MATURITY OF CONCRETE: FIELD IMPLEMENTATION

Final Report
For
MLR-96-1

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Project Development Division

Iowa Department
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by
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8. ABSTRACT

The result and experience of field implementation of the maturity method on 14 portland cement concrete (PCC) paving and patching projects during 1995 are summarized in this report. The procedure for developing reference PCC maturity-strength curve of concrete is discussed. Temperature measurement as well as effects of datum temperature, entrained air content and type of aggregate on maturity-strength relationship are examined. Some limitations of the maturity method are discussed. The available field experience and results indicate that the maturity method provides a simple approach to determine strength of concrete, and can be easily implemented in field paving and patching projects. The use of the maturity method may result in reduced project construction time.

9. KEY WORDS

Maturity
Strength
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10. NO. OF PAGES

36

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DISCLAIMER

INTRODUCTION

A previous laboratory study[1] has shown that strength development of concrete within normal range of curing temperature can be monitored by using the maturity concept. This result indicates that the maturity method could be used for determining PCC pavement strength as well as the time of pavement opening to traffic in the field, which may reduce project construction time. In order to achieve this goal and to further evaluate the maturity method in comparison with the existing procedures, it has been used on fourteen PCC paving and patching projects during 1995. These projects are listed in Tables 1 and 2. The objective of this report is to summarize the field implementation of the maturity method, and to provide some guidance for future field use.

TEST PROGRAM AND SET UP FOR MATURITY MEASUREMENT

The test program is based on ASTM C1074 for measurement of maturity. Test set up includes some thermocouple wires, and either a maturity meter (Humboldt MFG. Co., model H-2680) or a thermal meter. A field set up for maturity measurement is shown in Fig. 1. Several beams were cast for measuring modulus of rupture (MOR) of concrete at different ages. The thermocouple wires were embedded in pavement slab or a beam, and connected to either the maturity meter or the thermal meter. When a maturity meter is used, both temperature and maturity number, which is also termed as time temperature factor (TTF), can be directly obtained. On the other hand, if a thermal meter is used, only temperature can be obtained. Values of maturity number can then be calculated based on the temperature-time measurement using the following equation,

$$M = \sum (T - T_0)\Delta t \qquad (1)$$

where M is the maturity (or time-temperature factor) in degree-hours (or degree-days), Δt is the time interval in hours (or days), T is the average concrete temperature during the time interval Δt, and T_0 is the datum temperature at which concrete does not gain strength with time. The value of the datum temperature will be discussed later.

These beams were tested at different ages to obtain modulus of rupture (MOR) of concrete. Three beams were usually tested at the selected ages. The obtained values of MOR were plotted against corresponding values of maturity for different ages. This resulted in reference maturity-strength relationship. By comparing maturity reading of the same field concrete to the reference chart, strength of the field concrete can be easily determined. Based on the obtained strength of the field concrete, a decision on when the pavement can be opened to traffic can be made.

RESULTS AND DISCUSSIONS

The key issue for using the maturity method is to establish the maturity-strength relationship for field concrete. Some problems related to the determination of the maturity-strength relationship in field (or laboratory) will be discussed. The effects of temperature measurement, datum temperature, entrained air content and type of aggregate on the maturity-strength relationship will be examined in this section.

Maturity Measurements in Slab and Beam

For construction projects in Iowa, strength development of the pavement slab is generally monitored by testing 6 x 6 x 24 in. beams under center-point loading. Even though the pavement slab and the beams are made of the same concrete, they gain strength at different rates because they are cured somewhat differently. Therefore, the concrete strength obtained by testing the beams only approximates that of the slab. The beam and the slab have different masses of the concrete. As a result, they have different temperature values at a given age. A question to be answered is which temperature measurement, from the beam or from the slab, should be used to calculate the maturity values.

The temperature developments for an Iowa Department of Transportation Standard Mix C-3WR-C20 recorded in a beam and in the pavement slab for project IM-805(184)160--13-50 in Jasper County are shown in Fig. 2a. As expected, the slab initially has higher temperature than the beam. This may be due to the fact that the slab has greater mass of the concrete, which generates and stores more heat during hydration of cement. However, this difference in temperature gradually vanishes as age increases. Since maturity is an accumulated product of temperature and age as indicated by Eq. (1), the maturity values at a given age in the slab are somewhat greater than in the beam as shown in Fig. 2b. In Fig. 2c, MOR values of the concrete at different ages, which were measured using the beams, are plotted against the maturity values measured from the beam.

Similar results were also observed from Project FM-67(25)--55-67 using Mix B-5-C10 in Monona County (see Fig. 3).

These results indicate that for pavement constructed using B-mix or C-mix, which is expected to open to traffic after several days of age, the use of strength-maturity curve obtained from beams to estimate slab strength in pavement is somewhat conservative.

Temperature history of patching project, FM-37(22)--55-37 in Greene County, is shown in Fig.4a, where Mix M-4 with calcium chloride was used. Although the temperature in the patch is generally greater that in the beam, maturity values measured in the patch and in the beam are almost the same at any given age as indicated in Fig. 4b. As a result, the difference in maturity-strength relationship is negligible in this case.

Temperature measurements from a beam and from a patch (Mix M-4 with calcium chloride) for Project MP-3-3(700)18--76-75 in Plymouth County are shown in Fig. 5a. In this case, the patch has much higher temperature than the beam. This leads to much greater values of the maturity at a given age for the patch as indicated in Fig. 5b. The tested values of MOR for this concrete are plotted against the maturity values obtained from the beam in Fig. 5c.

Since a patch constructed using Mix M-4 with calcium chloride usually opens to traffic after several hours rather than several days, maturity values based on measurements from a beam and from the patching might be significantly different as discussed above. Because values of MOR are measured using beams, corresponding maturity measurement based on the beam, rather than on the patching, should be used to establish maturity-strength curve as shown in Fig. 5c. However, actual strength of patching is higher than that in the beam. In other words, the open to traffic strength obtained in such a way is conservative.

Effect of Datum Temperature

As indicated in Eq. (1), the value of maturity depends on the selection of the datum temperature, T_0, below which concrete will show no increase in strength with time. Different values for the datum temperature have been proposed by different investigators. These values are in the range from -10°C to -20°C. The value of -10°C is most commonly used[2].

The temperature measurement for Mix C-3WR-C20 used in Project IM-80-5(184)160--13-50 (Jasper County) is shown in Fig. 6a. Based on this temperature-age relationship, values of maturity can be calculated from Eq. (1) using the datum temperatures of -10°C and -20°C, respectively, as given in Fig. 6b. The maturity value for the datum temperature = -20°C is greater than that for the datum temperature = -10°C for a given age. These obtained values of MOR are plotted against the maturity values for the datum temperatures of -10°C and -20°C in Fig. 6c, respectively. Although different values of the datum temperature shift positions of the MOR-maturity curves, shapes of the curves are almost identical. This result implies that any values of the datum temperature with the range from -10°C to -20°C can be used to develop reference MOR-maturity curve. However, once a certain value of the datum temperature is selected to develop the reference MOR-maturity curve, the same value should be used later for calculating maturity values which will be compared with the reference curve to obtain corresponding strength of concrete. Although the datum temperature of -10°C and -20°C can be used, the value of -10°C is recommenced since it has been used by most investigators.

A similar result was observed from Project IM-29-3(52)-61--13-78 using Mix C-4WR-CIP-10 in Pottawattamie County as shown in Fig. 7.

Effect of Entrained Air Content

Maturity-age relationships for patching concrete, Project MP-3-3(700)18--76-75 in Plymouth County, with entrained air contents of 4.0% and 5.5%, respectively, are given in Fig. 8a, where Mix M-4 with calcium chloride was used. Corresponding MOR-maturity curves are shown in Fig. 8b. It is found that two patching concretes with air contents of 4.0% and 5.5%, respectively, have almost the same MOR-maturity curve. This result indicates that the influence of approximately up to 2% difference in entrained air content is negligible for field application of the maturity method.

Effect of Coarse Aggregate Type

Strength values of three concrete mixes used in Project IM-80-8(160)279--13-82 (Scott County) are plotted against concrete age and maturity in Figs. 9a and b, respectively. The three mixes include: 1) Mix C-3WR-C20 with coarse aggregate from Linwood (No. A82008), Scott County; 2) Mix C-3WR-C20 with 65% of Linwood coarse aggregate and 35% of 3/8" chips from the same source; and 3) Mix C-3WR-C20 with 10% reduction of cement and 35% of the chip replacement. The fine aggregate from General (AIL504), Rock Island, Illinois was used for all the mixes.

It was found that mix 2 (C-3WR-C20 with 35% chip replacement) has higher strength than mix 1 (C-3WR-C20 with 100% Linwood coarse aggregate) at any given age or maturity value. This result indicates that a 35% chip replacement to improve gradation will increase the strength of the concrete. On the other hand, mix 3 (C-3WR-C20 with 10% reduction of cement and 35% chip replacement) shows the lowest strength.

Effect of Reading Frequency of Temperature

When a thermal meter is used in the field, only readings of temperature can be obtained. A patch using M-mix with calcium chloride is expected to open to traffic several hours after placing. As a result, temperature should be read hourly for this case. On the other hand, a PCC pavement using C-mix or B-mix is expected to open to traffic several days after placing. The question of how often should the pavement temperature be read in order to produce acceptable values of maturity was investigated.

The actual values of temperature of Mix B-5-C10 used for Project FM-67(25)--55-67 in Monona County are shown in Fig. 10a by the solid line, where the temperature was continuously read (day and night readings). The dash line in Fig. 10a represents the temperature values read during daytime only (two readings per day). By substituting these two sets of temperature values into Eq. (1), corresponding values of maturity were obtained. These values of maturity are plotted in Fig. 10b. Although the maturity values based on the day temperature readings are generally greater than those based on the day-night temperature readings, difference between them is negligible. This is further confirmed by strength-maturity relationships shown in Fig. 10c.

Maturity-Strength Plots for Some Standard Mixes

To implement the maturity method in the field, the reference maturity-strength curve for the mix used is usually developed in advance. This leads to an interesting question. If several field projects use a same standard mix (for example Mix C-3WR-C20), can the reference maturity-strength curve developed in one project apply to other projects? This attempt had been looked at in this study.

Maturity-strength plots for Mixes C-3WR-C20, C-4-15 and M-4 from different projects are shown in Figs. 11, 12 and 13, respectively. Although the results indicate that concrete strength increases with increasing maturity value, all plots are quite scattered. This is primarily due to the fact that the maturity-strength relationship of concrete is not only affected by mix proportion, but also influenced by chemical compositions and particle size distributions of cement and fly ash, aggregate type and gradation, curing condition, and slump. As a result, the reference maturity-strength obtained in a project, which depends on certain materials sources and construction procedure, generally cannot be used in another project, even though both projects use the same standard mix. In other words, there is no "master" reference maturity-strength curve for a standard mix, and a curve should be developed on a project-by-project basis.

SOME LIMITATIONS FOR THE MATURITY METHOD

The maturity method is usually used to account for the influence of curing temperature and time on strength development of concrete. There are some limitations of this method, which should be known when this method is implemented in field. These limitations primarily include the following points.

(1) The maturity function given by Eq. (1) does not take into consideration the effect of humidity conditions during curing. However, it is clear that this is a major effect that cannot be ignored. To overcome this, beams, which are used to determine the reference maturity-strength curve, should be cured in similar humidity condition with pavement slab. The pavement slab is normally laid on wet subgrade and cured with a curing compound. To simulate this environment, it is suggested that the beams be cured in a pit of wet sand.

(2) The maturity method cannot account for the influence of the chemical composition and the fineness of the cement on strength development of concrete. Therefore, the cement from the same source should be used for field paving and for establishing the reference maturity-strength curve.

(3) Some maturity meters, model H-2680 manufactured by Humboldt MFG. Co. were purchased (at a cost greater than $1,200 each) and used for field projects. It was found that this meter is not very durable when it is exposed to moisture condition. Two meters (out of ten) have been damaged during 1995 paving season. Vulnerability of the maturity meter to moisture condition may be too expensive for field implementation of the method. An alternative is to use a thermal meter instead of the maturity meter for field data collecting. However, as previously indicated, the use of a thermal meter requires one to calculate maturity values using Eq. (1) based on the measured temperature readings. This leads to some inconvenience in field, but may be solved by providing a user-friendly PC software for calculating maturity values and for developing the reference maturity-strength curve.

CONCLUSIONS

The maturity method was used on fourteen PCC paving and patching projects during 1995 paving season. The following are the summary of the field experience:

(1) The maturity method can be easily used to monitor strength development of field concrete. Only a maturity meter (or a thermal meter) and some thermocouple wires are needed for implementing this technique. The method can be used to decide when a new PCC pavement can be opened to traffic. The use of the maturity method may reduce project construction time.

(2) When using the method, thermocouple wires should be embedded into mid-depth of a beam to monitor change of temperature. The thermocouple wires should be in good contact with surrounding concrete.

(3) The use of the datum temperature in the range of -10°C and -20°C doesn't affect the validity of the maturity method. However, the same datum temperature should be used for developing the reference maturity-strength curve and for evaluating maturity values of field concrete. For simplicity, the datum temperature of -10°C is recommended for all field applications.

(4) The same reference maturity-strength curve may be used for concretes with entrained air content within the specification limits. These concretes should have the same materials and mix proportion.

(5) When sources of materials (cement, fly ash and aggregate), aggregate gradation, or mix proportion change, new reference maturity-strength curve should be developed. There is no "master" reference maturity-strength curve for any standard mix.

(6) The effect of humidity condition during curing cannot be taken into account by the maturity method. Therefore, beams should be cured in similar humidity condition with pavement slab. It is suggested that the beams should be cured in a pit of wet sand.

(7) When a thermal meter is used for temperature measurement, temperature values should be read hourly for patch using M-mix with calcium chloride. On the other hand, two readings on temperature values per day (one in morning, and the other in evening) are generally enough for pavement using C-Mix or B-mix.

RECOMMENDED FIELD PROCEDURE

Based on the above study, the following procedure is recommended for field implementation of the maturity method.

(1) Cast nine 6" x 6" x 20" beams. These beams should be cured in a pit of wet sand.

(2) Embed a thermocouple wire couple into the mid-depth of a beam and make sure that the wire is in good contact with surrounding concrete. This monitors the change in temperature. The thermocouple wire is connected to a maturity meter (or a thermal meter).

(3) Set up and turn on the maturity meter (or thermal meter). Make sure that the datum temperature is set to -10°C. Record changes of temperature and maturity with time. When a thermal meter is used, temperature values should be read hourly for patch using M-mix with calcium chloride. On the other hand, two readings on temperature values per day (one in morning, and the other in evening) are generally enough for pavement using C-Mix or B-mix. When a

thermal meter is used, values of maturity should be calculated using Eq. (1) based on temperature-time history.

(4) Select four different ages and test two beams to obtain average strength of the concrete at each age. The ages are selected in such a way that they should reasonably cover target strength used. The last beam, beam #9, should be tested at a age later than the other eight beams. This is intended to provide a strength value of the concrete at later age. Maturity values listed in Table 3 may be used as reference for selecting these ages at which the beams are tested. The obtained strength values are then plotted against corresponding values of maturity to establish reference maturity-strength curve for the concrete.

(5) Compare maturity values of the field concrete with the established reference maturity-strength relationship to evaluate strength of the concrete. The time for traffic opening of the field concrete can then be determined based on the obtained concrete strength.

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1. Ouyang, C., "Strength Development of Concrete Based on Maturity and Pulse Velocity," Final Report for MLR-95-3, Project Development Division, Iowa Department of Transportation, June 1995, 28pp.

2. Mindess, S., and Young, J. F., CONCRETE, Prentice-Hall, Inc., Englewood Cliffs, H.J. 07632, 1982, P.390.

TABLE TITLES

Table 1 List of Field Paving Projects

Transp. Centers	Counties	Project No.	Mix No.	Air Content	Curing Conditions	Slump (in.)
Central Lab.	Story	BG-9A10-000-80-85	C-3WR-C20	6.9%	Plastic.	1 1/4
	Lee	FM-56(18)--55-56	C-3WR-C15	7.0%	1st day plastic, then moisture room.	1 3/4
Central Iowa	Jasper	IM-80-5(184)160--13-50	C-3WR-C20	6.8%	Curing compound.	2 1/4
Northeast Iowa	Cerro Gordo	STP-U-1372(1)--70-17	C-4-C15	7.4%	Plastic and burlap.	3 1/2
Northwest Iowa	Monona	FM-67(25)--55-67	B-5-C10	7.4%	Plastic.	2 1/2
	Woodbury	STP-U-7057(6)--70-97	C-4-C15	6.9%	Plastic.	2 1/2
Southwest Iowa	Pottawattamie	IM-29-3(52)-61--13-78	C-4WR-CIP-10	7.3%	1st day wet burlap & plastic, then water tank.	1.0
Southeast Iowa	Des Moines	NHS-61-2(47)--19-29	C-4WR-C15	6.5%	Curing compound.	1 1/2
	Lee	NHS-61-1(67)--19-56	C-4WR-C20	7.4%	Curing compound.	1 1/2
East-central Iowa	Scott	IM-80-8(160)279--13-82	C-3WR-C20	11.5%	1st day plastic, then wet sand & curing compound.	1 1/2
			C-3WR-C20*	10.6% hardened	1st day plastic, then wet sand & curing compound.	1 1/2
			C-3WR-C20#	14.9% hardened	1st day plastic, then wet sand & curing compound.	1 1/2

* 35% of coarse aggregate was replaced by chip.
# 35% of coarse aggregate was replaced by chip and cement content was reduced by 10%.

Table 2 List of Field Patching Projects

Transp. Centers	Counties	Project No.	Mix No.*	Air content	Curing condition	Slump (in.)
Central Iowa	Greene	FM-37(22)--55-37	M-4	4.0%	Insulated blanket & fiber board	2 1/4
Northwest Iowa	Buena Vista	MP-7-7(701)21--76-11	M-4	5.0%	Insulated blanket & fiber board	3.0
	Dickinson	MP-86-3(700)0--76-30	M-4	5.0%	Insulated blanket & fiber board	3.0
	Plymouth	MP-3-3(700)18--76-75	M-4	5.5%	Insulated blanket & fiber board	2 1/2
			M-4	4.0%	Insulated blanket & fiber board	2 1/4

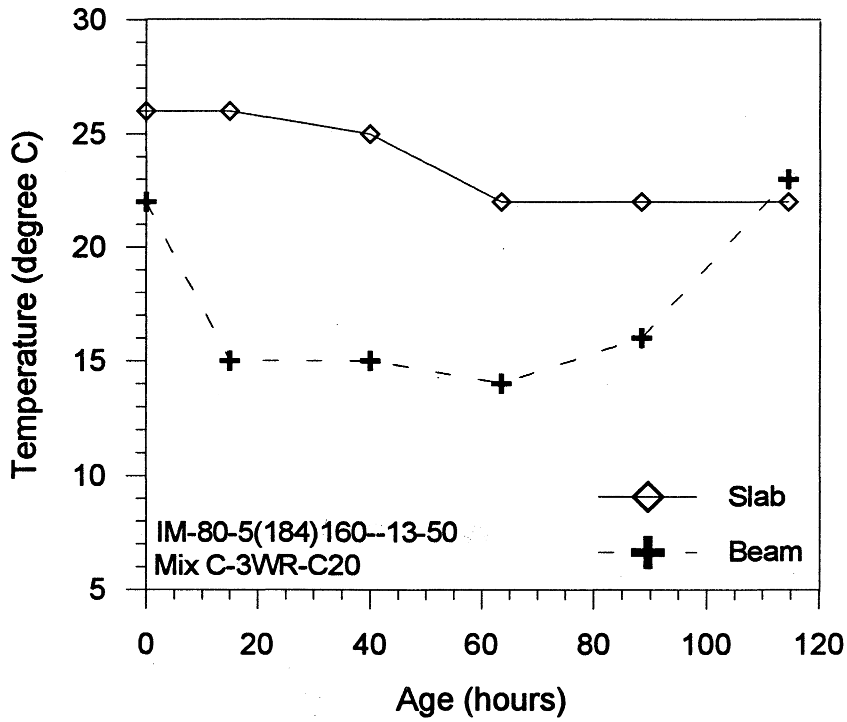
* Calcium chloride liquor (32%) was applied to all mixes.

Table 3 Reference Maturity Values for Testing Beams

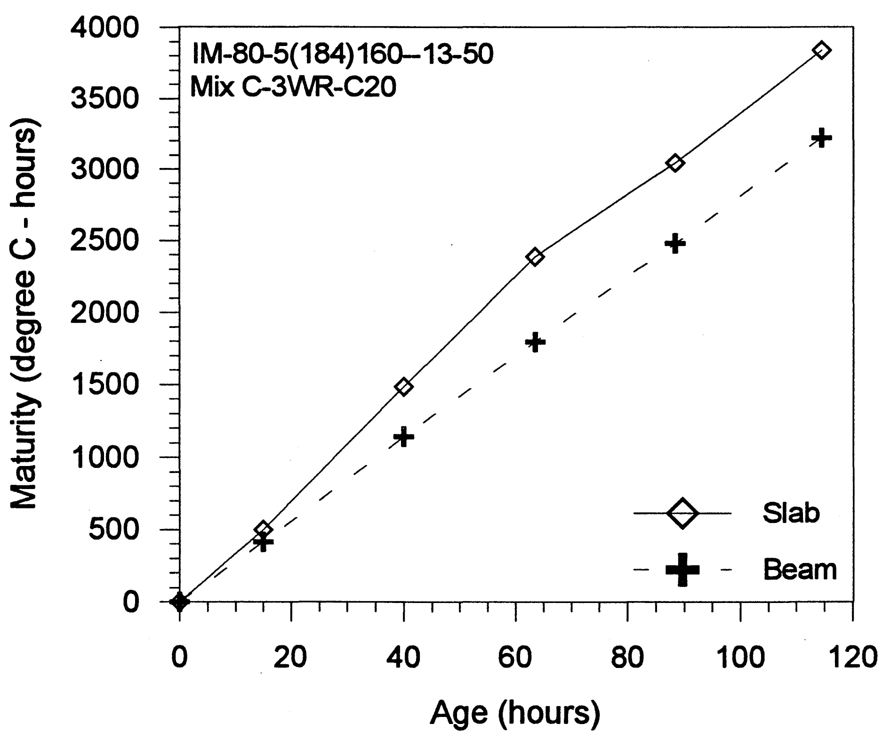
	Test 1	Test 2	Test 3	Test 4	Beam #9
B Mix	1500	3500	5500	7500	10000
C Mix	1000	2000	3000	4000	5000
M Mix with CaCl	100	200	300	400	500

FIGURE CAPTIONS

Fig. 1 Field Set-Up of the Maturity Measurement

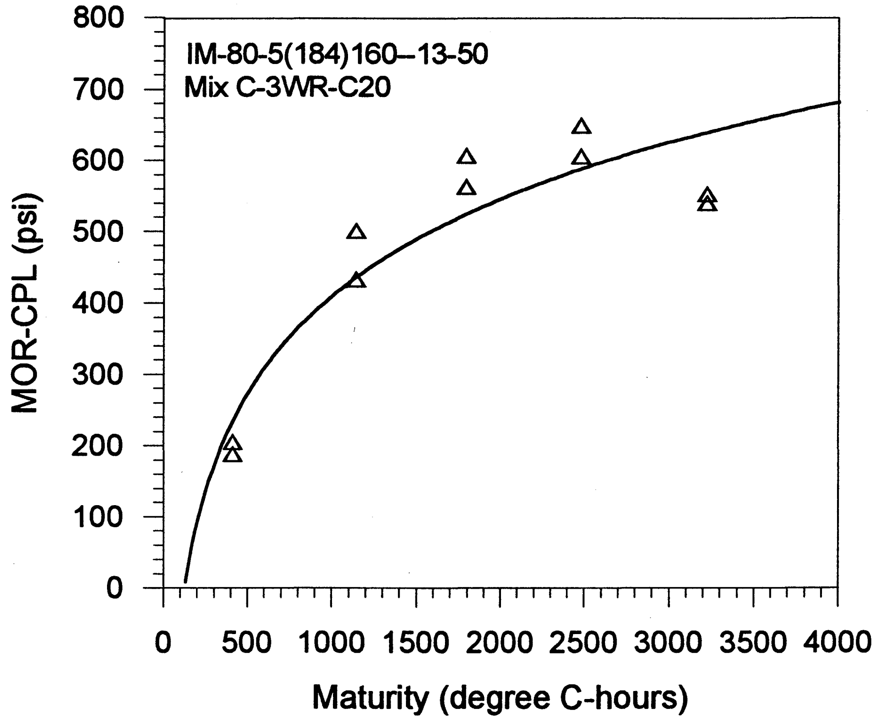


(a) Temperature-age relationship



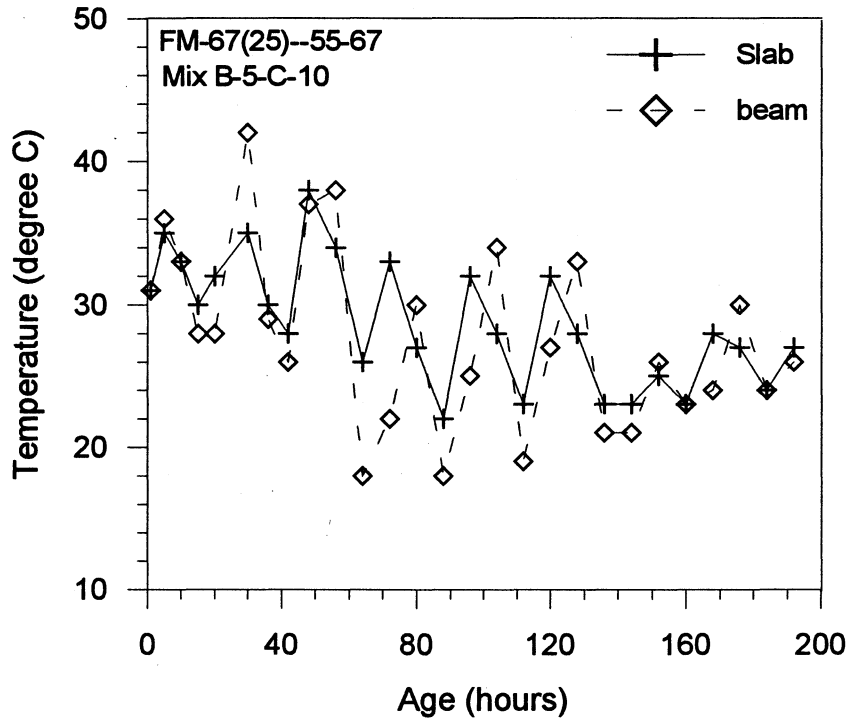
(b) Maturity-age relationship

Fig. 2 Maturity Measurement for Project IM-80-5(184)160--13-50
(Jasper County)

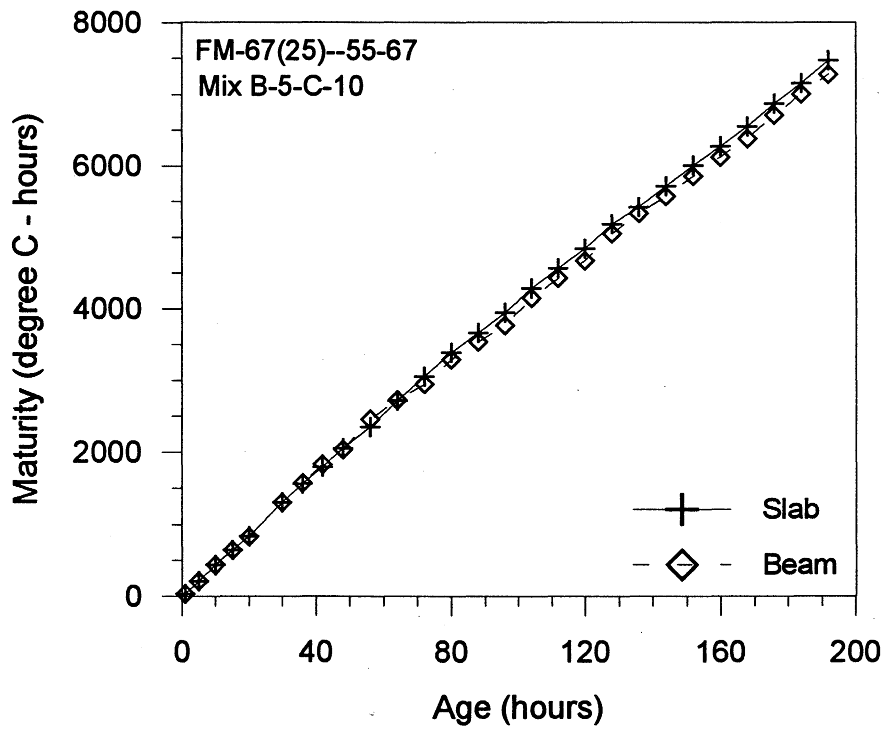


(c) Maturity-strength relationship

Fig. 2 Maturity Measurement for Project IM-80-5(184)160--13-50 (Jasper County)

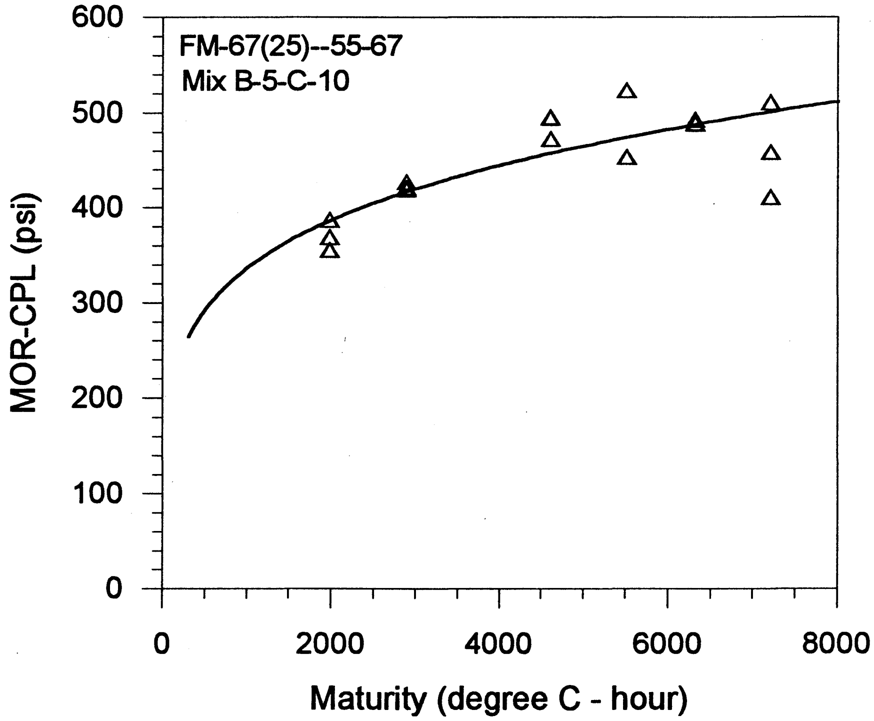


(a) Temperature-age relationship



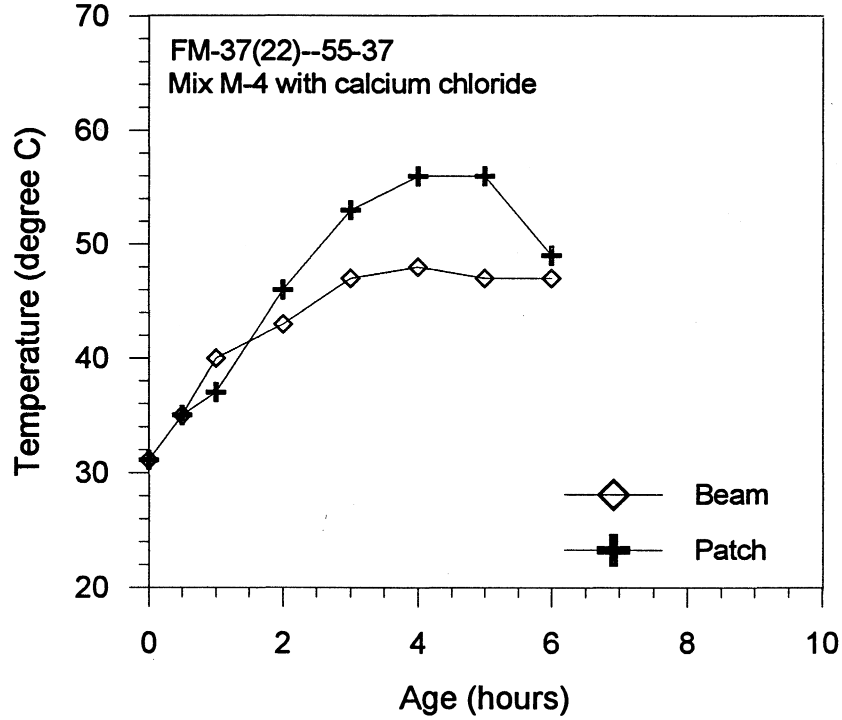
(b) Maturity-age relationship

Fig. 3 Maturity Measurement for Project FM-67(25)--55-67
(Monona County)

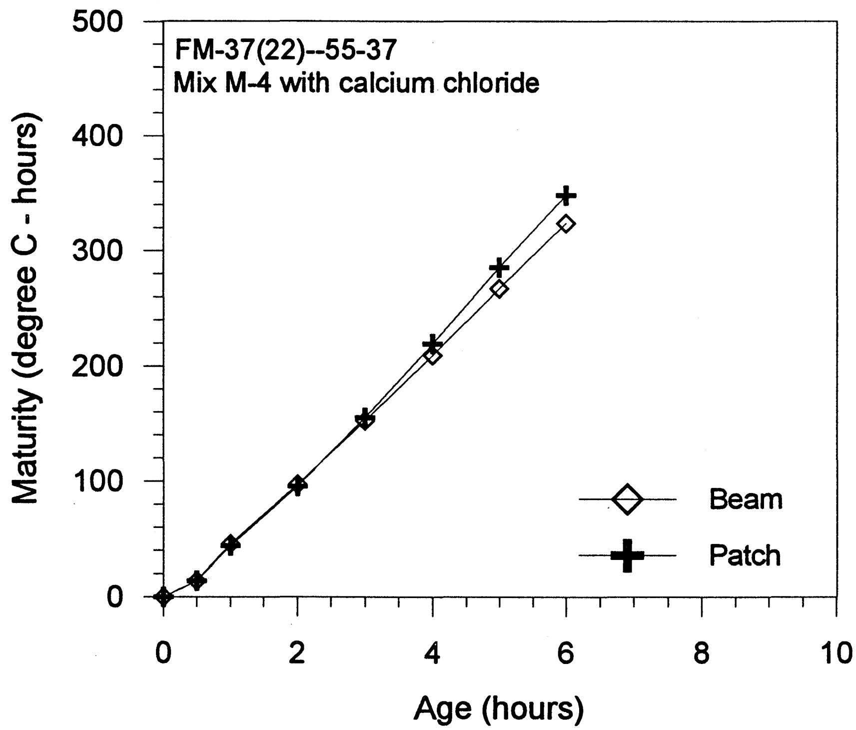


(c) Maturity-strength relationship

Fig. 3 Maturity Measurement for Project FM-67(25)--55-67 (Monona County)

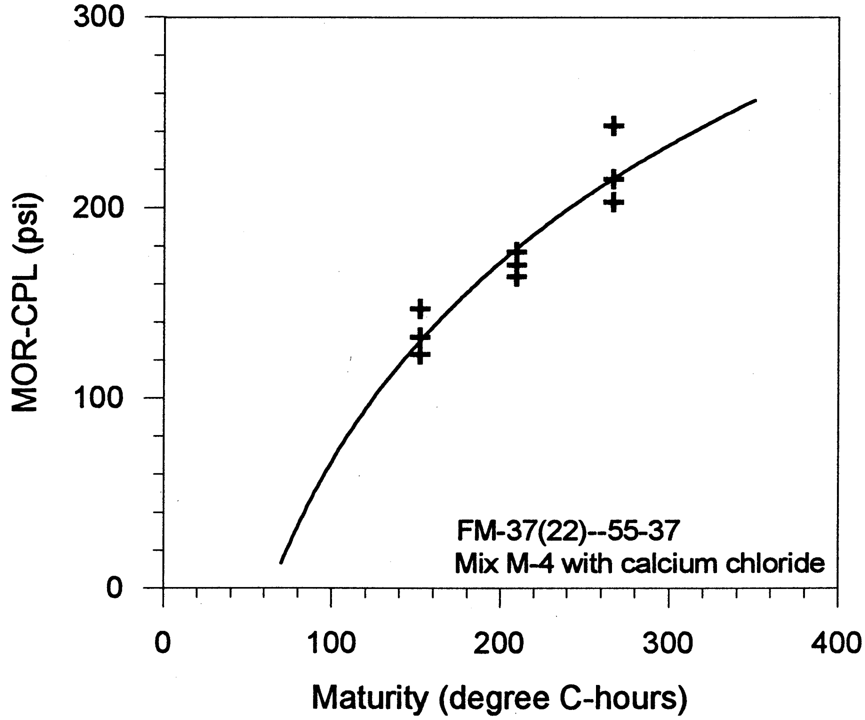


(a) Temperature-age relationship



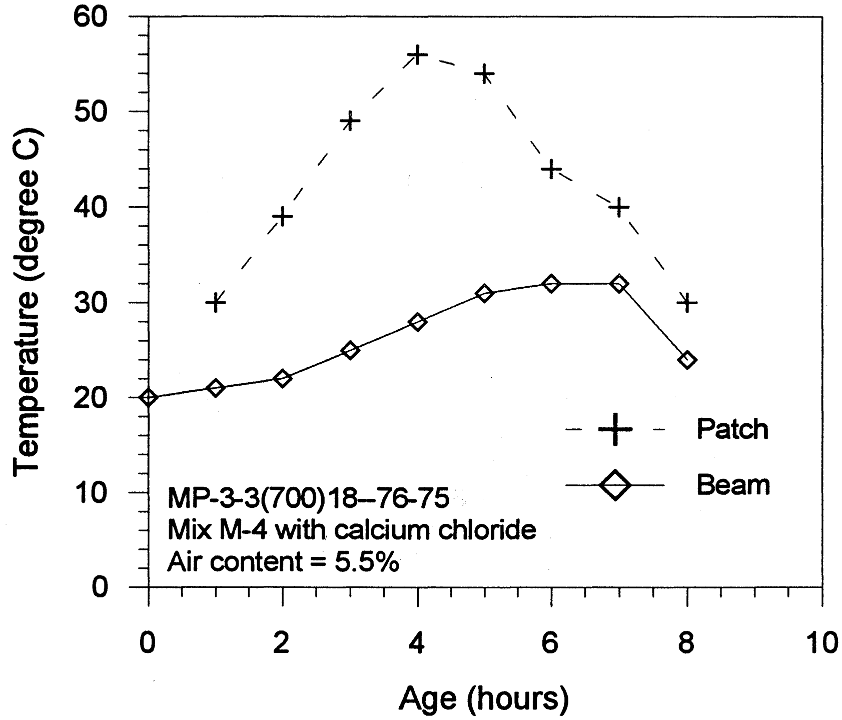
(b) Maturity-age relationship

Fig. 4 Maturity Measurement for Project FM-37(22)--55-37
(Greene County)

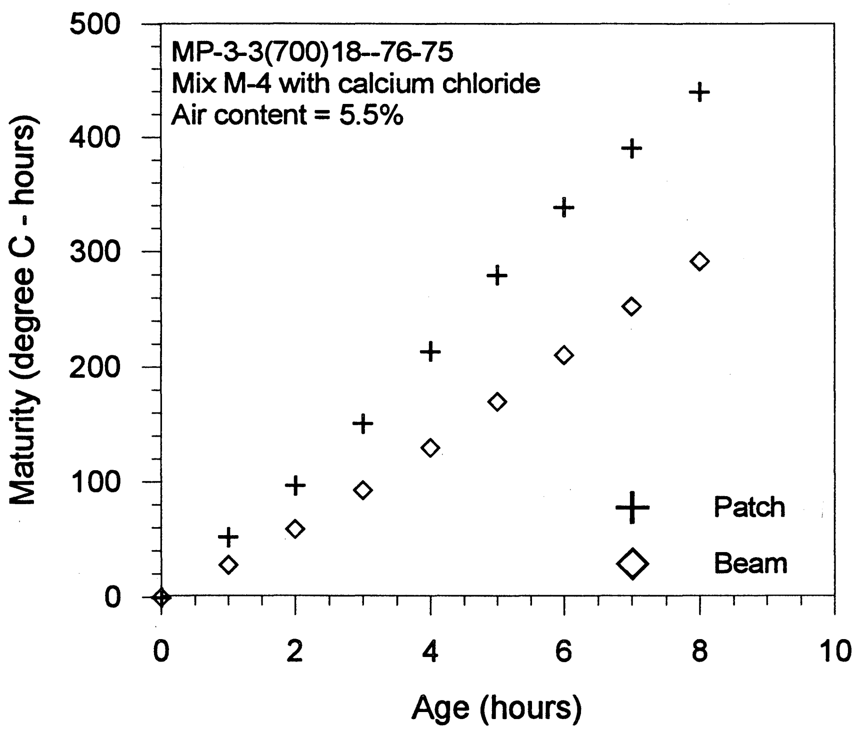


(c) Maturity-strength relationship

Fig. 4 Maturity Measurement for Project FM-37(22)--55-37
(Greene County)

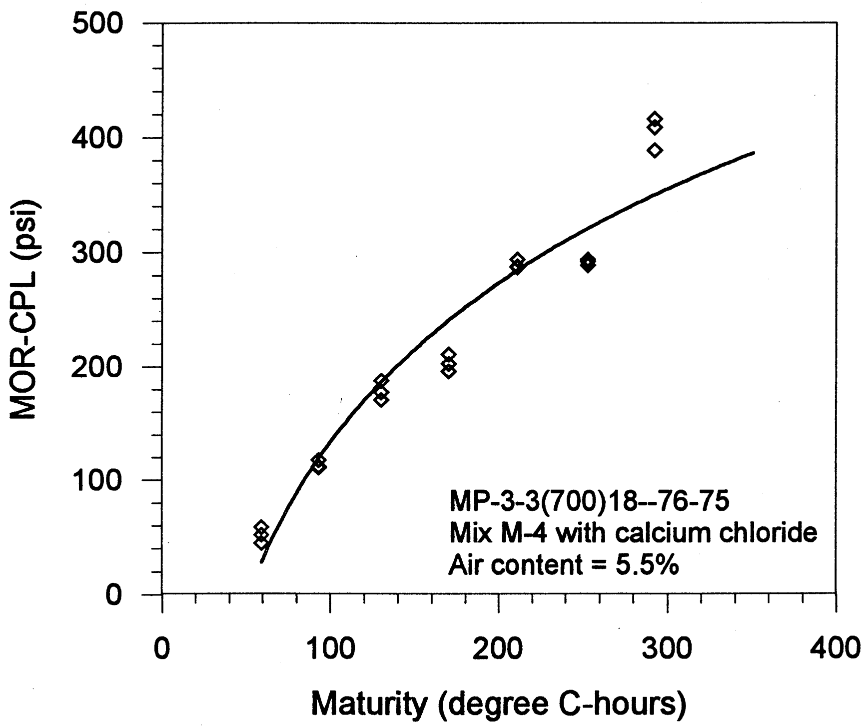


(a) Temperature-age relationship



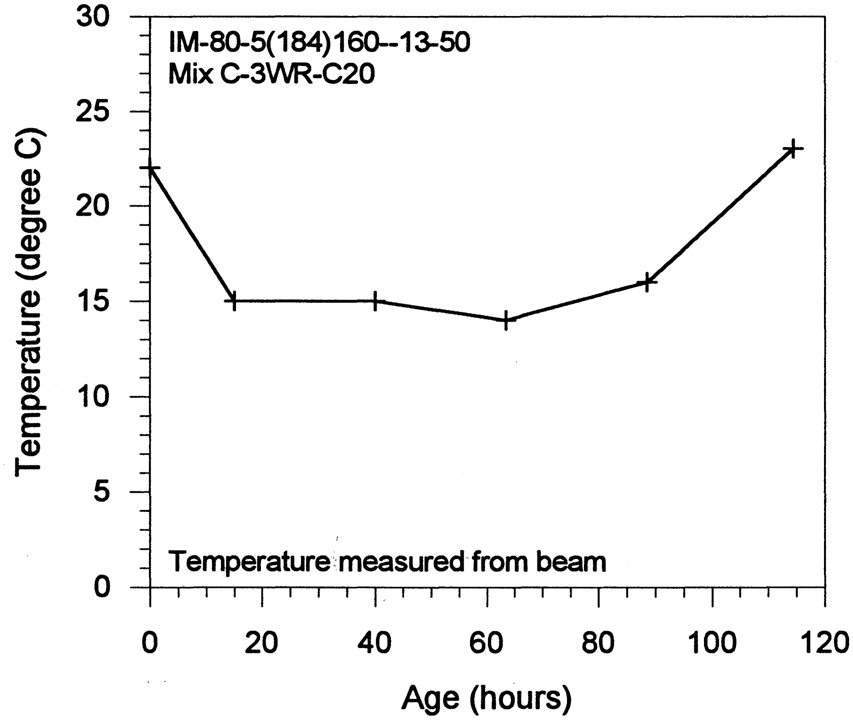
(b) Maturity-age relationship

Fig. 5 Maturity Measurement for Project MP-3-3(700)18--76-75 (Plymouth County)

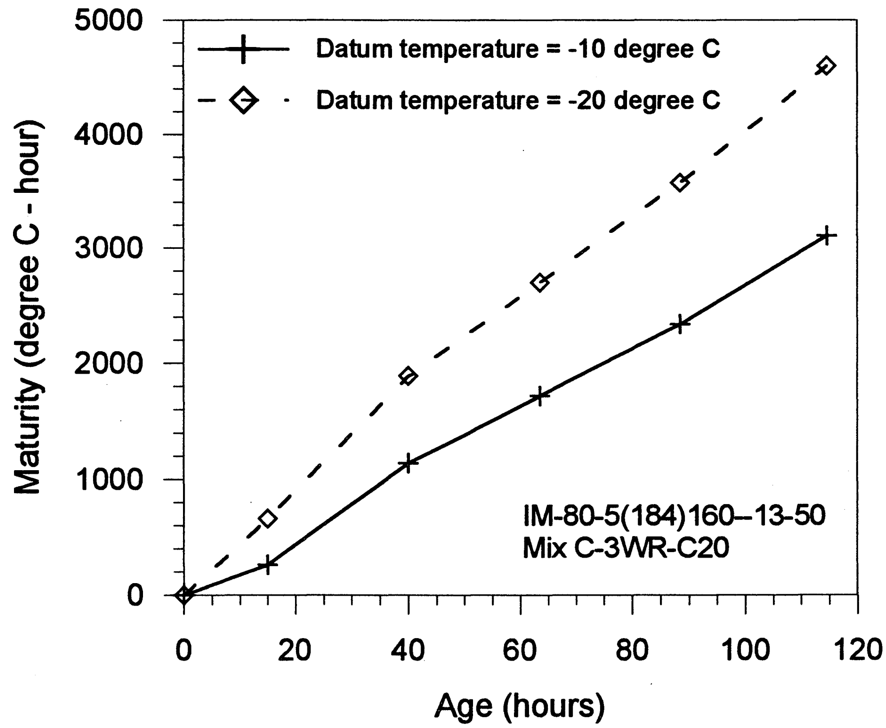


(c) Maturity-strength relationship

Fig. 5 Maturity Measurement for Project MP-3-3(700)18--76-75 (Plymouth County)

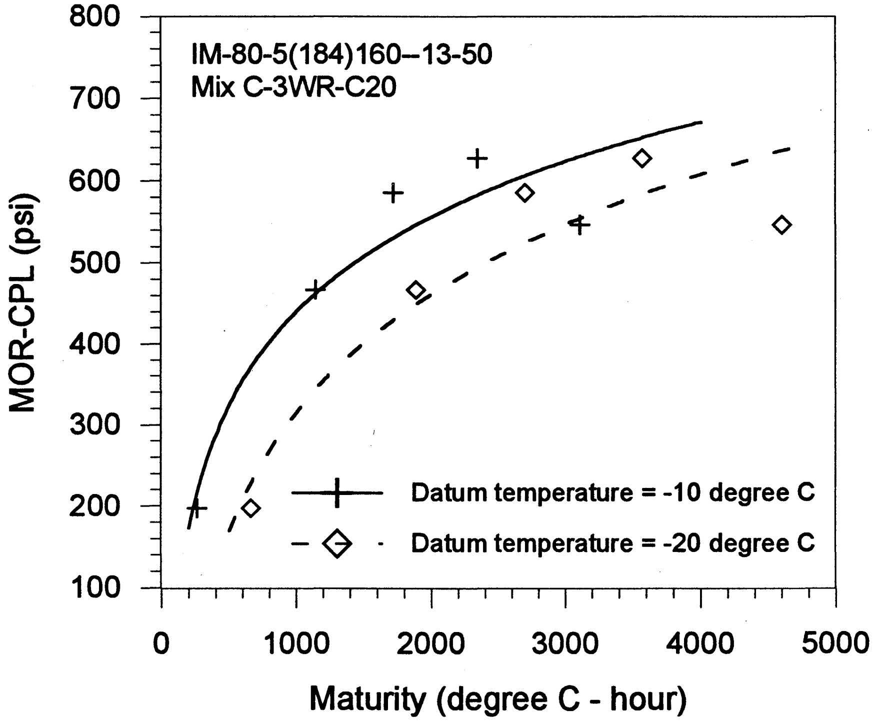


(a) Temperature-age relationship



(b) Maturity-age relationships

Fig. 6 Effect of Datum Temperature on Maturity Measurement, Project IM-80-5(184)160--13-50 (Jasper County)



(c) Maturity-strength curves

Fig. 6 Effect of Datum Temperature on Maturity Measurement, Project IM-80-5(184)160--13-50 (Jasper County)

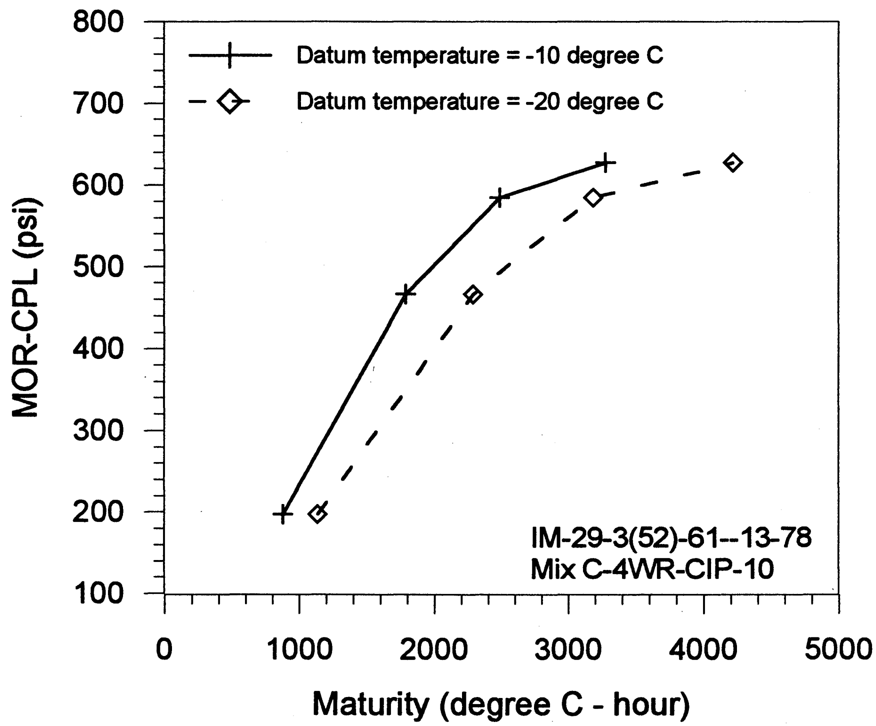
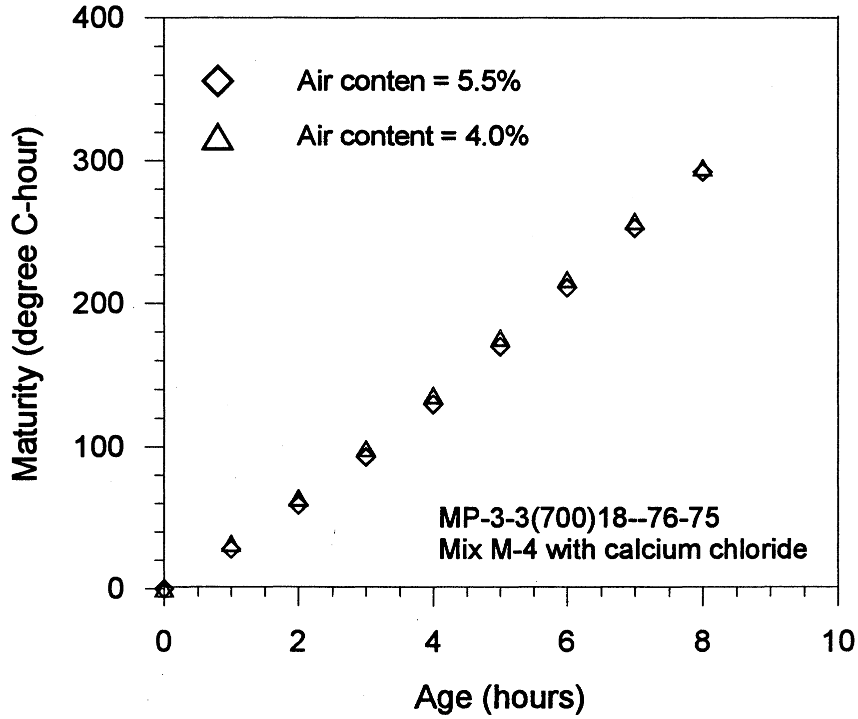
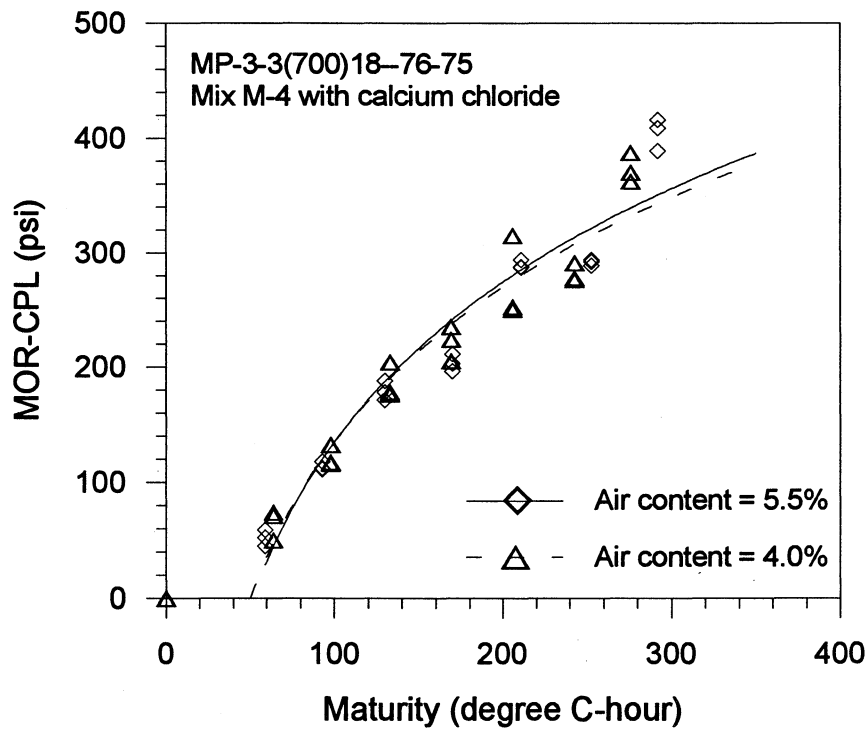


Fig. 7 Effect of Datum Temperature on Maturity-Strength Curve, Project IM-29-3(52)-61--13-78 (Pottawattamie County)

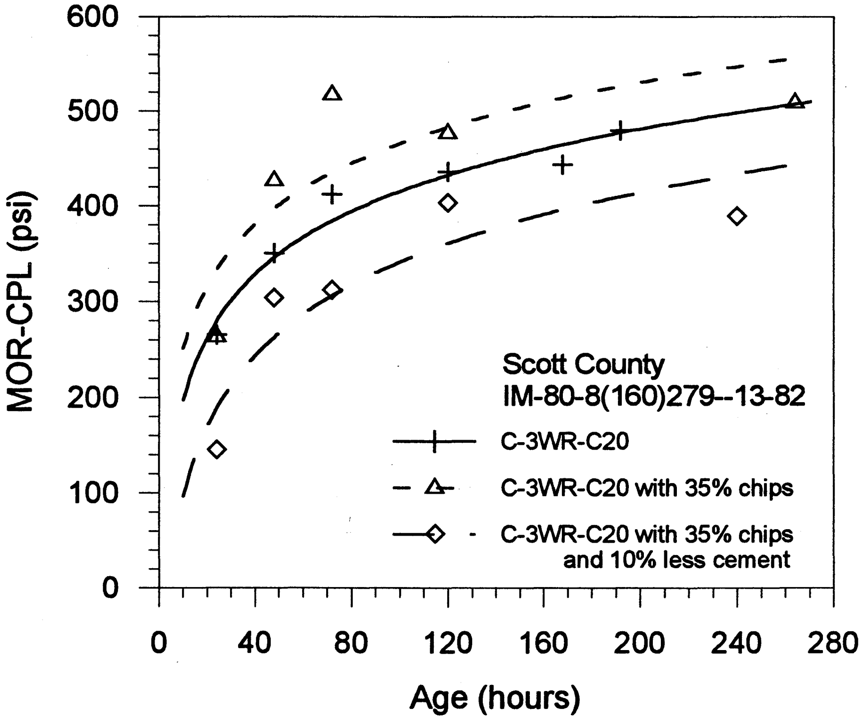


(a) Maturity-age relationships

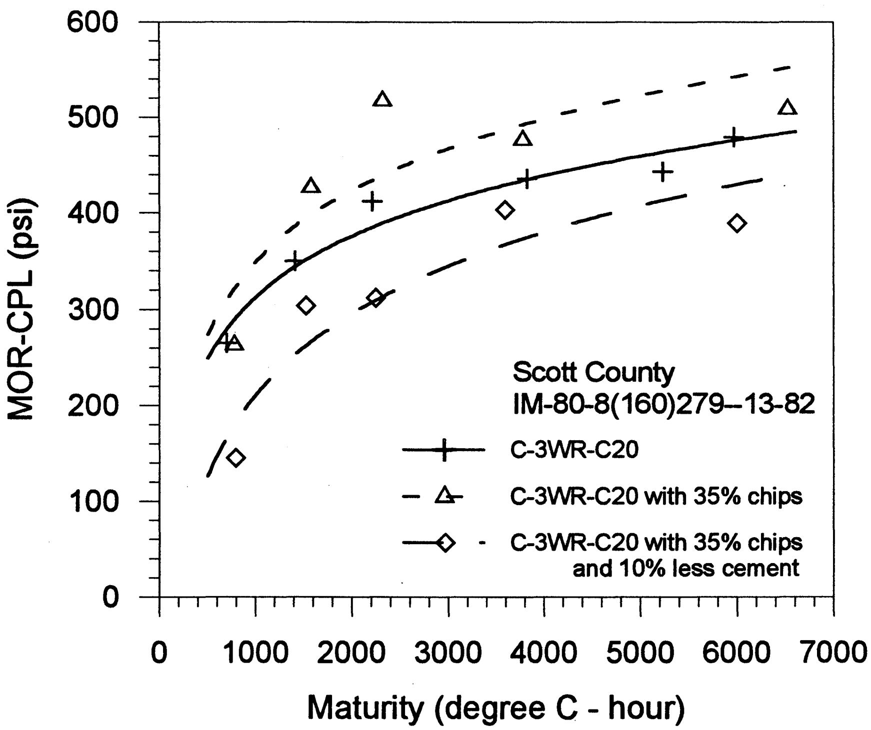


(b) Maturity-strength relationships

Fig. 8 Effect of Entrained Air Content on Maturity-Strength Curve, Project MP-3-3(700-18--76-75 (Plymouth County)

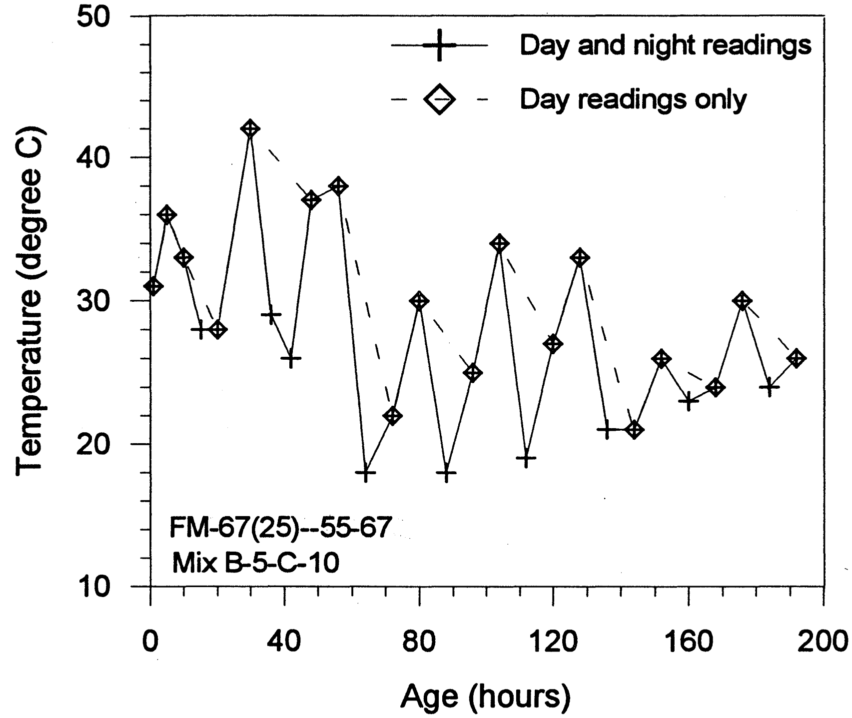


(a) MOR-age relationship

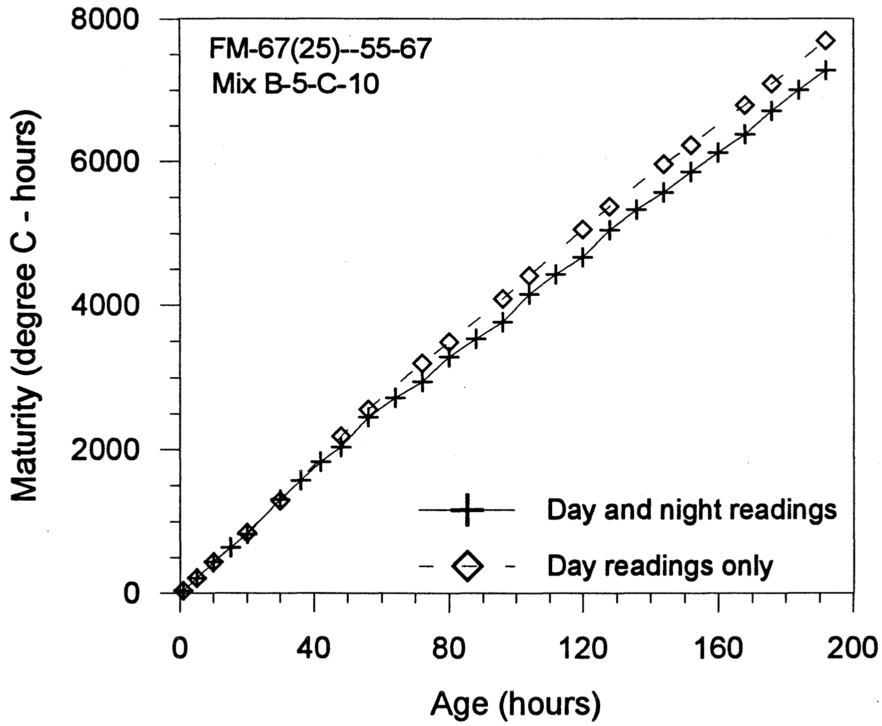


(b) MOR-maturity relationship

Fig. 9 Effect of Aggregate Type on Maturity-Strength Relation, Project IM-80-8(160)279--13-52 (Scott County)

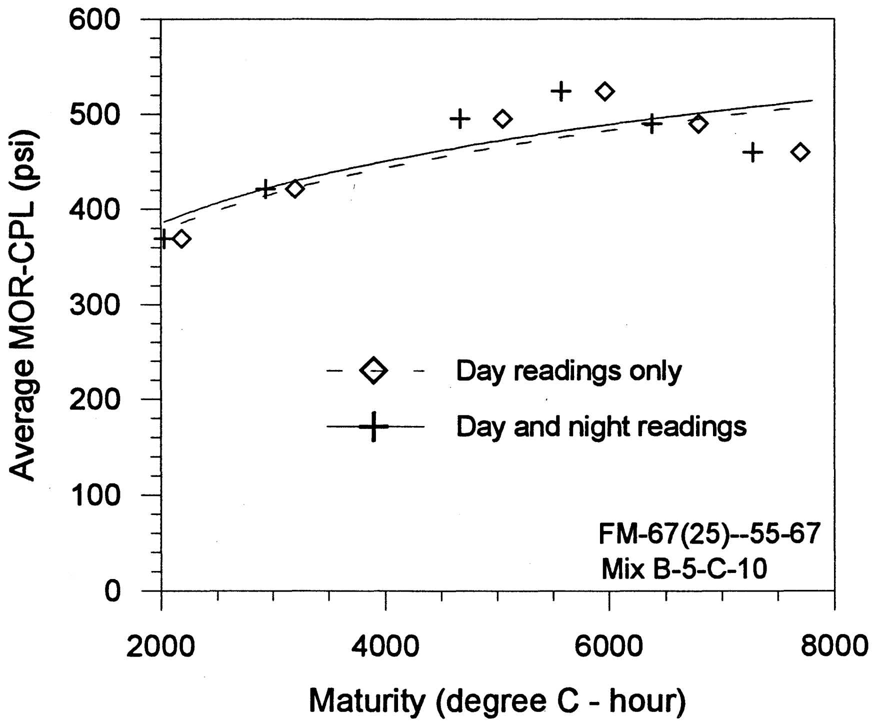


(a) Temperature-age relationship



(b) Maturity-age relationship

Fig. 10 Effect of Reading Frequency of Temperature on Maturity
(Project FM-67(25)--55-67, Monona County)



(c) Strength-maturity relationships

Fig. 10 Effect of Reading Frequency of Temperature on Maturity
(Project FM-67(25)--55-67, Monona County)

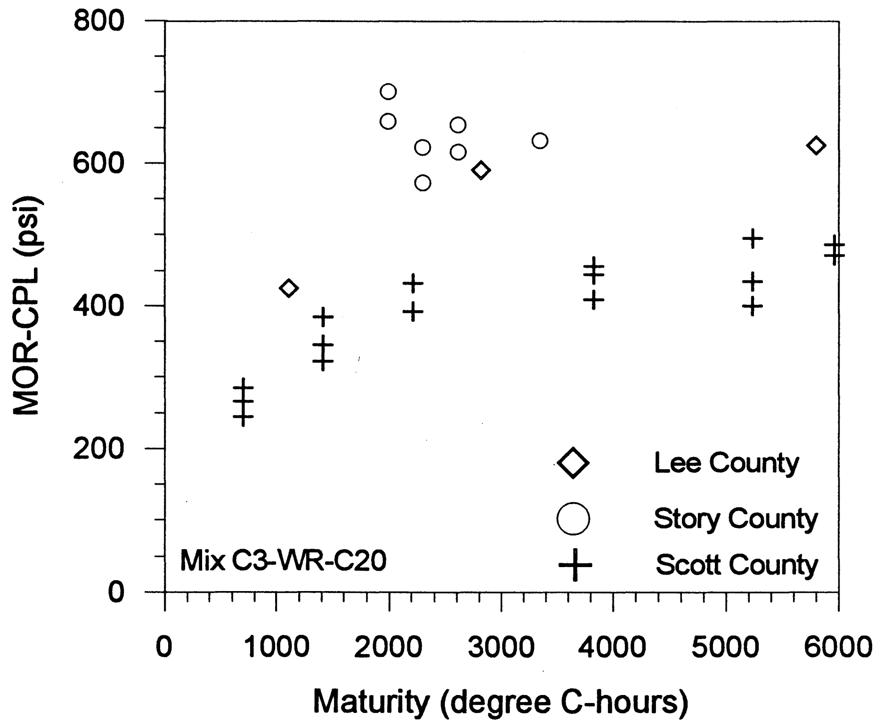


Fig. 11 Maturity-Strength Plot for Mix C3-WR-C20 from Several Projects

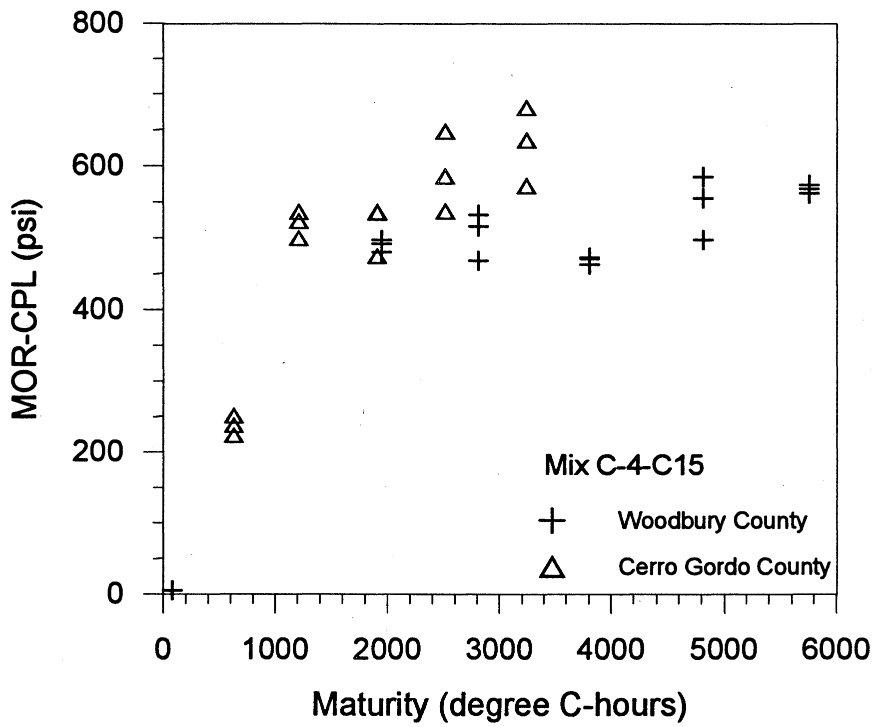


Fig. 12 Maturity-Strength Plot for Mix C-4-C15 from Several Projects

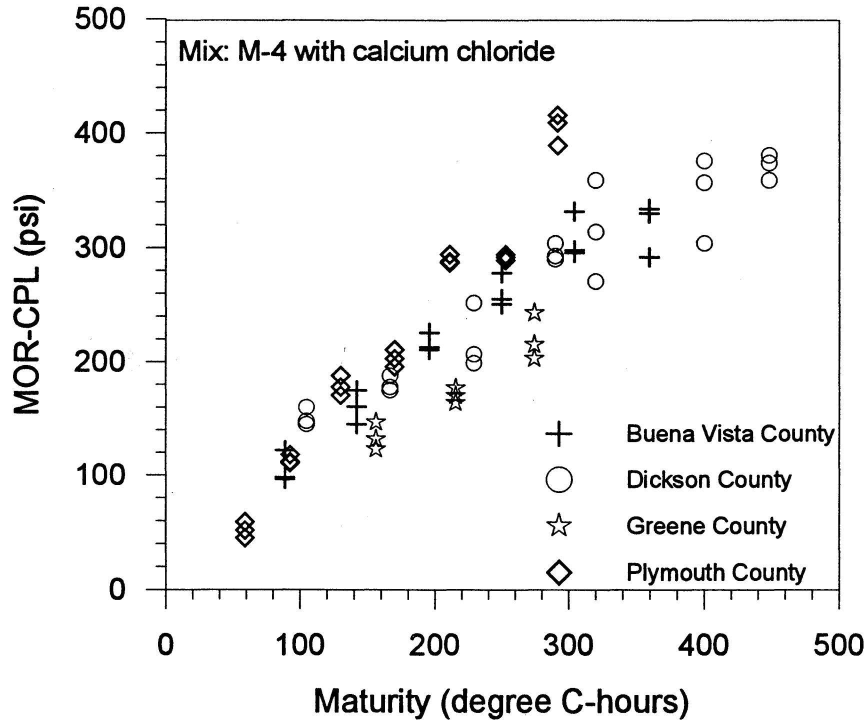


Fig. 13 Maturity-Strength Plot for Mix M-4 from Several Projects