VAKKA

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Purpose

The **VAKKA** sensors are durable and waterproof wireless monitoring devices used to measure the internal temperature and relative humidity of newly cast concrete up to a depth of 3 meters for the following purposes:

- Estimating the compressive strength at an early age using a user defined strength-maturity relationship.
- Timing of pullout testing with **LOK-TEST** for early-age strength measurement.
- Evaluating the effective in-place curing temperature
- Timing the surface treatment on floor slabs.
- Monitoring water penetration in concrete

Proper curing of concrete is essential as it allows the cement particles to effectively hydrate, ensuring the desired concrete strength and durability. It is current practice to make concrete cylinders during concrete placement. These cylinders are left on site to allow the concrete to set and then transported to the laboratory, capped, and then tested in a compression machine to determine the compressive strength.

However, this practice does not measure the actual field curing conditions or the temperature history of the structure because unlike the cast concrete elements, cylinders have small volume and large surface areas which makes them retain much less heat and moisture. This causes a significant difference in the rate of strength gain that does not allow to have real-time information of the strength development of the structure.

Additionally, this method is also very labor-intensive and costly, as the practice is repeated throughout the project and is highly subject to operator errors and frequent delays.

With the **VAKKA** sensors, the traditional method is improved in accuracy and project cost savings by reflecting better the concrete strength gain in real-time. On the other hand, by knowing the up-to-date level of relative humidity of in-place concrete, the timing in which floor coverings are installed, such as resilient flooring, wood, epoxy or polymer-based coatings, can be optimized.

Maturity Method

The maturity method is a technique to estimate in-place strength after casting by accounting for the effects of temperature and time on the strength gain of concrete. It is described in ASTM C1074 "Practice for Estimating Concrete Strength by the Maturity Method."

The temperature history of the concrete and a maturity function are used to calculate a maturity index that quantifies the combined effects of time and temperature. The strength of a particular concrete mixture is expressed as a function of its maturity index by means of a **strength-maturity relationship**. If portions of the same concrete are subjected to different conditions, the strength-maturity relationship for that concrete and the temperature histories measured at the different locations in the structures can be used to estimate in-place strengths at those locations.

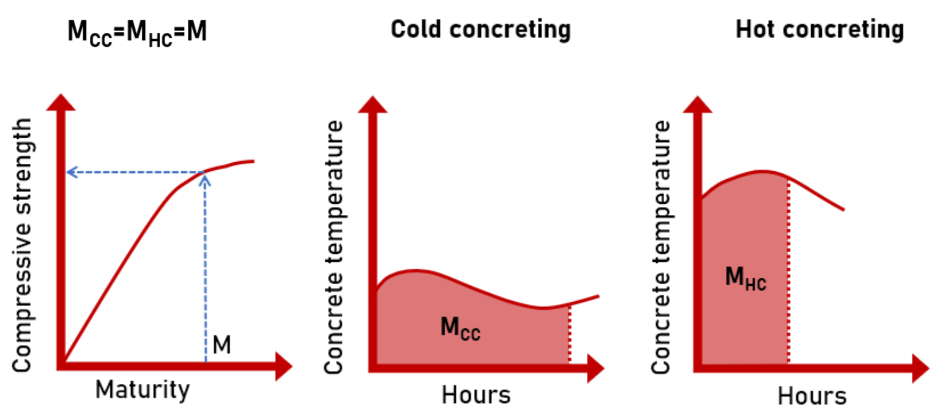
Various maturity functions have been proposed to convert the measured temperature history to a maturity value. The one that has proven to be most accurate in accounting for the combined effects of time and temperature over wide temperature ranges is based on the Arrhenius equation.

$$t_e = \sum_0^t e^{\frac{-E}{R}\left(\frac{1}{T}-\frac{1}{T_r}\right)} \Delta t$$

where:
Δt = time interval at actual concrete temperature
te = the equivalent age at the reference temperature,
E = apparent activation energy, J/mol,
R = universal gas constant, 8.314 J/mol-K,
T = average absolute temperature of the concrete during interval Δt, Kelvin, and
Tr = absolute reference temperature, Kelvin.

The exponential function is an age conversion factor that converts a time interval at the actual concrete temperature to an equivalent time interval, in terms of strength gain, at the reference temperature. The reference temperature is usually taken as the standard-curing temperature for concrete specimens, typically 20 °C (293 K) or 23 °C (296 K).

The activation energy represents the temperature sensitivity of the rate of strength gain during the acceleratory period following final setting and it depends on the cementitious materials in the concrete. For ordinary Portland cement, it has a value of about 40 kJ/mol, and it is greater for mixtures with slag cement and smaller for mixtures with fly ash (1, 2). ASTM C1074 provides strength-testing procedures for estimating the activation energy for a specific cementitious system. Others have used isothermal calorimetry (2) and setting time tests to evaluate activation energy (3).



To use the maturity method for estimating in-place strength, it is necessary to develop the strength-maturity relationship for the particular concrete mixture. As described in ASTM C1074, this can be done by measuring the strength of specimens of the concrete mixture at different values of maturity. The strength-maturity data can thus be used for estimating the strength as a function of age at the locations of the **VAKKA** sensors.

The VAKKA-Sensors

VAKKA is a durable, waterproof concrete sensor that wirelessly monitors the environmental conditions within the concrete as it hardens. The patent-pending environmental chamber is unique to the **VAKKA** system and allows for faster and more accurate readings. It quickly equalizes the surrounding environment allowing precise measurements to be recorded within minutes of pouring your concrete.

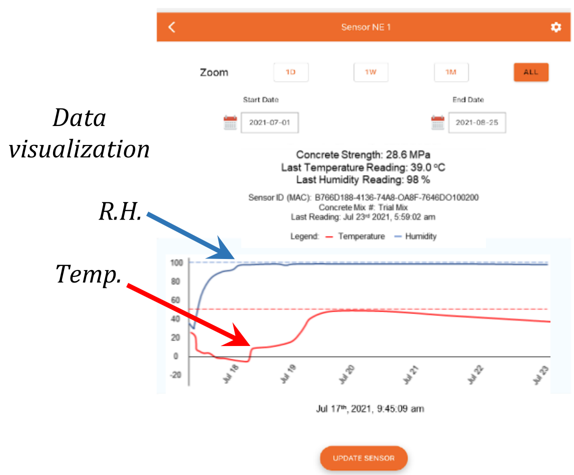
The free mobile app and cloud service empowers the user's team to make faster and more confident decisions. The data can be downloaded to the app at any time when a connected device is within the 3-4 m range of the sensor and is instantly uploaded to the cloud where it is shared with the team. The app estimates the compressive strength by using the user defined maturity curve and allows instant access to the temperature and relative humidity readings, plotting data, and reports.

Application

a) Install sensor

b) Synchronize sensor with app

c) Cast concrete



d) Record data

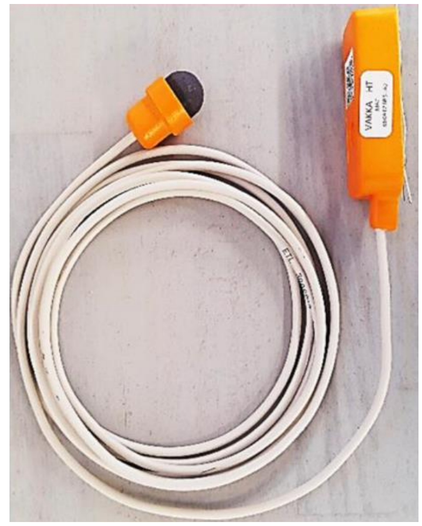
VAKKA Features and Specifications:

- Free mobile App for Android and IOS devices
- Wireless technology
- Easy installation and activation
- Accurate real-time data display of relative humidity and temperature
- Normalizes to ambient conditions within minutes of placement
- Long storage life with external magnetic activation
- Rugged, crush proof and waterproof design
- Full reporting
- Cloud data storage for team access to projects from any location
- Maturity methods: ASTM C1074 Nurse/Saul and Arrhenius
- Measurement interval: 30 min (fixed)
- Maximum data collection: 4,000 data points (60 days)
- Operational battery life: > 4 months (active)
- Storage battery life: 10 years (unactive)

- Temperature accuracy: +/- 0.3 °C
- R.H. accuracy: +/-2%
- Embedment depth: 1 m or 3 m probe available for VAKKA-Tx/HTx sensors
- Attachment: Galvanized tie-wires

VAKKA Ordering Numbers

Item	Order #
Sensor for temperature at the depth of the reinforcement	VAKKA-T
Sensor for temperature with a 1-meter extension probe.	VAKKA-T1
Sensor for temperature with a 3-meter extension probe.	VAKKA-T3
Sensor for temperature and relative humidity at the depth of the reinforcement	VAKKA-HT
Sensor for temperature and relative humidity with a 1-meter extension probe.	VAKKA-HT1
Sensor for temperature and relative humidity with a 3-meter extension probe.	VAKKA-HT3
Sensor for relative humidity with an extended battery life	VAKKA-RHmax



Test Methods

ASTM C1074 -Standard Practice for Estimating Concrete Strength by the Maturity Method.

ASTM F2170 -Standard Test Method for Determining Relative Humidity in Concrete Floor Slabs Using in situ Probes.

References

1. Carino, N.J. and Lew, H.S., "The Maturity Method: From Theory to Application" http://fire.nist.gov/bfrlpubs/build01/PDF/b01006.pdf
2. . Schindler, A.K., "Effect of Temperature on Hydration of Cementitious Materials," *ACI Materials Journal*, Vo. 101, No1, Jan-Feb 2004, pp. 72-81.
3. Pinto, R.C.A. and Schindler, A.K., "Unified modeling of setting and strength development," *Cement and Concrete Research*, Vol. 40, 2010, pp. 58-65.