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A Study on Setting Behaviour and Shrinkage of High Performance Pavement Concrete-A Review

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Abstract – *The work presented in this thesis focuses on setting the behavior and shrinkage properties of high-performance pavement concrete and the effect factors, such as supplementary cementitious materials (SCMs), chemical admixtures, and temperature. The thesis consists of two papers: (1) the relation between setting behavior and the maturity of pavement concrete materials and (2) a simple statistical model to predict the shrinkage behavior of high-performance concrete containing supplementary cementitious materials.*

setting behaviour and maturity of six different concrete mixtures under three different curing temperatures (18.3, 23.9, and 29.4℃, corresponding to 65,75 and 85°F) were investigated. The mixtures were made with two different retarders (ASTM Types B and D) and with 0 or 20% Class C fly ash replacement for Type I cement. The initial and final set times of these mixtures were measured by the penetration resistance method according to ASTM C 403. The temperature rise of the mixtures was monitored using a thermal couple, and the concrete maturity was then computed based on the time- temperature factor (TTF). A new approach is introduced for predicting concrete set time (penetration resistance) based on the concrete maturity (time-temperature factor). The results indicate that concrete penetration resistance well correlates with maturity measurements. This relationship enables engineers to assess setting behaviour of field concrete on site.

autogenous shrinkage and free drying shrinkage of nine different highperformance concrete mixtures used for bridge decks and bridge overlays constructions were measured, and the total shrinkage (defined as autogenous shrinkage plus free drying shrinkage) was studied. The mixtures were systemically designed for evaluating effects of class C fly ash and ground granulated blast-furance slag replacement on shrinkage proporties. A simplified exponential model $\varepsilon_{auto/drying}(t)=a+b*e^{(c*t)}$ *was introduced for describing and predicting shrinkage in high-performance concrete when different types and amounts of supplementary cementitious materials were used. This model fits for both autogenous and free drying shrinkage and is validated and proved bycomparing measured value with predicted shrinkage value of an independent group of mixtures. The results indicate that compare to GGBF slag, fly ash performs much better to reduce the total shrinkage. Additionally, free drying shrinkage increases linearly with autogenous shrinkage between 0 and 14 days.*

The results of the present study indicate that the concrete maturity method successfully describes the concrete setting behavior; and the exponential model successfully predicts the shrinkage behavior of high-performance concrete with SCMs. Additionally, the results indicate Class C fly ash replacement can reduce the total shrinkage and extend the setting time of high-performance concrete. The addition of Class C fly ash should be considered if extending concrete setting time and reducing therisk of shrinkage cracking are needed.

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I. INTRODUCTION

1 In recent times, builders have commonly used high-performance concrete (HPC) in bridge decks and bridge overlays construction due to its high strength and rapid strength development. However, due to its properties—such as low water-to- cementitious material ratio, high doses of chemical admixtures, and high cementitious materials content—HPC always has a high potential risk of shrinkage cracking and exhibiting short setting time. At present, a study that evaluates and predicts shrinkage and setting behavior of high-performance concrete is necessary.

2 The purpose of this thesis is to use new approaches to describe the setting behavior and shrinkage properties of high-performance concrete. A comprehensive study was conducted to examine the effects of supplementary cementitious materials, such as fly ash, on the setting behavior and shrinkage of high-performance concrete.

3 For the setting behavior study (paper 1), six different HPC mixtures were designed to investigate how

the 20% fly ash replacement, retarders, and curing temperatures would affect concrete initial and final setting times, as well as to investigate the relationship between the maturity index (a time–temperature factor) and penetration resistance under 18.3, 23.9, and 29.4°C. Theoretically speaking, for a specific mixture, if a concrete sample reaches an equal maturity index with another sample, its strength should also be equal. The results of this study indicate that concretematurity is related to penetration resistance because penetration resistance relates to concrete strength. The penetration resistance -elapsed time curves at three different

4 temperatures should normalize as one curve if the datum temperature is properly selected. Once the normalized curve is established, the penetration resistance at a certaintemperature can be predicted by measuring only the concrete maturity.

5 For shrinkage model study (paper 2), nine different HPC mixtures with different replacement rates of class-C fly ash and slag were systemically designed. Two of them were designed independently to use for a model validation test. Compared to normal- strength concrete, the amount of autogenous shrinkage of HPC is always considerable and contributes to the total shrinkage. Therefore, an exponential model was developed to add the autogenous shrinkage and free drying shrinkage together to determine the total shrinkage.

6 Those two studies both focused on high-performance pavement concrete with similar materials (such as fine aggregate, Class C fly ash) and mix proportions and, therefore, were highly related. In some cases, concrete setting behavior also affects shrinkage measurements. For instance, to measure the autogenous shrinkage of mortar instudy 2, I first determined the corresponding final setting time according to the standard. For the 20% fly ash HPC mixture, rather that measuring its final setting, simply using the conclusion of the study 1, which meant simply multiplying the final setting time for the corresponding control mixture by a factor of 1.10.

II. OBJECTIVES

This study is aimed at developing a new approach to describe the relationship between penetration resistance and elapsed time of concrete based on the maturityconcept.

III. LITERATURE SURVEY

Maturity method and function

The “maturity method” is used as a non-destructive approach to predict concrete strength by establishing the strength-maturity relationship. The maturity method according to ASTM C 1074-04 is defined as “a technique for estimating concrete strength that is based on the assumption that samples of a given concrete mixture attain equal strengths if they attain equal values of the maturity index.”

There are two functions for calculation the maturity index: temperature-timefactor (TTF) and equivalent age. In this thesis, the temperature-time factor is used toconnect maturity with penetration resistance. The TTF function, or the Nurse-Saul function, is given below:

$$M(t) = \Sigma\, [(T_a - T_0)\, \Delta t]$$

Where M(t) is the TTF at age of t, Δt is a time interval, T_a is average concretetemperature during time interval Δt, and T_o is the datum temperature. (1)

The maturity function is depended based on the temperature sensitivity of the concrete strength development at early age. (2) Generally, maturity factor is affected by factors such as ambient temperature, relative humidity, and wind during construction process. Additionally, other factors such as cement type, pozzolans, SCM and water to cement ratio are also contributed to maturity factor. The application of maturity method is to predict strength in field by developing the maturity curve of given mixture in the laboratory. (3)

Datum Temperature

Datum temperature is defined as the temperature below which there is no strength development. (2) Datum temperature, or T_o at the TTF function above, may depend on the type of cementitious materials, type and dosage of chemical admixtures orother factors which can affect cement hydration rate. The ASCT C1074 recommends 0^oC for type I cement without admxitures and a curing temoerature ranges from 0 to 40 ^oC. (1) Table 1 presents the range and value of datum temperature that were determined based on the experimental work. However, the State DOTs always select -10^oC or 0^oC as the default datum temperatures to calculate concrete maturity. Table 2 below shows the datum temperature used by State DOTs. A datum temperature of -10 ^oC was selected by Iowa DOT, and which was also used in this study.

MnDOT office of materials did a series of concrete maturity test to predict the concrete strength in field. The maturity-strength curves at three different datum temperatures, 0^oC, -5^oC and -10^oC were established. It was found that a datum temperature of 0^oC is too high. The maturity-strength curves related better under datumtemperatures of -5^oC and -10^oC. (3)

Table 1. Literature study of different datum temperature

Materials	Curing Temp.	T_0	References
Type I Cement without Admixture	0 to 40 °C	0 °C	Carino,1984 (4)
Type I Cement with Varied SCMs	8 °C, 23 °C, 40 °C	-1.3 to 3.4 °C	Brooks ,2007 (5)
Maryland DOT Pavement Concrete	4.4°, 21.1°, 32.2 °C	3.8 °C	R. Johnson,2011 (6)
AKDOT&PF Type I/II PC	-	-2.0 to 4.5 °C	Y. Dong, 2009 (7)
Type I/II cement with fly ash	50 °F & 90 °F	-2.66 to -7.17 °C	Wang K, 2003 (8)

Table 2. Datum temperature used by State DOTs

State DOTs	Specification	T_0 (°C)
Alabama	ALDOT-425	0
Indiana	ITM 402-04T	-10
Iowa	IM 383	-10
Kansas	KT-44	-10
Kentucky	64-322-08	-10
Missouri	Section 507	-10
Ohio	Supplement 1098	0
Tennessee	Developing	-10
Texas	Tex-426-A	-10
Wisconsin	CMM 8.70	0

Concrete Setting Behavior

Penetration Resistance Test

Setting time of concrete can be obtained by testing a representative mortar sample sieved of the corresponding concrete, according to ASCT C403. The mortar is curried at the certain ambient temperature, and at regular time periods the measurement is taken by penetrating a standard needle 1 inch into the mortar. The initial and final setting time can be determined by plotting penetration resistance vs. elapsed time. Initialset and final set are defined as the times when the penetration resistance reaches to 500 psi [3.5 MPa] and 4000 psi [27.6 MPa], respectively. (9)

Temperature Affecting on Setting Time

Temperature affects concrete setting behavior due to it affecting hydration rate ofcement. A clear linear relationship between concrete initial setting time and temperature was established as shown in figure 1 (a). Additionally, a linear relationship between inverse of setting time and inverse of absolute temperature was also found. Conclusioncan be made that the setting times for any temperature can be predicted based on the linear relationship by only measuring setting times at two extreme temperatures. The figure 1 (b) can be used to determine the activation energy referring to the method in ASTM C1074. (10)

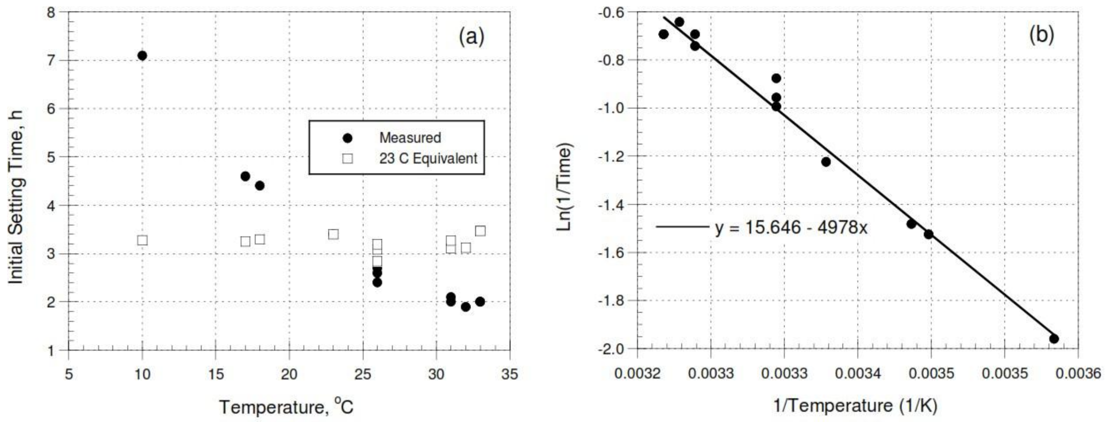

Figure 1. (a) Initial drtting time vs. temperature (b) inverse of setting time vs.inverse of absolute temperature

Figure 2 (a) below shows a signicicant effect of temperature on concrete setting time. The temperature for hot, control and cold range from 32-41°C, 20-24°C and 4-13°C respectively. The concrete strength development is much quicker at hot condition compared to the one at cold condition. Figure 2 (b) shows setting-maturity relationship by using equivalent age method. An activation engergy value of 26,700 J/mol was used to determine equivlent age. (11)

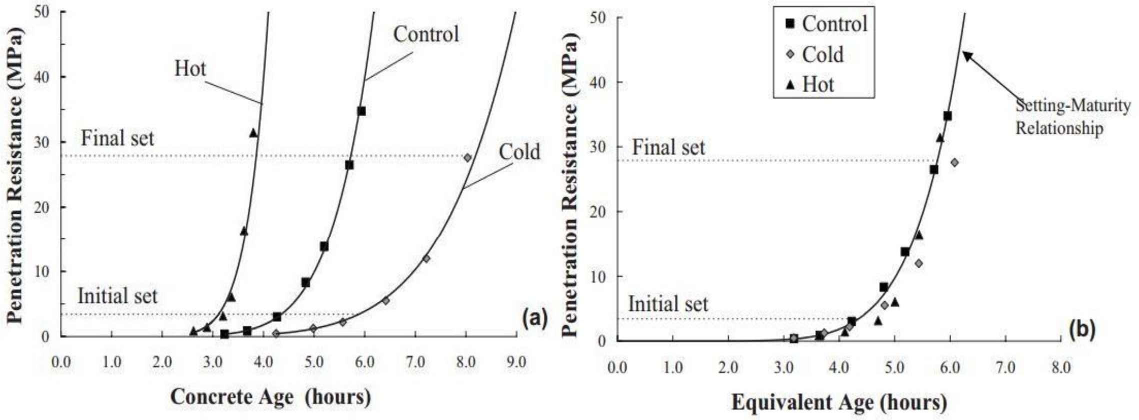

Figure 2. Results for the 30% slag mixture: (a) effect of temperature on setting time,

(b) **setting-maturity relationship**

SCMs Affecting on Setting Time

GGBF Slag: The effects of slag on concrete setting time depend on factors such as curing temperature, present replacement, and slag composition (Grade). Generally the slag replacement at a lower temperature increases the concrete setting time, especially for slag replacement higher than 40%. (12) The temperature is the key factor for slag to affect setting time. For temperature greater that 20°C (68°F), it shown that 30% and 50% slag replacements decrease the setting time of concrete. (13) However, another study shows that for slag replacements of 30, 50 and 70%, there is no delay on setting time at temperature above 35 °C (95°F). (14) For Grade 120 GGBF slag, research shows that it has very tinny effect on concrete setting time, thus, slightly accelerate concrete setting rate. (11)

Class F Fly Ash: The effects of class C fly ash and class F fly ash on concretesetting time are not all the same, since class C fly ash has a better early strength development. (15) Generally, class F fly ash increases the setting time of concrete due toits poor early strength development.

Class C Fly Ash: In this thesis, only class C fly ash was studied. For concrete with high percent fly ash replacement, the final setting time can be extended up to 6 hours. (16) Resent study also compared the effects of class C fly ash and class F fly ash on concrete setting time. Experimental results show that for a same replacement level, class C fly ash has more ability to extend concrete setting time. (11) However, research also shows that the effect on concrete setting time depends on the fly ash content. The initial and final setting times were delay below 60% replacement, and beyond this replacement level the rapid setting occurred. (17)

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