"Moving Advancements into Practice"
MAP Brief 3-1:

Describing promising technologies that can be used now to enhance concrete paving practices

SmartCure: An Integral Part of an Intelligent Construction System

Introduction

The SmartCure System is a new technology, developed by the Federal Highway Administration, that uses various measuring devices and computer software to provide continuous, real-time, and site-specific recommendations for concrete pavement curing. These recommendations are based on immediate ambient conditions (including wind speed, relative humidity, air temperature, and concrete surface temperature), job-specific concrete materials, and user-defined thresholds (figure 1).

How SmartCure works

SmartCure measuring devices collect ambient weather conditions and concrete surface temperatures at set time intervals (e.g., every two minutes) for as long as the software is set to run. This data is transferred to a laptop and stored in a computer software program. The software organizes the data

and calculates evaporation rate, bleed rate, and set times. Measured and calculated data are organized and displayed by the software for easy viewing by any user.

Threshold values for evaporation rate, temperature of the concrete, and air temperature are inputs to the software. The thresholds indicate critical conditions at which the risk for damage to the pavement is higher if proper curing methods are not followed. When any of the data (i.e., measured or calculated) are close to or above threshold values, the software alerts the user and generates recommendations for how to handle that risk.

Background on curing

Curing concrete is a vital step in the pavement construction process. Proper curing minimizes moisture loss from the surface of the pavement caused by evaporation and reduces thermal gradients, thus decreasing the
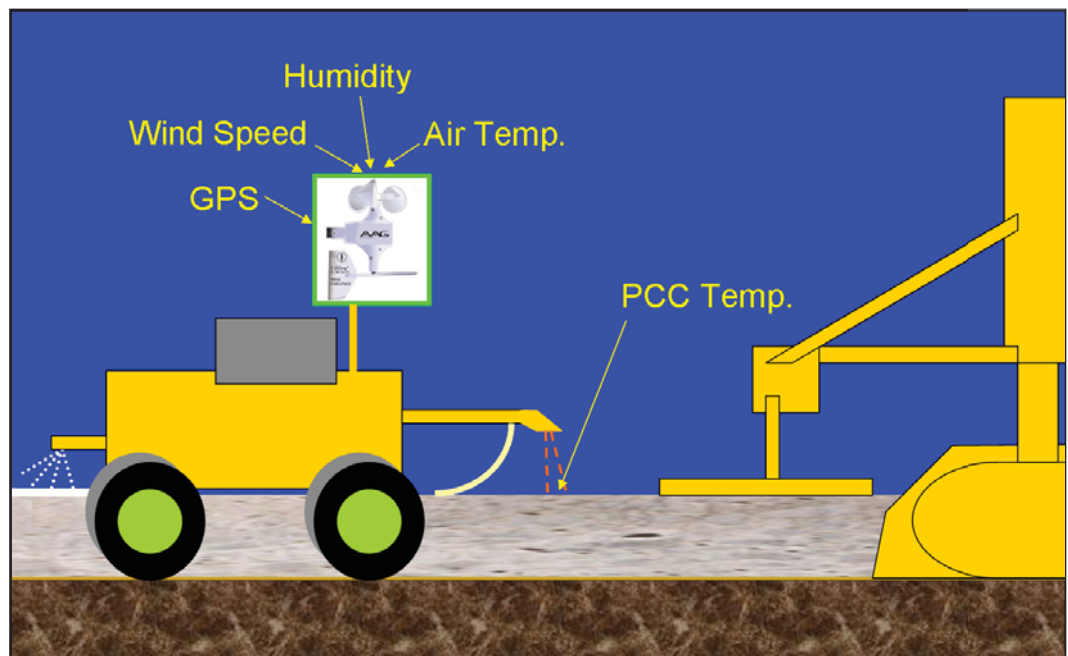

Figure 1. Schematic of SmartCure measuring devices in the field

potential for pavement damage caused by plastic shrinkage cracking and spalling (crusting of surface mortar) (figure 2).

A variety of curing methods are currently used in the field. The most common include the use of liquid curing compounds. In cold weather, polyethylene sheeting and cotton mats or burlap covers are sometimes used. Applying the right curing method at the right time is vital in order for the pavement to meet its design objectives. Knowing the relationship between the concrete materials and the environment in which the pavement is being constructed is key to ensuring that the right curing method is applied at the right time.

The relationship between materials and the environment is not always intuitive. There are tools and guidelines that most contractors are familiar with and use regularly in construction. For example, the *International Guide to Curing Concrete* by the American Concrete Institute (ACI 308R-01) includes a nomograph that helps contractors calculate evaporation rate based on air temperature, relative humidity, concrete temperature, and wind velocity (figure 3).

Tools such as the ACI nomograph are helpful in that they provide general knowledge and recommendations for how to properly cure concrete for a variety of environments and conditions. However, a site-specific tool used during construction that continuously measures real-time ambient conditions and provides real-time guidelines for proper curing in those conditions would be of significantly greater benefit to paving contractors. The need for such a tool and the intention of improving current curing practices led to the development of a SmartCure prototype.

Field trials that tested the potential and ability of a SmartCure prototype validated the benefit of such a tool for contractors. The system prototype, however, needed to be further developed in order for it to be more practical in the field. For example, the prototype was a completely wired system, which made setup on the cure cart somewhat cumbersome. Recent SmartCure improvements have overcome this limitation.

SmartCure components

SmartCure consists of several measuring devices connected to a laptop computer operating a Windows® based software program. The measuring devices include a weather station, global positioning system (GPS), and an infrared (IR) temperature sensor. The weather station measures ambient air temperature, relative humidity, and wind speed. The GPS device provides latitude and longitude to identify location. The IR sensor measures the concrete surface temperature.

The information measured by the weather station, GPS, and IR sensor is sent to the laptop. In the prototype, this was accomplished via a wired connection between the measuring
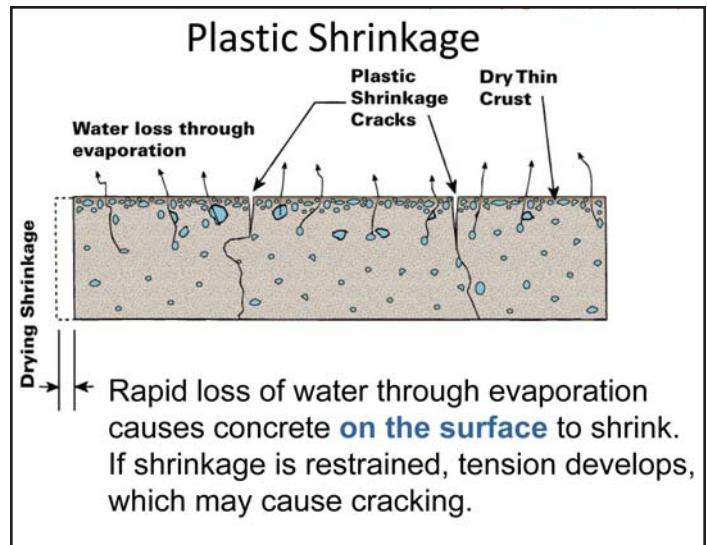

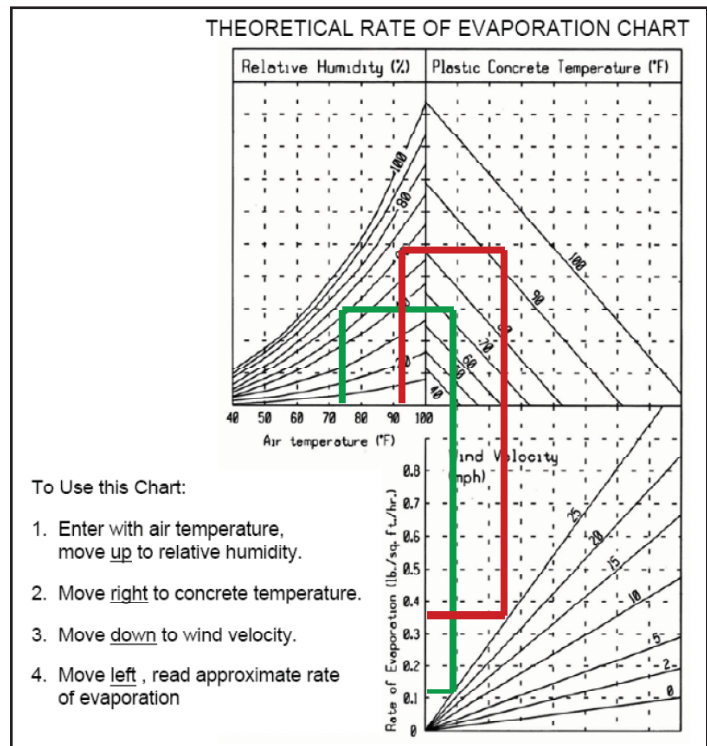**Figure 2. Plastic shrinkage due to moisture loss at the surface**

Figure 3. Nomograph from *ACI International Guide to Curing Concrete*

devices and the laptop. Recent improvements, however, include a wireless connection, which allows the laptop to be set up anywhere. It is connected to one of two XPress™ Ethernet Bridge modems. There must be continuous line-of-sight between the two modems in order for the laptop to receive any data from the measuring devices. As long as line-of-sight is not compromised, the laptop can be up to two miles away from the cure cart.

The weather station and the second XPress™ Ethernet Bridge modem are mounted to one end of a collapsible pole. The IR sensor is attached to the other end of the same pole. The pole is secured to the front of the cure cart and the length of the

pole is adjusted so that the IR sensor is positioned as close as possible to the surface of the fresh concrete (figure 4).

For practical reasons, the weather station and modem should be positioned above the cure cart at a sufficient height to avoid excessive wind obstruction caused by the cure cart. The GPS has a magnetic back and is attached to the cure cart directly. The weather station, modem, GPS, and IR sensor are connected via cables to a serial-to-Ethernet server (figure 5).

The serial server is secured inside a white metal box that must be mounted onto the cure cart. Housed inside the box, along with the server, is an inverter, which is used to provide power to the IR sensor, modem, and GPS. Power is supplied by either a direct connection to the cure cart motor battery or a 12-volt battery that can be supplied and attached to the cure cart.

Using the software

All of the data sent over the wireless connection from the measuring devices to the laptop is logged by the SmartCure software. The software calculates evaporation, bleed rates, and set time rates (initial and final), while monitoring critical thresholds that are defined by the user as an input to the software. When thresholds are approached, the software triggers an alert to the user by generating recommendations on the selection of curing methods, curing applications, curing durations, and temperature management issues.

Inputs to the SmartCure software include material properties for mixture constituents, general site information, any known laboratory testing results for bleed rate and set times, and user-defined thresholds for evaporation rate, ambient air temperatures, and concrete surface temperatures. Default values for all inputs are based on a normal concrete paving mixture and generally accepted tolerances.

The more inputs the user can provide that are specific to the job, the more accurate SmartCure will be in predicting calculated values. Inputs for user-defined thresholds require the user to select from a set of default options. Any number of these options can be selected by the user. The default options identify critical values above which the recommendation for a type of curing procedure specific to that situation is provided. These critical values and recommendations for procedures can be modified to reflect local and/or State specifications or experience.

Once all inputs have been entered and the software starts to collect and log data, the user can view the data on one of
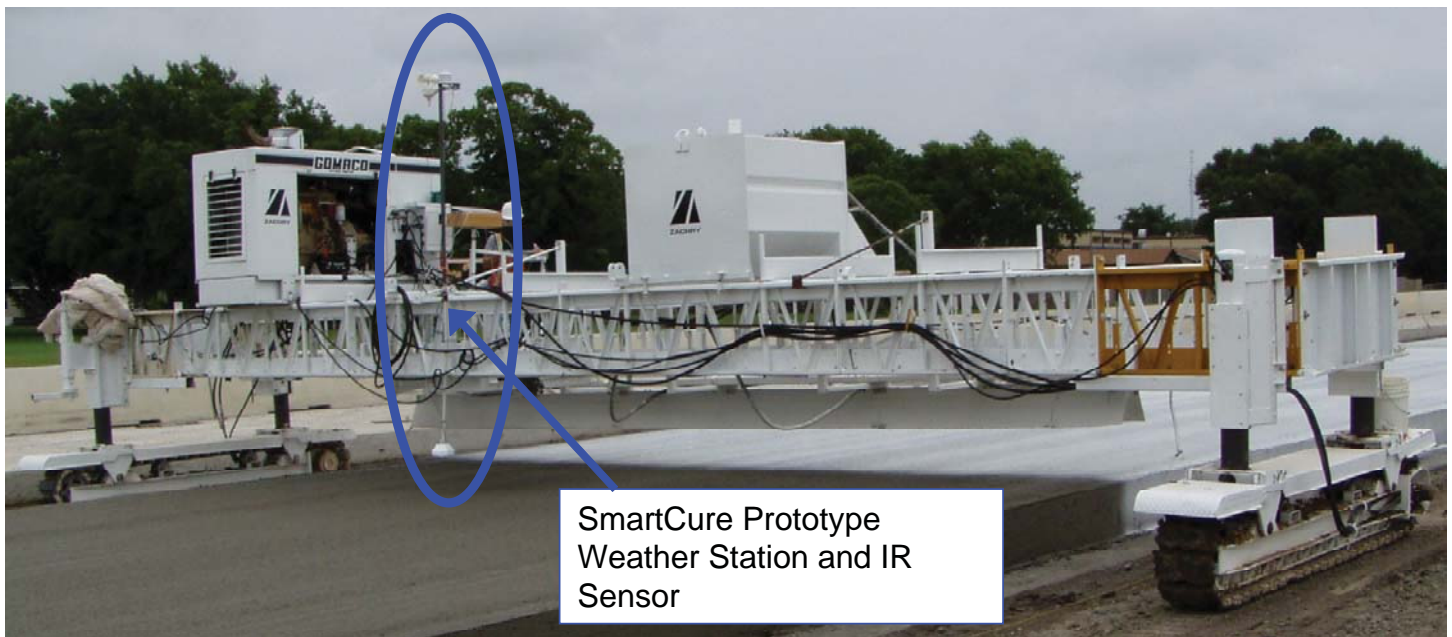

SmartCure Prototype Weather Station and IR Sensor

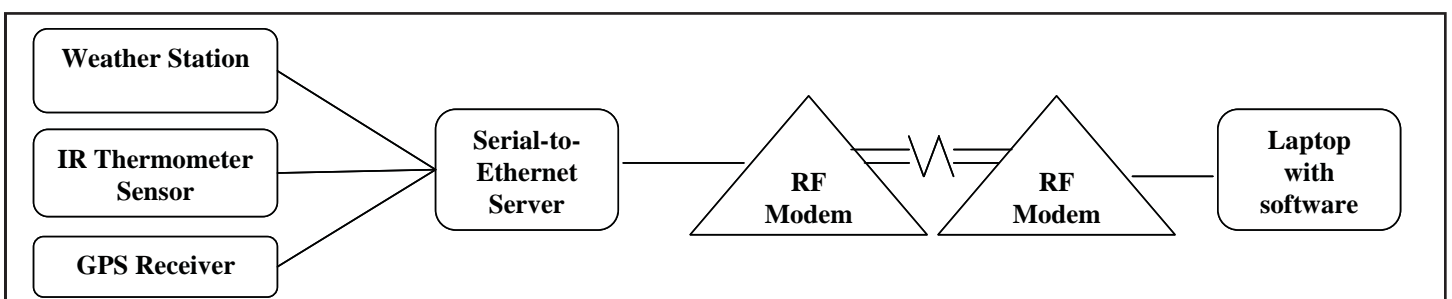**Figure 4. SmartCure prototype in the field**

Figure 5. Schematic of SmartCure system components

three screens: Main, Overview, or Details. The Main screen graphics show immediate measured values for air temperature, concrete surface temperature, relative humidity, and wind speed (figure 6). Calculated values for evaporation rate are also displayed. Measured and calculated data are logged every two minutes; this interval can be adjusted by the user. A summary of data for each station can be viewed in the overview screen. A station is typically 100 feet in length, but the user can modify this value when entering general site information inputs. A summary of data over time can be viewed in the Details screen.

Upon completion of data collection, the user can opt for the software to generate a report of all logged data that can be printed as a hard copy. A User's Manual is currently being developed that will provide detailed guidance on how to properly set up SmartCure components in the field and instruct the user on how to use the SmartCure software. It is expected to be available in spring or summer 2011.

SmartCure in the field

Field evaluations of the SmartCure prototype were performed in Houston, TX, Kansas City, KS, and Martinsburg, WV. The goal of each evaluation was to validate the performance of the system with regard to functionality, reliability, and accuracy. The FHWA mobile testing lab was present for two of the three evaluations and performed set time and bleed rate tests. The results of the FHWA mobile lab testing were used as inputs to the SmartCure software, and helped validate the software's ability to predict these rates in the field.

The field evaluations proved that SmartCure can perform well in the field and that it could be a useful tool for a contractor, contingent upon improvements to the prototype that would make it more practical for a field environment.

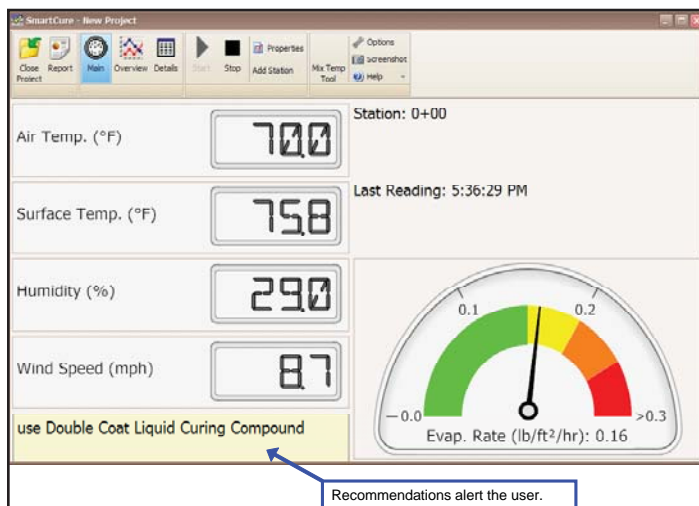Improvements following the field trials have included incor-

porating a wireless connection between the laptop and the measuring devices. This allows the laptop to be set up along the side of the paving operation, or even in a vehicle parked alongside the paving job (figure 7).

Conclusion

Made to be more practical for the field and proven to work successfully, SmartCure is intended to improve curing practices by providing guidelines for proper curing methods based on immediate ambient conditions. Currently, FHWA is in review of the recent improvements to the prototype. Additional improvements can easily be made as refinements are identified that will continue to make SmartCure even more practical for use in the field.

For more information

For information on how to obtain SmartCure or any additional literature, please contact Fred Faridazar at the Federal Highway Administration Turner-Fairbank Highway Research Center, 202-493-3076, fred.faridazar@fhwa.dot.gov.

Resources

Standard Practice for Curing Concrete, ACI 308R-01, American Concrete Institute, 2001.

J. Mauricio Ruiz, *SmartCure: Automated Curing Monitoring and Curing Guidelines*, http://www.cptechcenter.org/t2/documents/5RuizSmartCure.pdf, 2010.

Ruiz, J. M., R. O. Rasmussen, J. C. Dick, S. I. Garber, and D. Jacobson, *SmartCure Practical Enhancements for Field Application*, Transtec Final Report for FHWA project No. DTFH61-08-D-00034-T-9003, FHWA, 2011.

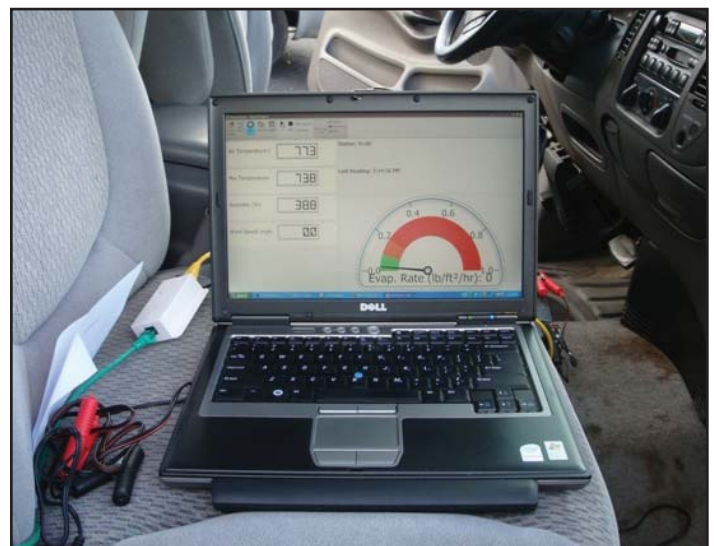**Figure 6. SmartCure software Main screen showing an alert**

Figure 7. Laptop set up to run software in contractor vehicle