Concrete Pavement Mixture Design and Analysis (MDA):

Comparison of Setting Time Measured Using Ultrasonic Wave Propagation With Saw-Cutting Times on Pavements in Iowa

National Concrete Pavement Technology Center

Tech Center

Technical Report
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16. Abstract

Concrete setting behavior strongly influences scheduling of construction operations, such as surfacing, trowelling, jointing, and saw-cutting. To conduct pavement sawing activities effectively, it is useful for contractors to know when a concrete mixture is going to reach initial set, or when the sawing window will open. Monitoring the set time of a fresh mixture also provides a tool to assess the uniformity between material and concrete batches.

The aim of this project was to confirm that initial set could be measured using an ultrasonic pulse velocity (UPV) approach, and to assess whether there was a relationship between initial set and sawing time for pavement concrete in the field.

Eight construction sites were visited in Iowa over a single summer/fall period. At each site, initial set was determined using a p-wave propagation technique with a commercial device. It was also determined on mortar samples in accordance with ASTM C 403. Calorimetric data were collected using a commercial semi-adiabatic device on some of the sites.

The data collected to date revealed the following:

- UPV approaches appear to be able to report initial set times
- Early entry sawing time can be predicted for the range of mixtures tested here

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COMPARISON OF SETTING TIME MEASURED USING ULTRASONIC WAVE PROPAGATION WITH SAW-CUTTING TIMES ON PAVEMENTS IN IOWA

Technical Report
January 2014

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

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EXECUTIVE SUMMARY

Concrete setting behavior strongly influences scheduling of construction operations, such as surfacing, trowelling, jointing, and saw-cutting. To conduct pavement finishing and sawing activities effectively, it is useful for contractors to know when a concrete mixture is going to reach initial set, or when the sawing window will open. Monitoring the set time of a fresh mixture also provides a tool to assess the uniformity between material and concrete batches.

The aim of this project was to confirm that initial set could be measured using an ultrasonic pulse velocity (UPV) approach, and to assess whether there was a relationship between initial set and sawing time for pavement concrete in the field.

Eight construction sites were visited in Iowa over a single summer/fall period. At each site, initial set was determined using a p-wave propagation technique with a commercial device. It was also determined on mortar samples in accordance with ASTM C 403. Calorimetric data were collected using a commercial semi-adiabatic device on some of the sites.

The data collected to date revealed the following:

- UPV approaches appear to be able to report initial set times
- It seems that early entry sawing time can be predicted for the range of mixtures tested here

INTRODUCTION

To conduct finishing and sawing activities of pavements effectively, it is useful for contractors to know when a concrete mixture is going to reach initial set, or when the sawing window will open. Monitoring the set time of a fresh mixture also provides a tool to assess the uniformity between material and concrete batches.

Work has been reported in Australia on the effective use of calorimetry for this purpose. There is, however, concern that temperature is not uniquely tied to setting, and that tests conducted in a semi-adiabatic calorimeter may not represent the environment being experienced by a given slab.

An alternative approach to measuring initial set is to monitor the speed of sound through a concrete sample. Previous work has shown a clear relationship between this parameter and initial set.

The aim of this project was to confirm that initial set could be measured using an ultrasonic pulse velocity (UPV) approach, and to assess whether there was a relationship between initial set and sawing time for pavement concrete in the field.

BACKGROUND

The “correct” time to conduct sawing of a freshly placed concrete slab is often a subjective decision based on the experience of the saw operator. Conventional guidance is normally in the form of inspecting the amount of raveling. A very clean cut is normally indicative of late sawing and, therefore, a high risk of random cracking. Severe raveling is an indicator that sawing should not yet start. Other approaches include scratching the surface with a penknife or standing on the slab and observing footprint depth. There is a need for a more rigorous approach to determining when sawing should start that will reduce errors and disputes.

Challenges to contractors include the fact that the rate of hydration of a slab is strongly influenced by the temperature of the slab, as well as the chemistry of the cementitious system. Any approach that will help understand the state of concrete hydration will reduce construction (i.e., repair) costs. Likewise, crews will not have to be paid overtime to sit on the site waiting for sawing to start, and can be called in at an appropriate time.

Based on the idea that sawing time can be correlated with initial setting, this work used a UPV device to collect initial setting times at a number of sites and to compare that with the timing at which sawing occurred.

The basic principle behind the method used in this work is that the speed of sound is lower in a fluid than in a solid. The time taken for an impulse to travel through a sample will therefore start to increase when hydration products start to interact with each other, which is coincident with initial set.

Two types of waves are utilized in this type of application: compression (p-waves) that travel through the material, or shear (s-waves) that travel at the interface between the material and its container or air. According to Biot's theory [1, 2], two types of compression wave are observed with one being fast and the other being slow. The fast wave is observed at all frequency ranges but the slow wave only exists at a high frequency [3].

Studies have also reported that p-waves are less sensitive to difficulties with the sample-transducer contact than s-waves and allow a more accurate determination of the velocity through concrete due to their high signal-to-noise ratio [4]. Both methods have been used to assess the following:

- Setting behavior [5-15]
- Strength development [16-22]
- Formwork pressure development [23]
- Chemical shrinkage [5]

According to Biot, the velocity of sound in a continuous medium is as follows:

$$V = \sqrt{\frac{E(1-\mu)}{\rho(1+\mu)(1-2\mu)}}$$

where:
E = dynamic modulus of elasticity
μ = Poisson's ratio
ρ =density

The velocity of sound can be determined using a device that tracks the time taken for a signal to travel through a sample with a known length.

Previously reported work at Iowa State University (ISU) [15] clearly showed a good relationship between when the speed of sound accelerates in a sample and the initial set time. The work described in this report was to compare setting times measured in the field with sawing times on the same slabs in an attempt to develop a correlation.

Initial set is taken to be when the sound velocity starts to increase (Figure 1).

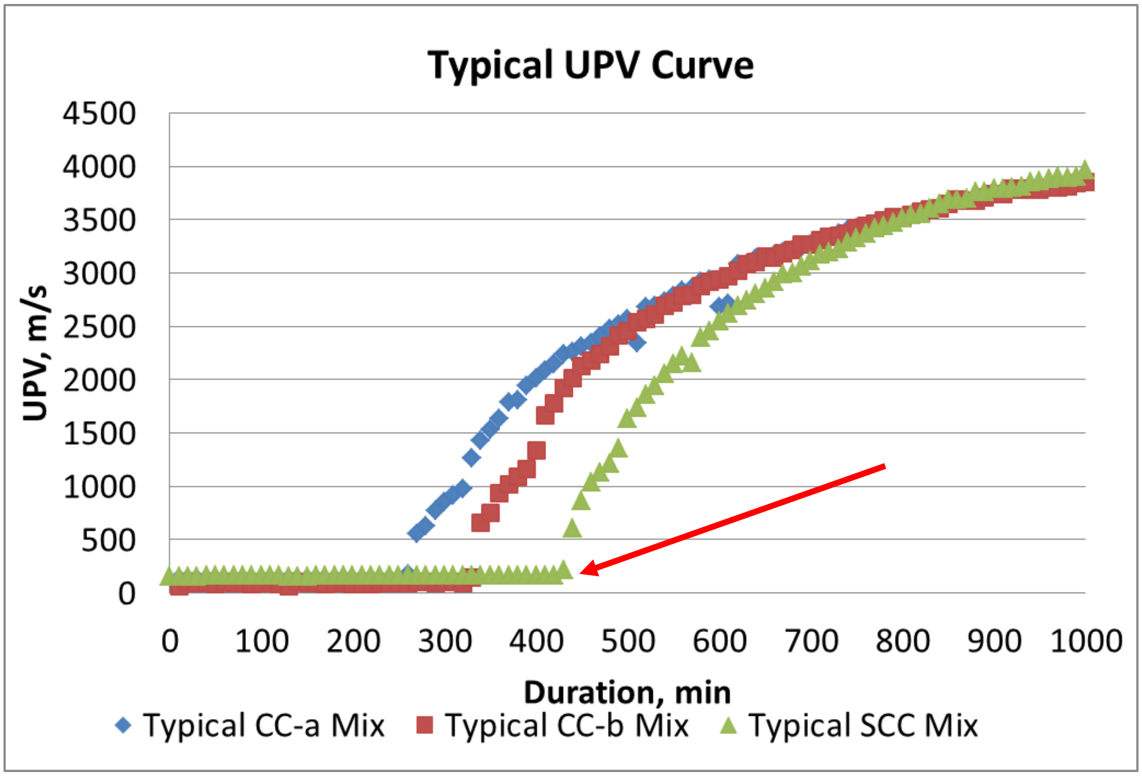

Figure 1. Typical UPV data with initial set taken as the time when the velocity starts to rise as marked [15]

Correlation between the penetrometer, UPV, and calorimetric approaches is reasonable as observed in a typical set for a single mix shown in Figure 2.

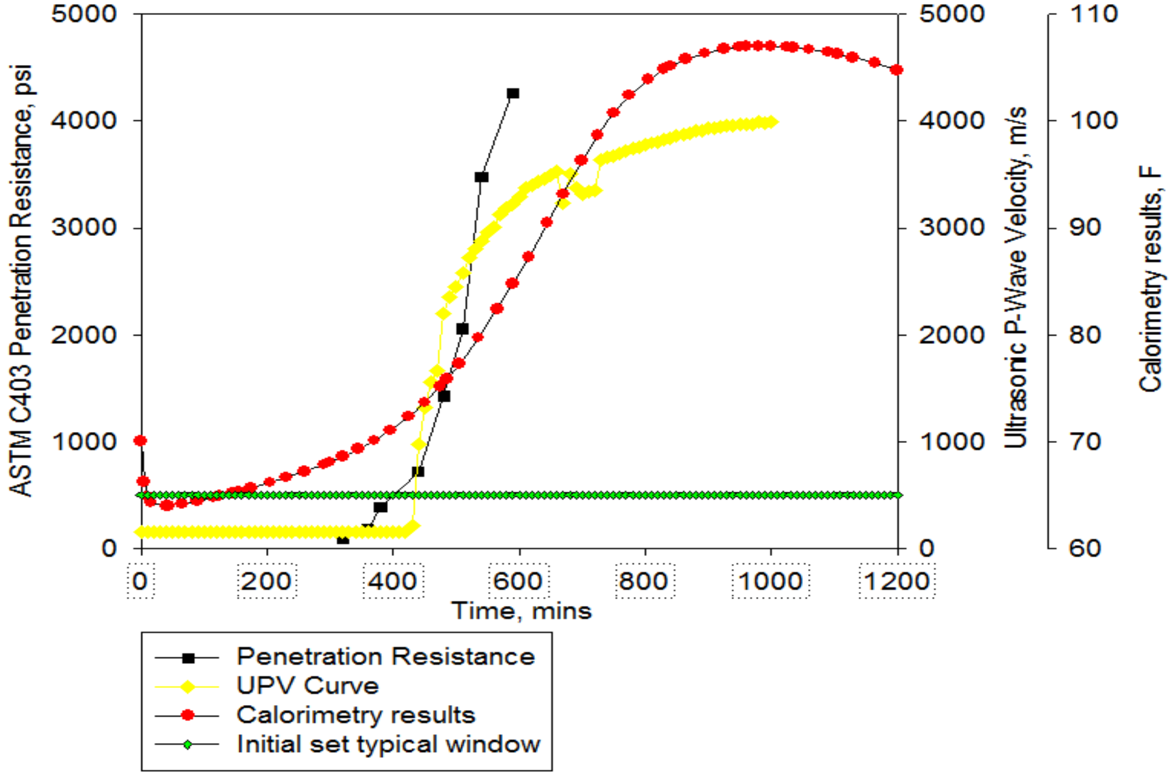

Figure 2. Plots from different measurement techniques for a single mix

WORK CONDUCTED

Eight construction sites were visited in Iowa over a single summer/fall period. At each site, a sample of concrete was obtained at the point of delivery and formed into a 4x8 in. cylinder mold. The mold was placed in a frame that also held two transducers used by a commercial p-wave device. The lower transducer was placed in contact with the bottom of the mold with a gel couplant interlayer. The top transducer was placed on a polyethylene disk floating on the concrete surface, also with the couplant between the transducer and the disk. A frame was used to keep the system stable.

Sound impulses were sent every minute from the top transducer, and the time of flight to the lower was collected and recorded on a laptop computer. During the test, the device was stored in or next to an open vehicle to maintain the test sample at the same temperature that the slab was experiencing (Figure 3). Initial set time was also determined on mortar samples in accordance with ASTM C 403. Calorimetric data were collected using a commercial semi-adiabatic device on some of the sites.

Site staff then reported the time at which that portion of the slab was sawn. They were not given any instructions on when sawing should take place.

Data on mix proportions, weather, setting time, and sawing time were then collected.

Figure 3. Test setup with sample and transducers in a wooden frame for stability

Details of the sites visited are shown in Table 1.

Table 1. Sites where samples were tested

Site	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
Date	May 24	June 18	Aug. 7	Aug. 19	Aug. 26	Oct. 2	Oct. 15	Oct. 18
Agency	DOT	County	DOT	DOT	DOT	DOT	City	City
Cementitious content, pcy	560	561	552	561	552	563	561	571
Fly ash content, %	20	20	20	20	20	20	20	20
w/cm	0.40	0.40	0.41	0.40	0.41	0.40	0.41	0.43
Coarse aggregate type	Lime-stone	Lime-stone	Quartzite	Lime-stone	Lime-stone	Lime-stone	Lime-stone	Lime-stone
Coarse aggregate size	1½"	1½"	1"	1"	1"	1½"	1"	1"
Fine aggregate type	River sand	River sand	River sand	River sand	River sand	River sand	River sand	River sand

All of the sites visited used early entry saws (Figure 4).

Figure 4. Use of early entry saws

RESULTS

The data collected are shown in Table 2.

Table 2. Collated test data

Site	1	2	3	4	5	6	7	8
Average Air Temperature, °F	63.1	83.5	72.5	80.6	86.9	75.5	48.9	46.2
Initial set ASTM C 403, min	290	153	285	184	255	209	441	316
Initial set UPV, min	276	135	270	195	260	220	400	295
Initial set Calorimetry, min	N/A	N/A	390	180	228	230	300	330
Sawing time, min	480	330	460	450	455	470	625	1,050
Comments		Cracked						Sawn next day

Data plots from the calorimetric tests are shown in Figure 5.

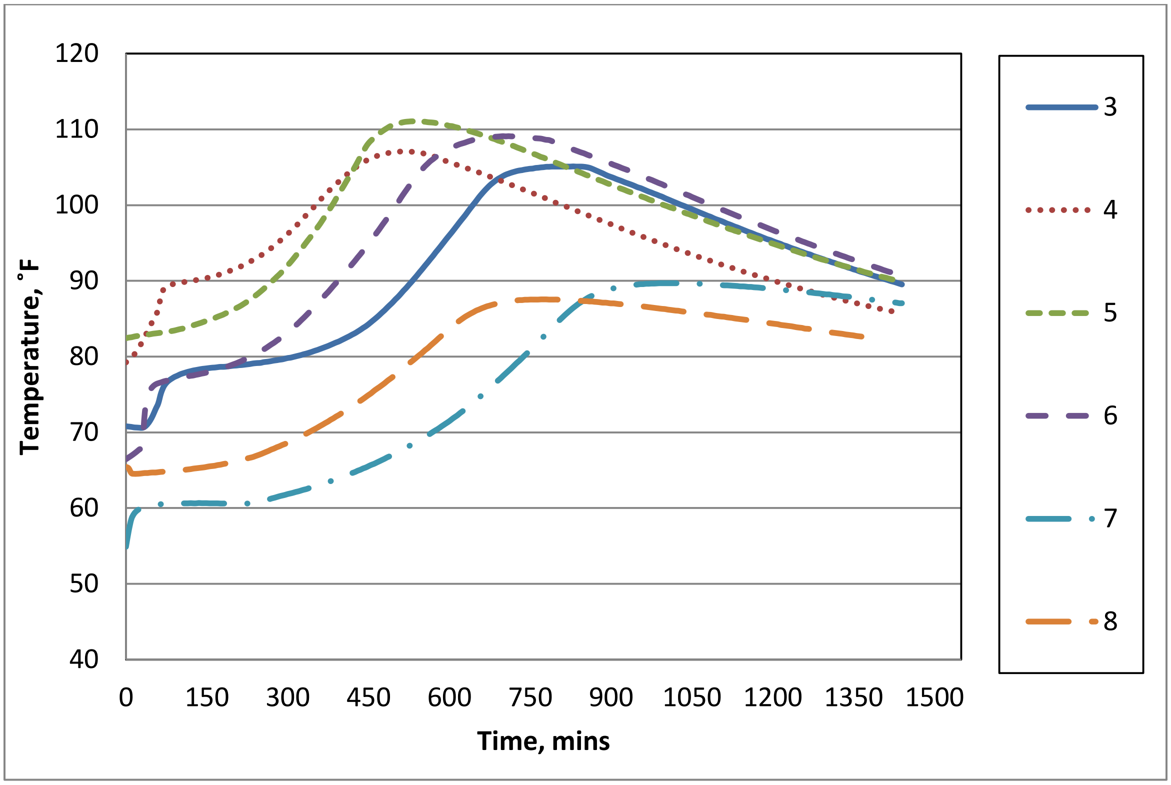

Figure 5. Calorimetric data

One site (Site 2) was observed to have a crack parallel to the saw cut (Figure 6); all others appeared to be satisfactory.

Figure 6. Crack at Site 2

DISCUSSION

There appears to be a good correlation between sawing and setting times, except for Site 8 where the sawing was conducted the following day (Figure 7). The data seems to indicate that once initial set is observed, sawing should begin about 220 minutes later for the sort of mixtures observed here and for early entry sawing.

It is interesting that the trend is a seeming constant amount of time added after initial set rather than a multiplier, despite the range of initial set times. This can be explained by observing the calorimetric plots (Figure 5), which show that once hydration starts, the rate of hydration is similar for all the mixtures.

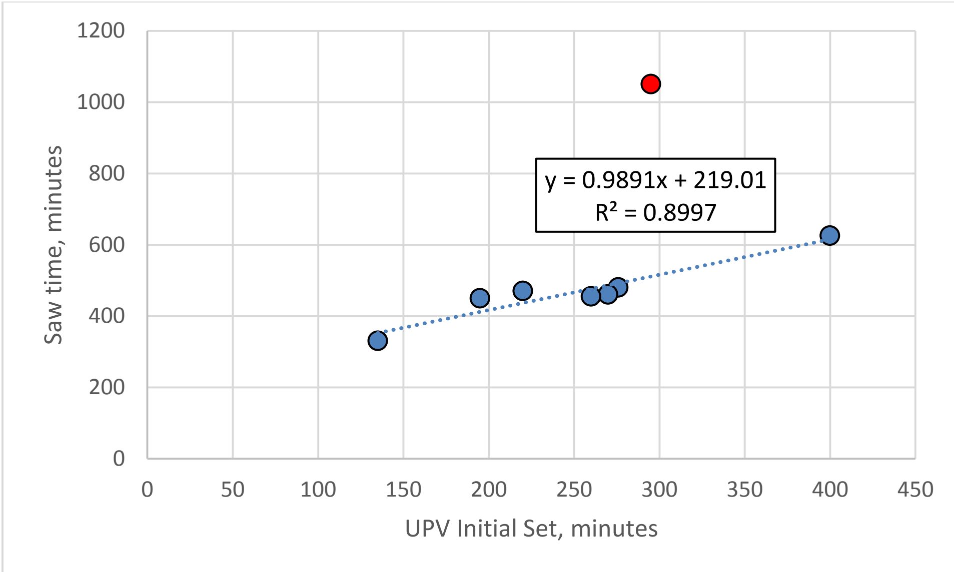

Figure 7. Comparison of setting and sawing times

The reason for the variation in setting times seems to be related to the temperature of the mixture as shown in Figure 8.

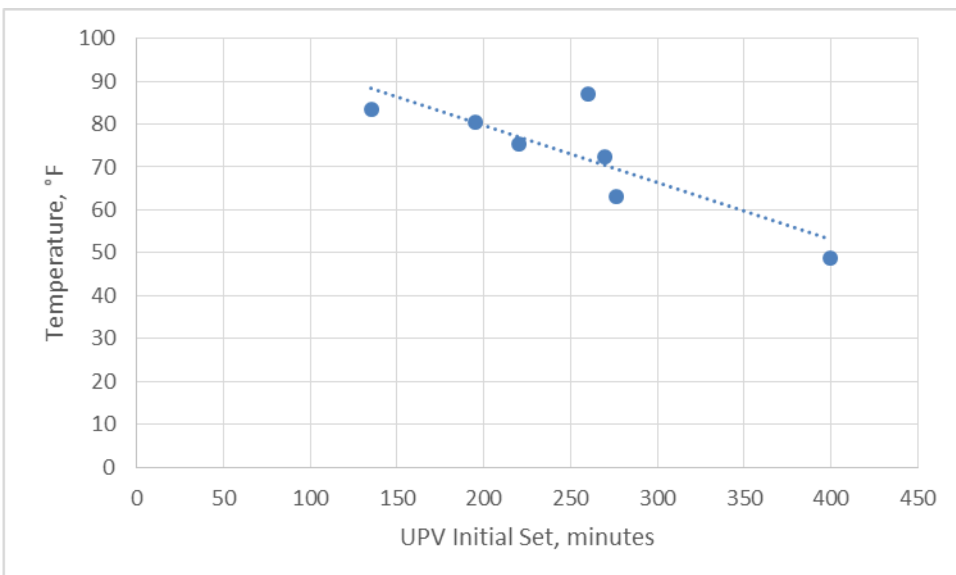

Figure 8. Comparison of setting and average air temperature

It is not known why Site 2 cracked despite the sawing time reported being on the line in Figure 7. It was, however, placed at the highest temperature and it's possible that, while sawing started on time as reported in this dataset, the saw crew may not have been able to keep up with the rapidly hydrating concrete. On the other hand, Site 8 does not appear to have cracked despite the very late sawing.

It is notable that the only mixture containing the harder quartzite aggregate fell into the same dataset as the limestone mixtures.

While the data presented here are limited to early entry sawing, it is believed that the approach will be equally applicable to conventional sawing methods. All that will be required is that the system be operated as described above to compare actual sawing with initial set on a given construction site. Once a reasonable correlation has been determined, the initial set can then be used to direct sawing operations as long as the mixture does not change significantly. It is planned that further work will be conducted to verify this.

It should be noted that care will be required to ensure that the rate of sawing is similar to the rate of paving. If sawing lags significantly behind the paver because insufficient equipment or staff are available, then the risk of random cracking will increase.

CLOSING

The data collected to date indicates the following:

- UPV approaches appear to be able to report initial set times
- It seems that early entry sawing time can be predicted for the range of mixtures tested here

Data needs to be collected for a wider range of mixtures, and for conventional sawing.

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