HOW TO PREVENT PLASTIC SHRINKAGE CRACKS

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ABSTRACT:

One of the problems that contractors face is to identify the weather conditions and to determine if the concrete placements should proceeds. From past research, it has been shown that the three weather conditions (air temperature, humidity and wind velocity) and the concrete temperatures are the best indicators to determine if plastic shrinkage cracks will develop. A Nomograph was developed and published in many American Concrete Institute (ACI) committee reports as well as by the Portland Cement Association (PCA). Unfortunately, it is difficult to get the required information and the Nomograph is not easy to use.
Plastic shrinkage cracks can be prevented, provided the contractor properly assessed the weather and the fresh concrete conditions. This paper will present an assessment of some of the available inexpensive equipment that can be used by the contractor's field personnel to quickly determine both weather conditions and concrete temperatures. The paper will also include computer programs that use the above information to assist the contractor in making the decisions on what they can do to prevent the formation of plastic shrinkage cracks.
Keywords: plastic shrinkage cracks, weather conditions, Nomograph, concrete temperatures

INTRODUCTION:

One of the problems contractors face is to reduce the number of plastic shrinkage cracks on their projects. Although the mechanism of what causes plastic shrinkage cracks is well understood and the parameters have been researched and well documented, there is a disconnect in applying this information to the construction site.

Figure 1: A typical plastic shrinkage crack.
(Courtesy of Portland Cement Association)

MECHANISM OF PLASTIC SHRINKAGE CRACKING:

The American Concrete Institute (ACI) in ACI 116 defines plastic shrinkage cracking as “cracking that occurs in the surface of fresh concrete soon after it is placed and while it is still plastic.” These cracks form because of the loss of bleed water from the surface of the fresh concrete by evaporation. The tensile strength of the fresh concrete is very low since the concrete has not had time to set, thus the volume change caused by this evaporation of the bleed water results in the formation of plastic shrinkage cracks.

The research in the parameters that effect evaporation rates of the bleed water goes back to Dalton is work in 1802. His research developed the formula for evaporation rate from water surfaces (ponds, reservoirs, lakes, etc). Carl Menzel of the Portland Cement Association simplified the formulae and established the evaporation rates that would result in the formation of plastic shrinkage cracks in fresh concrete. Delmar Bloem of the National Ready Mixed Concrete Association developed a Nomograph that related the air temperature, relative humidity, concrete temperature and wind velocity parameters, which are relatively easy to measure, to predict the evaporation rates for a concrete surface with bleed water. These Nomographs have been published by many sources such as ACI, “Hot Weather Concrete” (ACI 305) and the PCA, “Design and Control of Concrete Mixtures.”

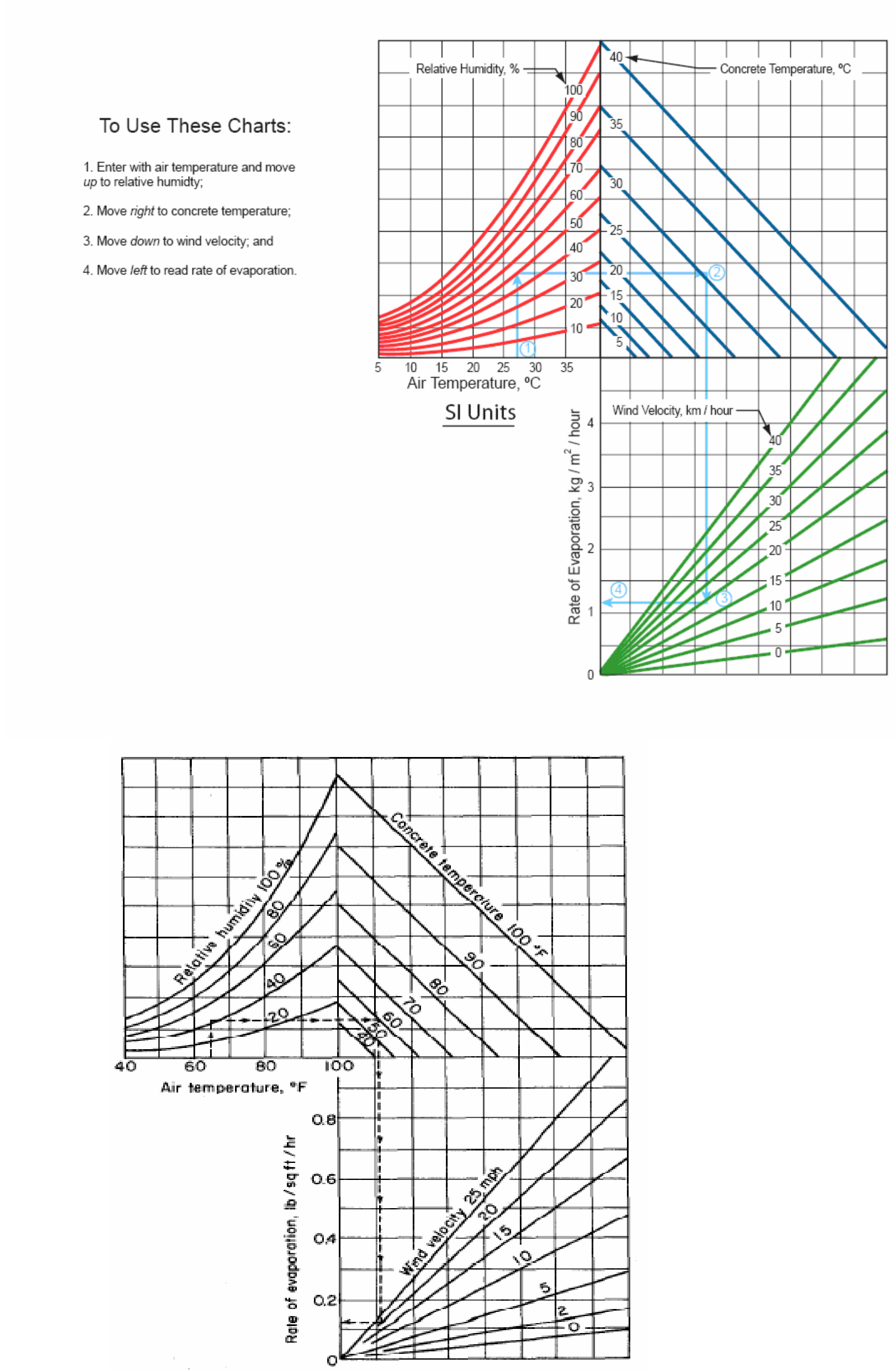

Figure 2: Nomograph for estimating the rate of evaporation of water from a concrete surface (Courtesy of Portland Cement Association)

Recently, new equations have been offered that make it easier to calculate the evaporation rate in concrete. These are:

English units: $E = (Tc^{2.5} - r\ Ta^{2.5})\ (1+0.4V) x\ 10^{-6}$

E = Evaporation Rate, $lb/ft^2/hr$

Tc = Concrete (water surface) Temperature, F

Ta = Air Temperature, F

r = Relative Humidity (percent)/100

V = Wind Velocity, mph

Metric units: $E = 5\ (\ [\ Tc + 18]^{2.5}\ - r\ [\ Ta+ 18\ ]^{2.5}\ )(V + 4)\ X\ 10^{-6}$

E = Evaporation Rate, $kg/m^2/hr$

Tc = Concrete (water surface) Temperature, C

Ta = Air Temperature, C

r = Relative Humidity (percent)/100

V = Wind Velocity, kph

WHAT EVAPORATION RATE CAUSES PLASTIC SHRINKAGE CRACKING TO FORM:

In the United States of America (USA), two values of evaporation rates are used to provide guidance to the contractors on when plastic shrinkage cracks will form. When the evaporation rates exceed 0.2 $lb/ft^2/hr$ (1.0 $kg/m^2/hr$) plastic shrinkage cracks are expected. Precautionary measures are almost manitory. Some of these are erecting a wind screen, cooling the concrete, using a fogging system, and placing concrete at night. When the evaporation rate is between 0.1 and 0.2 $lb/ft^2/hr$ (0.5 and 1.0 $kg/m^2/hr$) plastic shrinkage cracking may occur. Since evaporation rates in these ranges can occur and to avoid plastic shrinkage cracks, the above precautionary measures are recommended. When the evaporation rates are 0.1 $lb/ft^2/hr$ (0.5 $kg/m^2/hr$), plastic shrinkage cracks are not expected.

WHY IS THE NOMOGRAPH AND FORMULAE NOT WIDELY USED?

1. Contractors, Ready Mixed Concrete Companies personnel, and Designers are unaware of the Nomographs:

Using the Nomograph and formulae are not a part of the ACI's Building Code, and its use is not manitory. As stated before, the Nomograph is in many publications, however, most people do not read these until problems occur on their jobsite. From my experience, engineering and construction education at the universities spend little or no time discussing plastic shrinkage cracks. In examining several of the textbooks, commonly used in university concrete materials courses, plastic shrinkage cracking is either omitted or receives cursory coverage. Thus, few people know that the Nomograph or equation exist or have used experience in using them.

2. The Nomograph and equations are not easy to use:
Once a person does find or becomes aware of the Nomograph and the equation, they find that they are not easy to use. The Nomograph is a series of three (3) graphs and the user must go from graph one (1) to graph two (2) to graph three (3). Although this is not difficult, most people do not routinely use these types of graphic techniques and are uncomfortable with this approach. The equations require both understanding and experience in advanced mathematical skills. Again, most people are not experienced in solving an equation that raises a number to the 2.5 power. Neither the Nomograph nor the equations will allow the user to do a "what if." (If I lower the concrete temperatures, how low do the temperatures need to be so that plastic shrinkage cracks do not occur?) It is one thing to assess the current situation. However, the user needs to know how he/she can modify the concrete or the construction environments so that the project will not have plastic shrinkage cracks.
3. Unaware of how to get weather information:
The Nomograph gives exact locations at where weather is to be measured. The wind is to be the average wind speed and is to be measured at 20 inches (500 mm) above the evaporating surface. The air temperature and relative humidity is to be measured at 4 to 6 feet (1.2 – 1.8 meters) above the concrete surface on the windward side and shielded from the sun.
When consultants are asked to evaluate plastic shrinkage cracking, they have to find the available weather information. Typically, they will use weather information provided by the nearest airport. The airport measures wind speed at 33 feet (10 meters) above the ground. The wind speed on the job site may vary from the airport. Typically, the wind speed is less than the wind speeds measured at the airport. If the construction project is remote from the nearest weather station, the air temperature and the relative humidity measured at the airport may also vary from those that exist on the jobsite. Thus, using weather information from the airport, the Nomograph or the equation may inaccurately predict the evaporation rate and whether plastic shrinkage cracking would occur at jobsites.

COMPUTER PROGRAM:

Recently, a computer program was developed that makes the Nomograph and the equations easy to use. The user simply enters the air temperature, concrete temperature, relative humidity, and wind velocity. The program will determine the evaporation rate and warn the user if precautionary methods are needed. To further emphasize the fact that some conditions may cause or might cause plastic shrinkage cracking, the answers are color coded. The color codes are similar to a traffic light. The output is in red when plastic shrinkage cracks are expected and precautions against plastic shrinkage cracking are manitory. This occurs when the evaporation rates are more than 0.2 lbs/ ft^2/ hr (1.0kg/m^2/hr). The output is in yellow when the plastic shrinkage cracks can occur. This occurs when the evaporation rates are between 0.1 to 0.2 lbs/ ft^2/ hr (0.5 to 1.0kg/m^2/hr). The output is green is used when the plastic shrinkage cracking is not expected. This occurs when the evaporation rates are less than 0.2 lbs/ ft^2/ hr (1.0kg/m^2/hr).

The computer program also allows the user to solve problems or do the "what if" questions about plastic shrinkage cracks. If the plastic shrinkage cracking is likely to occur, the user can select one of the variables they would like to control. The program will calculate how much change is required so that plastic shrinkage cracks are not expected or when the evaporation rates are below 0.1lbs/ft^2/hr (lbs0.5kg/m^2/hr). This computer program can be found on the following website:
http://construction.asu.edu/cim/curingfirstpage.htm

http://construction.asu.edu/cim/curing_metric.html

It is available for a free download.
As part of the research, several handheld weather stations were also examined that allow the user to measure the wind velocity, relative humidity, and air temperature at the appropriate location on the jobsite as stated in the Nomograph. From the research, it was found that each of these pieces of equipment can accurately predict the humidity, air temperature, and wind speed when compared to a certified weather station. These can be obtained for under $210US.

Kestrel 3500 **Kestrel 3000**

Figure 3: Photographs of two handheld weather stations

Also done was an evaluation of using Infrared thermometers. This equipment allows the user to simply point the equipment at the concrete to measure the concrete surface temperature (the equipment collects infrared radiation that an object emits, this information can be used to determine the surface temperature of concrete). Infrared thermometers can be obtained for under $100US.

CONCLUSIONS:

This paper attempts to solve all three (3) of the issue of why plastic shrinkage cracking Nomograph and equation are not used:
1. This paper hopefully alerts several users, university professors and students about the Nomograph and equation, thus increasing awareness that these methods do exist and can be used to prevent plastic shrinkage cracking from occurring on the jobsite.
2. The computer program makes the Nomograph and equation very easy to use and thus, have eliminated the difficulty many people have when they attempt to use either the Nomograph or the equation. The computer program also allows the user to determine what needs to be done so that the likelihood of plastic shrinkage cracking is reduced.

3. The handheld weather stations and the infrared thermometer allows the user to measure the four (4) values needed to determine if plastic shrinkage cracking is likely to occur.

REFERENCES:

1. American Concrete Institute (ACI) Committee 308, "Guide to Curing Concrete", ACI 308R-01, American Concrete Institute, 2001.
2. Concrete Q & A, "Estimating Evaporation Rates to Prevent Plastic Shrinkage Cracking", Concrete International, March 2007
3. Kestrel 3500 and Kestrel 3000, Retrieved in February 21, 2007 from http://www.kestrelmeters.com/Kestrel-Meter-3500.pro http://www.kestrelmeters.com/Kestrel-Meter-3000.pro
4. Kosmatka, Kerkhoff, and Panarese, "Design and Control of Concrete Mixtures," 14th Edition, Portland Cement Association, 2002.
5. Menzel, Carl; "Cause and Prevention of Cracks Developing in Plastic Concrete," Portland Cement Association, Annual Meeting 1954.
6. Munir, Aamir and Snell, Luke, "Prevention of Plastic Shrinkage Cracks in Fresh Concrete," Concrete Producer, August 2005.
7. Radnaabazar, Khishgee; Snell, Luke; and Yagaanbuyant, Duinkherjav, "Globization through Collaborative Research,"4th Proceedings Mongolian Concrete Conference, Ulaanbaatar, Mongolia, 2005.
8. Uno, Paul; "Plastic Shrinkage and Evaporating Formula", ACI Materials Journal, American Concrete Institute, July–August 1998.