

**INDIANA DEPARTMENT OF TRANSPORTATION
OFFICE OF MATERIALS MANAGEMENT**

**STRENGTH OF PORTLAND CEMENT CONCRETE PAVEMENT (PCCP)
USING THE MATURITY METHOD
UTILIZING THE TIME TEMPERATURE FACTOR METHODOLOGY
ITM 402-15T**

1.0 SCOPE.

- 1.1** This test method covers the maturity concept as a non-destructive method to determine in-place concrete flexural strength in the field for opening of PCCP to traffic and during the verification of a new Concrete Mix Design (CMD).
- 1.2** This ITM may involve hazardous materials, operations, and equipment and may not address all of the safety problems associated with the use of the test method. The user of the ITM is responsible for establishing appropriate safety and health practices and determining the applicability of regulatory limitations prior to use.

2.0 REFERENCES.

2.1 AASHTO Standards.

- T 23 Making and Curing Concrete Test Specimens in the Field
T 97 Flexural Strength of Concrete
T 119 Slump of Hydraulic Cement Concrete
T 126 Making and Curing Concrete Test Specimens in the Laboratory
T 152 Air Content of Freshly Mixed Concrete by the Pressure Method
T 196 Air Content of Freshly Mixed Concrete by the Volumetric Method
M 241 Concrete Made by Volumetric Batching and Continuous Mixing

2.2 ASTM Standards.

- C-1074 Estimating Concrete Strength by the Maturity Method

2.3 ITM Standards.

- 403 Water-Cementitious Ratio
802 Random Sampling
909 Verifying Thermometers

3.0 TERMINOLOGY. Definitions for terms and abbreviations shall be in accordance with the Department Standard Specifications, Section 101, and as follows.

- 3.1** Equivalent Age. The time in days or hours at a specified temperature required to produce a flexural strength equal to the flexural strength achieved by a curing period at temperatures different from the specified temperature
- 3.2** Maturity Function. A mathematical expression that uses the measured temperature history of a cementitious mixture during the curing period to calculate a maturity index that is indicative of the flexural strength at the end of that period
- 3.3** Maturity Index. An indicator of flexural strength that is calculated from the temperature history of the cementitious mixture by using a maturity function
- 3.4** Maturity Method. A technique for estimating concrete flexural strength that is based on the assumption that samples of a given concrete mixture attain equal flexural strengths if they attain equal maturity index values
- 3.5** Maturity Curve. A curve established by plotting the flexural strength values vs time-temperature factor values
- 3.6** Maturity-Strength Relationship. A relationship between the beam flexural strength and maturity index that is obtained by testing beam specimens whose temperature history up to the time of test has been recorded
- 3.7** Time-Temperature Factor (TTF). TTF is a calculated value determined from time and temperature readings used to indicate the flexural strength of the concrete

4.0 SIGNIFICANCE AND USE.

- 4.1** This ITM shall be used to determine in-place flexural strength of concrete for opening of PCCP to traffic.
- 4.2** The hydration of cement and gain in strength of the concrete are dependent on both curing time and temperature. Thus, the strength of the concrete may be expressed as a function of time and temperature. This information may then be used to determine the strength of PCCP without conducting destructive tests.

5.0 APPARATUS.

- 5.1** Beam mold. Beam molds shall have the nominal dimensions of 6 in. x 6 in. x 20 in. in accordance with AASHTO T 23 and T 126.
- 5.2** Flexural Strength Testing Machine. A testing machine in accordance with AASHTO T 97 used to determine the flexural strength of concrete by breaking simply supported beams loaded at third points.
- 5.3** Maturity Meter. A device that automatically measures, computes and displays a time-temperature factor.
- 5.4** Hand-held Digital Thermometer. A verified thermometer having a temperature probe/sensor input connector and a power source. The minimum temperature measuring range shall be 0°C to 66°C. The thermometer shall be readable to 0.1 ° C and accurate to 1° C. Thermometers shall be verified in accordance with the applicable requirements of ITM 909.
- 5.5** Temperature Probe/ Sensor. Thermocouple, thermistor or other device suitable for embedment in the PCCP.
- 5.6** Data Acquisition System. A device suitable for monitoring and recording the temperature of the concrete. The device may be a system with a computer remote from the job-site which reads and logs the probes/sensors through a modem for necessary calculations, or a system with a computer at the job-site which automatically reads the probe/sensor signals, calculates the maturity index, and digitally displays the data on demand.
- 5.7** Concrete Mixing Equipment. The mixers shall be equipped with a metal plate or plates on which are plainly marked the gross volume of the unit in terms of mixed concrete, discharge speed, and the weight-calibrated constant of the machine in terms of a revolution counter or other output indicator in accordance with AASHTO M 241. The capacity of the concrete mixer shall be large enough to place twelve beams at one time and to conduct all other tests.

6.0 GENERAL.

- 6.1** This test procedure is a three step process as follows.
 - 6.1.1** Laboratory procedure in accordance with 7.0
 - 6.1.2** Field procedure in accordance with 8.0
 - 6.1.3** Validation procedure in accordance with 9.0

- 6.2** An Excel based spread sheet computer program, MAT402, is furnished by the Department and shall be used to calculate TTF. The calculation is based on the following equation.

$$\Sigma \text{TTF} = \Sigma \left(\left(\frac{T_2 + T_3}{2} \right) + 10 \right) \times (A_1 - A_2)$$

where:

TTF = time-temperature factor in °C x hours

A₁ = age in hours

A₂ = previous age in hours

T₂ = concrete temperature in °C at measuring age

T₃ = previous temperature of concrete in °C

7.0 LABORATORY PROCEDURE.

- 7.1** Prior to construction, a relationship between the TTF and the concrete flexural strength as measured by destructive methods through testing of beams shall be developed in the laboratory using project materials and the project CMD.
- 7.2** Prepare concrete mixture and cast a minimum of twelve beams in accordance with AASHTO T 126. Tests for air content, slump and water-cementitious ratio shall be conducted for each batch and recorded in accordance with AASHTO T 152, AASHTO T 119 and ITM 403 respectively.
- 7.3** A temperature probe/sensor shall be inserted near each end of the last beam cast. The temperature/probe sensor shall be placed approximately mid-depth and approximately 3 in. (75 mm) from each end. This beam shall be designated the temperature control beam and shall be the last beam tested for flexural strength. When a wired probe is used, secure the loose end wire of the probe/sensor to the beam box to prevent being inadvertently pulled out of the beam during first 24 h of curing.
- 7.4** The beams shall be covered with wet burlap and polyethylene sheeting upon initial set. The forms, wet burlap and polyethylene sheeting shall be removed 24 h after casting. All beams shall be stored in a testing facility in accordance with 507.09, until each has been tested.
- 7.5** The TTF and flexural strength at four different ages shall be determined and used in the development of the maturity curve. Additional ages may be tested. Three specimens, per age, shall be tested for flexural strength in accordance with AASHTO T 97. The TTF shall be recorded directly using a maturity meter or

calculated from a temperature reading using a hand-held thermometer. The first three beams shall be tested for flexural strength 24 h after casting. The remaining tests shall be conducted at 12 h intervals and span a range in flexural strength that includes the desired flexural strength. An alternate testing schedule may be approved by the Engineer.

7.5.1 Maturity Meter. The Sum of TTF values are computed by the meter. The maturity meter shall remain connected to the temperature control beam until the last TTF is computed.

One Sum of TTF, per probe, shall be entered in the Maturity Testing Curve Development sheet for the appropriate age. This sheet is found in MAT402, under the tab labeled "Curve".

7.5.2 Hand Held Thermometer. The measured temperature shall be recorded and entered in the TTF worksheet for the appropriate age. This sheet is found in MAT402 under the tab labeled "TTF calc". Temperatures for each probe shall be entered in a separate worksheet. The initial temperature of the first three beams shall be recorded at the time of casting. See Appendix A for a sample sheet.

The Sum of TTF, for each probe, shall be entered in the Maturity Testing Curve Development Sheet of the appropriate age. This sheet is found in MAT402, under the tab labeled "Curve".

- 7.6** Test the beams for flexural strength in accordance with AASHTO T 97. Record the actual load, average depth, and average width in the Maturity Testing-Curve Development Sheet, for the appropriate age. This sheet is found in MAT402 under the tab labeled "Curve".
- 7.7** MAT402 shall be used to determine the maturity-strength relationship and to develop the maturity curve. The influence of maturity on flexural strength of concrete is CMD specific; therefore, a maturity-strength relationship and maturity curve established for one CMD shall not be used for another CMD.
- 7.8** The computed R^2 value obtained from regression analysis of the maturity-strength relationship shall be 0.950 or higher. The R^2 value may be found on the maturity curve chart. When R^2 value is below 0.950, the TTF value is not generated and the maturity curve is unacceptable.
- 7.9** The TTF corresponding to the required flexural strength is calculated by MAT402 and is reported in the Maturity Testing-Curve Development Sheet. This TTF shall be used to determine when the PCCP has reached the required flexural strength. See Appendix B for a sample.

8.0 FIELD PROCEDURE.

- 8.1** Insert the temperature probe/sensor into the plastic concrete prior to curing.
- 8.2** A minimum of two temperature probes/sensors shall be placed within 100 ft. (30 m) of the end of each production day or the last patch of the day. The Contractor may place additional temperature probes/sensors to substantiate required flexural strength at additional locations. The temperature probe/sensor shall not be placed within 5 ft (1.5 m) of transverse joint except for patching. The Engineer will determine the location of the temperature probe/sensor for patching. The tip of temperature probe/sensor shall be placed into the PCCP until the end is at approximately the pavement mid-depth and 1.6 ft (0.5 m) from the edge of the plastic PCCP. Insertion may be accomplished by attaching the tip of the temperature probe/sensor to a 0.25 in. (6 mm) diameter wooden dowel. The wooden dowel shall be removed.
- 8.3** The data may be collected by a maturity meter or a hand-held thermometer. When a wired maturity meter is used, the temperature probe/sensor connector end shall be connected to a maturity meter in accordance with the manufacturer's instructions. When a hand-held thermometer is used, the temperature probe/sensor connector end is connected to the thermometer when a temperature is taken. The initial temperature of the PCCP shall be taken immediately after the temperature probe/sensor is inserted. The initial temperature of the concrete shall be recorded in the TTF Worksheet for each probe. See Appendix A for a sample of the TTF Worksheet.
- 8.4** The PCCP may be opened to traffic when the average TTF of the two probes representing the end of the day's production reaches the required TTF as determined in accordance with 7.0. The average TTF at an additional location shall be calculated from the TTF of the additional probes at that location.

9.0 VALIDATION PROCEDURE.

9.1 Field Validation Tests.

- 9.1.1** Frequency of Validation Testing. Validation testing is performed to determine if the concrete being produced is represented by the maturity curve for the CMD.
- a) QC/QA PCCP Pavements. Validation tests shall be conducted on the third subplot of every fourth lot and on the first subplot of each new CMD in accordance with 501.04.

b) PCCP Patching. Validation tests shall be conducted on the first day of production and once every 600 yd³ for each CMD.

9.1.2 A minimum of three additional beams shall be cast in accordance with AASHTO T 23 at the time of the QC air content test for subplot.

9.1.3 A temperature probe/sensor shall be inserted near each end of the test beam used to monitor temperature. This beam shall be designated the temperature control beam. The temperature probe/sensor shall be placed approximately mid-depth and approximately 3 in. from each end. Insertion may be accomplished by attaching the tip of the temperature probe/sensor to a 0.25 in. diameter wooden dowel. The concrete shall be consolidated around the dowel. When a wired probe/sensor is used secure the loose end wire of the probe/sensor to the beam box to prevent being inadvertently pulled out of the beam during first 24 h of curing. This beam shall be the last beam tested for flexural strength.

9.1.4 The beams shall be covered with wet burlap and polyethylene sheeting upon initial set. The forms, wet burlap and polyethylene sheeting shall be removed 24 h after casting. All beams shall be cured in a testing facility in accordance with 508.09, until each has been tested.

9.1.5 The TTF of the temperature control beam shall be monitored with a maturity meter in accordance with 7.5.1 or by temperature reading using a hand-held thermometer in accordance with 7.5.2. All three beams shall be tested when the control beam average TTF reaches or exceeds the expected value determined to represent the required flexural strength. The Contractor's work schedule shall determine the time of testing. Report the TTF, the actual load, the depth, the width, and the age for each beam tested in the Maturity Testing-Curve Validation Sheet. This sheet is found in MAT402 under the tabs labeled "val".

9.1.6 The average flexural strength of these three beams is calculated and compared to the predicted flexural strength by MAT402. This data is summarized in the Maturity Testing-Curve Validation Sheet. If the average of these tests is within 50 psi of the original curve for the concrete mixture, the maturity curve is considered validated. If the average value is not within these limits, the maturity process is not valid. A computer printout example for validation of maturity curve is provided by Appendix C.

10.0 REPORT. Copies of all computer printouts, diskettes and field data shall be submitted to the Engineer upon completion of the work. All thermocouple assemblies shall be cutoff flush with the surface of the PCCP upon completion of the work.

INDIANA DEPARTMENT OF TRANSPORTATION

Maturity Testing Time Temperature Factor (TTF) Worksheet

Contractor: ABC Construction Co.

Probe No.: 12

Project No.: R-99999

Date: 10/22/07

Description: I-999 Reconstruction

Time: 3:00 pm

Datum Temperature: - 10° C

Reading			Age	TTF (C°-h)	Sum of TTF (C°-h)
Number	Date / Time	Temperature			
1	5/5/98 / 8:00 am	28 °C			
2	5/6/98 / 8:00 am	27 °C	24.0 h	900.0	900.0
3	5/6/98 / 8:00 pm	26 °C	36.0 h	438.0	1,338.0
4	5/7/98 / 8:00 am	25 °C	48.0 h	426.0	1,764.0
5	5/7/98 / 8:00 pm	20 °C	60.0 h	390.0	2,154.0
6	5/8/98 / 8:00 am	18 °C	72.0 h	348.0	2,502.0
7					
8					
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25					

Signature: _____

Contractor Representative

Indiana Department of Transportation
MATURITY TESTING - CURVE DEVELOPMENT

Contractor: ABC CONSTRUCTION CO.

Contract No.: R-99999

Date: 05/05/99

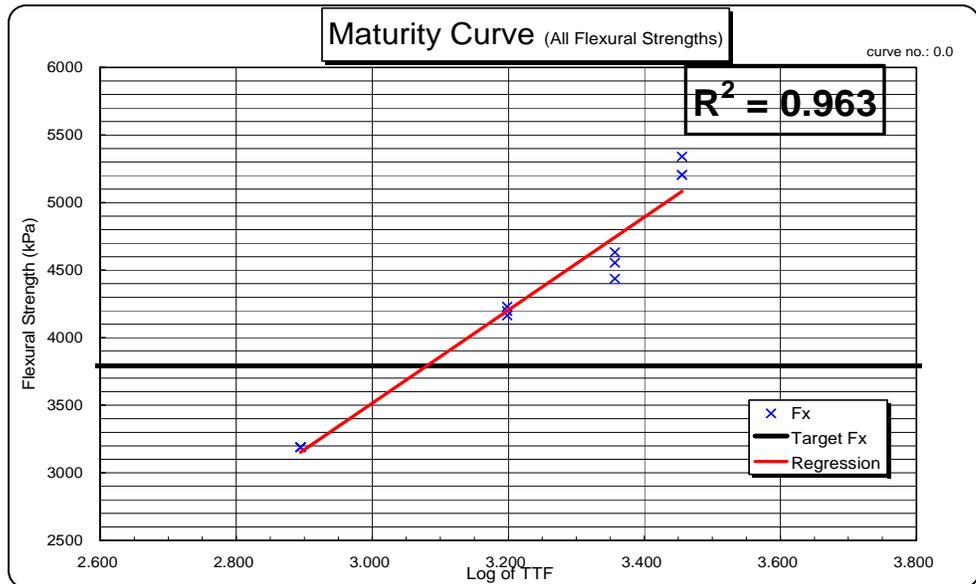
Time: 1:48 PM

Location: I-999 RECONSTRUCTION

Beam Number	Actual Load * (N)	Depth (mm)	Width (mm)	Flexural Coefficient	Flexural Strength (kPa)	Age at Break (hrs.)	Temperature-Time Factor		Average TTF (C°-hrs)
							Probe1 (C°-hrs)	Probe 2 (C°-hrs)	
1	24,500	152	152	0.1301	3,188	24	784	784	784
2	24,500	152	152	0.1301	3,188	24	784	784	784
3	24,500	152	152	0.1301	3,188	24	784	784	784
4	32,000	152	152	0.1301	4,164	36	1,566	1,591	1,579
5	32,500	152	152	0.1301	4,229	36	1,566	1,591	1,579
6	32,250	152	152	0.1301	4,197	36	1,566	1,591	1,579
7	35,600	152	152	0.1301	4,633	48	2,262	2,285	2,274
8	35,000	152	152	0.1301	4,555	48	2,262	2,285	2,274
9	35,000	154	152	0.1268	4,437	48	2,262	2,285	2,274
10	40,000	152	152	0.1301	5,205	60	2,858	2,852	2,855
11	40,500	152	150	0.1319	5,341	60	2,858	2,852	2,855
12	40,000	152	152	0.1301	5,205	60	2,858	2,852	2,855

Plastic Test Results	
Test No:	P7
Air Content:	5.8%
Slump:	51 mm
W/C Ratio:	0.420
Beam Monitoring	
Equipment Used:	Maturity meter
Starting Temperature:	20 °C

Maturity Criteria for Opening to Traffic	
(Equivalent to 3792kPa flexural beam strength)	
TTF (C°-hrs)	1,203
Log of TTF	3.080



Material		Type	Manufacturer / Plant	Admixture	Type	Source	Dosage
Cement	Type 1	Gray Bros. Industries		Water Reducer	SLS 5500	XL Chemical	14.00 mL/m³
Fly Ash	Type C	Just Ash		A. E. Agent	SOP2500	XL Chemical	14.00 mL/m³
Coarse Agg.	#8 Stone	Stone World / (3rd St. Plant)					
Fine Agg.	#23 Sand	Just In Time Sand Co. / (Red River)					

Comments:

Signature

Contractor Representative

VALIDATION

ITM 402-04

Indiana Department of Transportation
MATURITY TESTING - CURVE VALIDATION

Contractor: ABC CONSTRUCTION CO.

Curve No.: 0

Project No.: R-99999

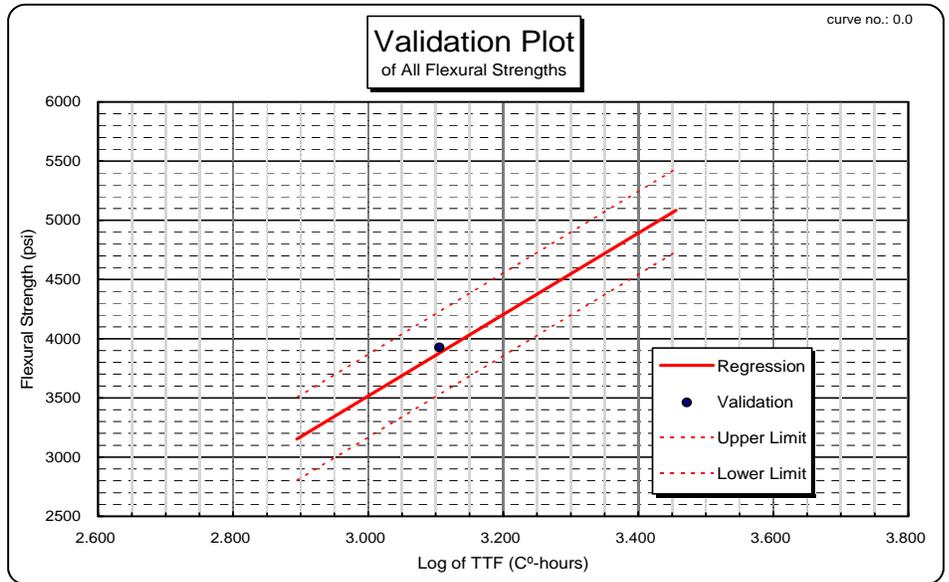
Date: 05/10/99

Description: I-999 RECONSTRUCTION

Time: 8:09 AM

Beam Number	Actual Load * (N)	Depth (mm)	Width (mm)	Flexural Coefficient	Flexural Strength (kPa)	Age at Break (hrs.)	Temperature-Time Factor		
							Probe 1 (C°-hrs)	Probe 2 (C°-hrs)	Average TTF (C°-hrs)
1	30,210	152	152	0.1301	3,931	36	1,275	1,275	1,275
2	30,200	152	152	0.1301	3,930	36	1,275	1,275	1,275
3	30,100	152	152	0.1301	3,917	36	1,275	1,275	1,275
Average						3,926 kPa	Average		1275
							Log		3.106

Plastic Test Results	
Test No:	P71
Air Content:	6.0%
Slump:	2 in.
W/C Ratio:	0.396
Beam Monitoring	
Equipment Used:	Digital thermometer
Starting Temperature:	22 ° C



Summary			
Predicted Beam Break*	Actual Beam Breaks (average)	Difference from Target	Result
Lower Limit 3,529 kPa	3,926 kPa	47 kPa above	Within Acceptable Range
Target 3,879 kPa			
Upper Limit 4,229 kPa			

* Predicted beam break results were obtained by plotting the validation TTF on the mix maturity curve (above). Upper and lower limits are as specified for the test method.

Comments:

Signature

Contractor Representative