Process Control for Sustainable Precast Slab Production

Proprietary solution helps control schedule

BY GEIR OVE SKJÆRVIK

Precast concrete plants have long used temperature-matched curing or maturity to verify that the concrete elements have reached the required strength for operations such as form removal or strand detensioning. These methods ensure that the elements are not subjected to excessive stress during production, making them important aspects of quality assurance. However, more detailed monitoring and control of the internal temperatures, relative humidity, and compressive strength can yield significant savings in terms of energy inputs while also affording the operator greater control over the production schedule.

PROCESS CONTROL

Our system, known as HPC-09, is a proprietary process control technology for the production of precast concrete slabs. The technology includes software and a data acquisition system that includes a wireless measurement system containing temperature and humidity sensors (Fig. 1). For each family of concrete mixture designs used at the plant, calibration data must be developed ahead of time. Based on target strength, curing time, ambient air temperature, and (optionally) air relative humidity, HPC-09 calculates an initial *predicted* temperature history (Fig. 2) and plots the resulting temperature and compressive strength (Fig. 3) versus time. While the element is curing, HPC-09 monitors and plots the *actual* temperature (green) and relative humidity (light blue) (Fig. 4).

The HPC-09 system

The HPC-09 system comprises a software module and wireless measurement stations. The wireless measurement stations collect and transmit data on the surface temperatures for the concrete element and the ambient relative humidity. By measuring surface temperatures rather than internal temperatures, measurement stations can simply be placed on top of the concrete element, with no or minimal impact on the production cycle. The software module calculates the predicted internal temperature history and compressive strengths, monitors the data from the measurement stations, and provides feedback to adjust plant operations. Where the casting bed is heated, HPC-09 can also be used to control the heating system to optimize energy use.

All calibrations are done at the plant where the system is installed. Thus, the predicted temperature histories

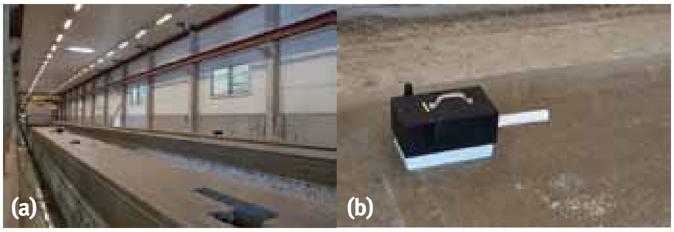

Fig. 1: Hollow-core production: (a) overview showing recently produced slab—a measurement station and production machine are visible in the background; and (b) close-up of measurement station

and strength gain curves are based on the specific materials and concrete mixture proportions used at the plant. The software can account for heating of the casting bed, so the specific behavior of the casting bed can be accounted for as the software calculates the placement temperature to achieve the required compressive strength within the desired time. The HPC-09 system inputs and outputs are summarized in Fig. 5.

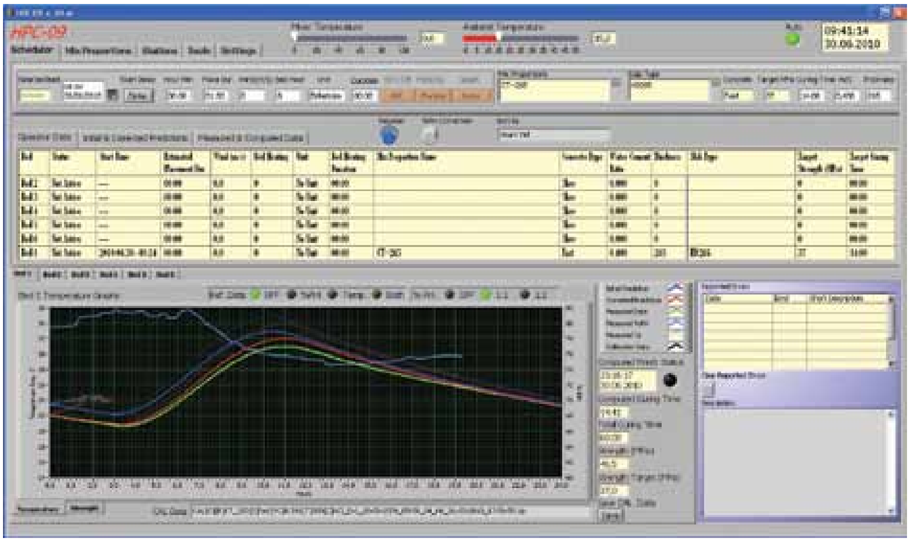

Fig. 2: Screen view of temperature and relative humidity data plotted by HPC-09 during curing of precast elements. The graph shows initial predicted concrete temperature history (dark blue), corrected predicted temperature history based on temperature from last placement (red), and measured temperature history (green). The air relative humidity (light blue line) is also shown

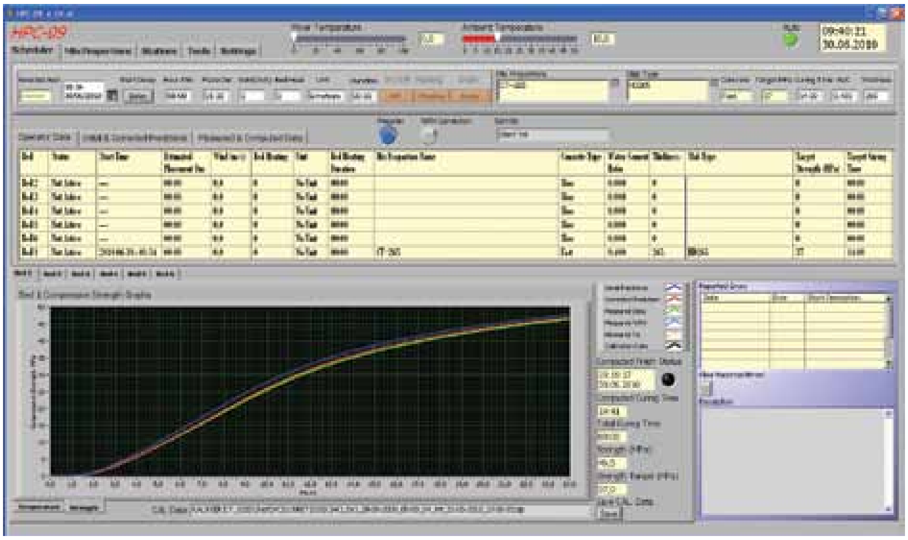

Fig. 3: Screen view of compressive strength data. The plot shows initial predicted compressive strength (blue); corrected compressive strength based on temperature from last placement (red); and compressive strength based on current, measured curing conditions (green)

Detecting production anomalies

By monitoring the HPC-09 system in real time, the operator gets early warning if anything does not go as predicted. In many cases, the advance warning also allows the operator to make adjustments to mitigate the effects. Some typical problems and corrections that might occur in production include:

- The concrete placement temperature is lower than anticipated due to low aggregate temperature. The software recalculates the curing regime and strength gain for the new initial temperature. If necessary, the curing bed can be heated to produce the desired strength at the desired time;
- The air temperature in the production hall is colder than usual because the doors were left open. The software recalculates the curing regime and strength gain for the reduced ambient temperature. If necessary, the curing bed can be heated to compensate for the slower strength gain; and
- The sand is wetter than accounted for in batching, resulting in a higher water-cement ratio. The software calculates the effect on strength gain to predict when strength will be adequate; if necessary, the bed temperature can be adjusted accordingly.

SAVINGS

Energy

Because the temperature and humidity are monitored in real time, the plant operator can readily see when, for example, the maturity will not be sufficient to yield adequate strength to remove the forms at 18 hours and can increase the heat to

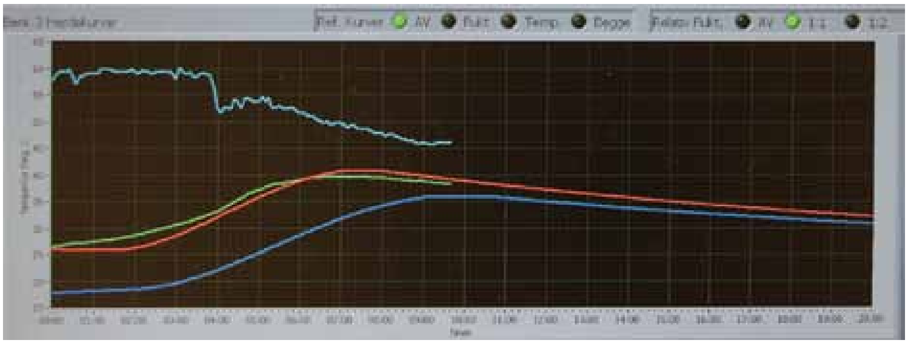

Fig. 4: Detailed view of a data plot. The dark blue line shows the initial predicted temperature history, the red line shows the temperature history of the last placement, the green line shows the actual temperature history, and the light blue line shows actual ambient relative humidity. As can be seen from the light blue line, the relative humidity dropped slightly about 4 hours into the curing cycle. This coincides with the opening of exterior doors, which briefly let in cold air

the curing bed accordingly, eliminating the necessity of having workers standing idle while waiting for the concrete to gain strength. Conversely, when the maturity is such as to yield higher strengths than required, the operator can turn down the heat in the curing bed and save energy without wasting time or compromising quality. For later placements, the plant operator can also adjust the placement temperature of the concrete or insulate the forms to optimize the amount of energy and labor required.

Labor costs

In Norwegian plants, only about 0.5 worker-hours is required to produce 1 tonne (1.1 tons) of hollow-core concrete slabs. Worker and supervisor overhead are very low. The only supervisors are usually the Concrete Mixer Operator and the Head of the Planning Department. Thus, the potential for labor savings is minimal for hollow-core slab production in Norwegian plants.

However, the production of beams and columns is eight times (4 worker-hours per tonne) more labor-intensive. HPC-09 provides a more predictable development of the curing and thus the timing of plant operations. This opens up the possibility of a more efficient use of labor and automation with related potential for cost savings. A production of 25,000 tonnes (27,000 tons) requires about 100,000 worker-hours. Based on our experience, the system provides at least a 10% savings in worker time. For this example, 10,000 worker-hours could be saved per year.

Carbon emissions

Almost all concrete hollow-core slab production in Norway is done using high-early-strength cement. When there is no means of accurately predicting the curing process, this gives the plant operator a large safety margin with respect to the curing time. The production of one unit (by weight) of high-early-strength cement generates about 0.74 units of CO_2. The production of one unit of a binary cement with fly ash results in about 0.62 units of CO_2 (a 16% reduction).

The production of 100,000 tonnes of concrete slabs requires about 15,600 tonnes of cement. Using high-early-strength cement, the CO_2 emission would be about 15,600 × 0.74 = 11,544 tonnes. Using binary cement with fly ash, the CO_2 emission would be about 15,600 × 0.62 = 9672 tonnes, saving over 1800 tonnes of CO_2.

To reach the same strength in the same time with the binary cement as with the high-early-strength cement, accelerators must be used or the placement and curing temperatures of the concrete must be increased. However, the additional heat needed to achieve the same curing time has a minimal effect on the total CO_2 emission.

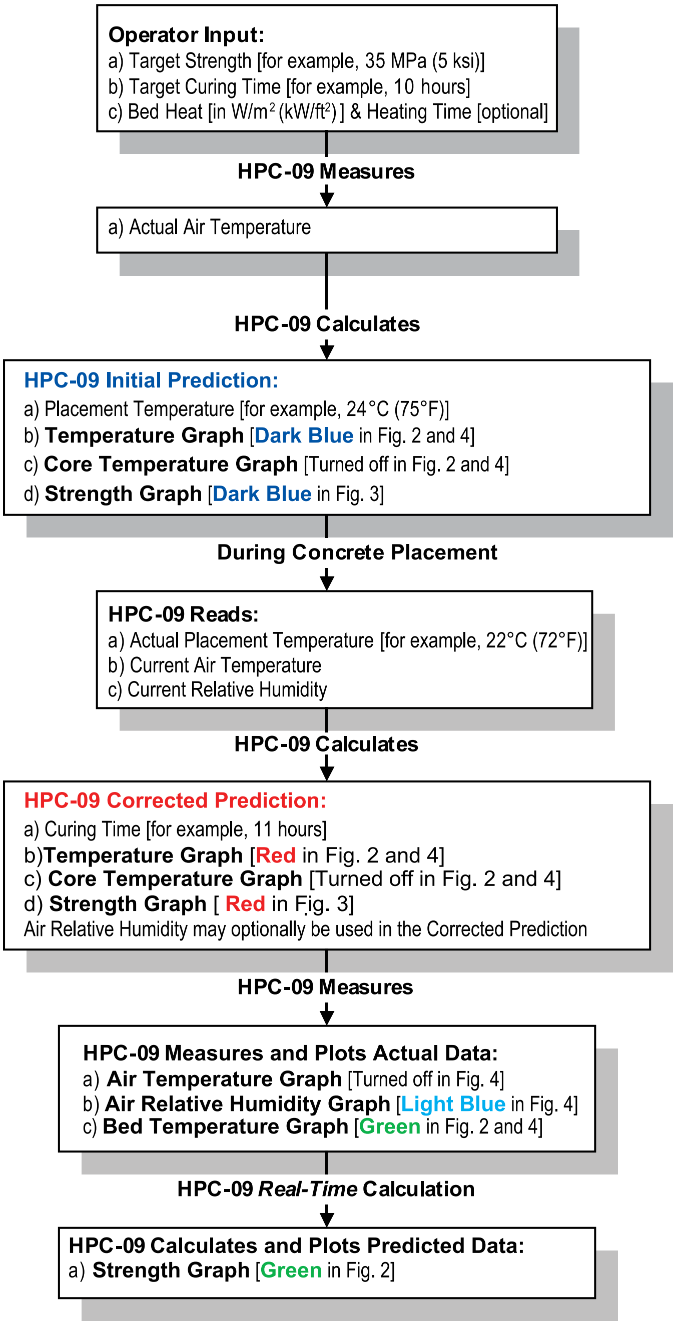

Fig. 5: Block diagram showing HPC-09 system inputs and outputs

Under Norwegian conditions, curing 100,000 tonnes of concrete slabs consumes approximately 2800 MWh of electricity to heat the beds. This results in about 300 tonnes of CO_2 emissions. Even if a producer had to double the heat input to improve curing time when using the blended cement, the CO_2 savings would still be more than 1500 tonnes. Using HPC-09 to minimize energy use would further reduce the carbon footprint from the above calculated values.

DATA-BASED DECISIONS

Precast concrete producers can now take full advantage of electronic equipment to collect, and analyze data and help make decisions regarding their processes. A precast plant has well-defined goals, limits, material parameters, and production deadlines. If anything in that plant's process goes wrong, however, product can be ruined, deadlines missed, and profits destroyed. If there's a problem, it has to be fixed immediately to avoid those consequences; but that's not possible if there isn't enough information to show what went wrong in the first place.

Tools like HPC-09 can be enablers: they provide insight into the processes and thereby enable producers to make better, smarter decisions. Real-time data, real-time insights, and real-time corrections will lead to real savings.

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