February 2010*

Producer	C_3S** (%)	C_3A** (%)	Heat Index (C_3S + 4.75 C_3A)	1 Day Strength (psi)	3 Day Strength (psi)	Fineness*** (m^2/kg)
1	62.6	7.7	99	2550	4230	386
2	54	8	93	2255	4011	408
3	55.2	7.4	90	2395	3989	357
4	55	7	88	2395	4087	385
5	54	7	87	2206	3739	376
6	52	7	85	2110	3650	375
7	58	6	87	Not Reported	4120	380
8	58	7	91	Not Reported	4060	403
9	56	8	94	2640	4162	401
10	63.8	5.8	91	2186	3695	394
11	55.3	6.3	85	2016	3423	393
12	56	7	89	2431	3940	395

* Data is presented as reported by the producer
** Chemical analysis is performed by ASTM C114 and composition is calculated per ASTM C150
*** Fineness data is reported in specific surface values per the Blaine air permeability method (ASTM C204 / AASTHO T-153)

FIELD PERFORMANCE OF TYPE II CEMENTS

In 2009, Florida Department of Transportation (FDOT) field engineers observed that concrete which utilized Type II cements for moderate heat applications were producing higher temperatures and developed more early-age cracking than in years past. Accordingly, the FDOT sampled 15 Type II cements produced in the State of Florida and tested them via the Standard Test Method for the Heat of

Hydration of Hydraulic Cement (ASTM C186). Figure 4 presents the seven-day heat of hydration versus the heat index equation calculated in Equation 2. The data indicates that 7 of the 15 Type II cements tested obtained a heat of hydration above the 80 cal/g "limit" as per Note 4 in the Standard Specification of Cement outlined in ASTM C 150 and AASHTO M 85.

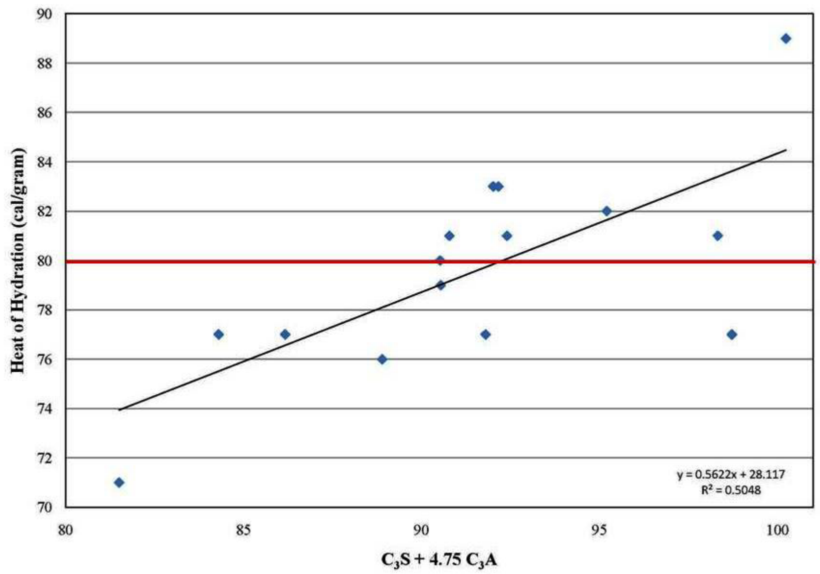

Figure 4. Seven-day heat of hydration versus heat index equation for Type II cements produced in Florida.

It is often the case that the ambient temperature in the State of Florida is above 90°F which requires that special provisions be taken for hot weather concrete [11]. For mass concrete structures, cements and concretes that produce higher than expected early age heat are of particular importance as the climate in Florida does not facilitate low placement temperatures, nor does it allow for the economical cooling of concrete. Thus, the appropriate reconciliation of the current problems associated with the placement of Type II cements is not easily resolved.

DISCUSSION

As a result of the harmonization of the ASTM and AASHTO cement specifications; there has been an increase in the C3S contents of Type II cements. There has also been a measurable increase in the heat of hydration and early strength of Type II cements. Currently, Type II cements being produced and used in the State of Florida qualify as Type I, Type II and Type III cements under the requirements outlined in ASTM C150 and AASHTO M85.

In 1998 Poole[8]recognized that the changes in the cement specifications have allowed for a divergence in the heat of hydration properties of Type II cements that are now made to comply with the optional heat of hydration limit . This optional limit, per Table 4 ASTM C150 and AASHTO M 85, requires that a Type II (MH) cement to have a maximum heat of hydration at 7 days in order to be 290KJ/kg (70cal/g). However, there are currently no cement producers in the State of Florida who currently offer Type II moderate heat cement with the optional physical requirements. Thus, the benefit to using Type II cement per the new cement specifications is diminished.

In addition to the above challenges, the lack of availability of Type II (MH) cement that conforms to the optional requirements outlined in Table 4 of ASTM C150 and AASHTO M 85 constrains the FDOT to the use of cements which produce more heat than in the past. Thus, the Type II cement currently being used for the construction of mass concrete in Florida would not perform as it has in the past. Therefore, it would be prudent for specialty engineers to consider Type II and Type III cements when designing massive elements. Considerations should also be given to smaller concrete elements containing Type III with regard to heat of hydration and mass concrete [12].

FDOT CEMENT SPECIFICATION

Currently, Section 921 of the FDOT Standard Specification for Road and Bridge Construction (Portland Cement and Blended Cement) does not stipulate any requirements for the chemical composition of Portland cement nor does it include any of the optional requirements in AASHTO M 85. However, in an effort to address some of the issues related to the field performance of Type II cements, it may be justified to require that the Type II (MH) cements produced for the FDOT conform with the optional requirement of a maximum heat of hydration at 7 days to be 290KJ/kg (70cal/g) per Table 4 of AASHTO M 85.

Currently the FDOT Standard Specification for Road and Bridge Construction imposes restrictions on Type II cements with heat of hydration of 81(cal/g) and higher than 7 days with regard to its use in moderately aggressive environments.

CONCLUSIONS

As a result of the investigation of the chemical composition and field performance of Type II Portland cements produced in the State of Florida, the following conclusions have been reached:

- Many of the Type II Portland cements currently being produced in the state of Florida have significantly higher content of C_3S due to harmonization.
- The Type I, II and II cements contain essentially the same chemical components with the exception of additional gypsum found in Type III cements.
- The changes in Type II Portland cement as a result of harmonization between AASHTO M 85 and ASTM C 150 have adversely affected the field performance of Type II cements produced in Florida.
- Note 4 in the current ASTM C 150 and AASHTO M 85 specifications states, "*The limit on the sum, C_3S+4.75 C_3A, in Table 1 Provides control on the heat of hydration and is consistent with a Test Method C186 7-day heat of hydration limit of 335KJ/kg (80cal/g)* [6,7]." is erroneous and does not represent a limit for the maximum heat of hydration. It does, however, represent a median value with respect to heat of hydration and the limit on the sum of C_3S and 4.75 C_3A.

RECOMMENDATIONS

The following revisions to the ASTM C 150 / AASHTO M 85 specification should be considered:

- Revise the current heat index equation to include the 95% confidence interval. Accordingly, the limit of the heat index equation, as denoted by Note 4 of ASTM C150 and AASHTO M 85, should be revised to ensure that 95% of all data does not exceed the maximum heat of hydration of 80 cal/g at 7 days. A more appropriate value for the heat index is denoted in Equation 3

  $C_3S + 4.75\ C_3A \leq 79$ (3).

- Lower the heat index for Type II (MH) cements, and impose a heat index or maximum limit on the heat of hydration for Type II cements.
- Impose fineness limits on cements that have $C_3S + 4.75\ C_3A \leq 90$.
- Utilize physical testing to impose maximum heat of hydration limits on Type II cements using physical tests such as ASTM C 1702 Isothermal Calorimetry of ASTM C186 Solution

Calorimetry, which makes use of physical data rather than a index equation for a heat index equation which is known to be flawed.

The following revisions to the Section 921 of the FDOT Standard Specification for Road and Bridge Constructions should be considered:

- Require the use of Pozzolans or Slag to be used with Type II cements in all concrete regardless of environmental classification.
- Require that Type II (MH) cements have a maximum heat of hydration that exceeds the maximum heat of hydration of 70 cal/g at 7 days per Table 4 of AASHTO M 85 and ASTM C150.

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