Evaluating SmartRock Temperature Sensor Performance in Measuring Concrete Strength

Jack Dasch
California Polytechnic State University
San Luis Obispo, California

Concrete testing is one of the most important parts of the concrete placement process. Traditionally, this is done through the use of 6x12 cylinders cured in a lab that are broken at various stages of the curing process. These cylinders are not necessarily representative of the in-situ concrete because of their differing curing conditions- indoors versus exposed to the elements. Wireless temperature sensors, like Giatec's SmartRock, have the potential to determine concrete strength based off the temperature of the placed concrete over time, thus eliminating the need for cylinder breaks. Once calibrated to the specific mix design, these wireless sensors could prove to be a valuable tool to contractors as they could allow early stripping of forms or removal of concrete that is unlikely to make a specified strength. The accuracy of these sensors, and the difference between lab-cured and in-situ concrete, was tested against break tests performed using Cal Poly's CM 114 Mix A. It was found that the sensors were within 7.7% of the broken results. The in-situ concrete compressive strength was within 3.6% of the lab-cured concrete. These results indicate no significant difference in compressive strength between sensors and cylinders, or between lab-cured and in-situ concrete.

Key Words: SmartRock, Concrete, Testing, Maturity Method, Non-Destructive Testing

Introduction

Verifying the in-situ strength of concrete is a vital part of the placement process. This is typically done by an independent testing agency that performs cylinder breaks on specified days after placement, typically to check 7, 14, 21, and 28- day strength. Except for those days, the contractor placing the concrete has little to no information about how the concrete is performing. A company called Giatec has introduced a wireless temperature sensor that can estimate the strength of in-situ concrete by applying the non-destructive maturity method. SmartRock sensors can transmit data every 15 minutes, which gives contractors much more information about how their freshly placed concrete is performing and eliminates the need for cylinder breaks (Giatec, SmartRock). With this information, a contractor may be able to strip forms early if the concrete achieves the specified strength before that information would have become available through weekly break tests. Conversely, if something happened and the mix is not performing as anticipated, a contractor may be able to remove it and replace it or at least begin exploring other options earlier than waiting on cylinder break information.

The Maturity Method

Concrete gains strength based on its temperature over time. These two variables, time and temperature, can be "used to determine the strength of concrete based on established correlations"

(Helal, et. al, 2015). Concrete gains strength any time its temperature is above 32 °F (Bagheri et. al., 2007). The Nurse-Saul equation, below, correlates these variables into a maturity index.

$$M(t) = \sum (T_a - T_0)\Delta t$$

$M(t)$ is the maturity index at age t, T_a is the average concrete temperature, Δt is the time interval, and T_0 is the data temperature (Bagheri et. al., 2007).

The next step is to apply the following equation to convert a maturity index to a compressive strength value (Giatec, Strength & Maturity).

$$Strength = a + bLOG(maturity)$$

A and *B* are variables based off a specific mix and the break results from the calibration process. Once break information is obtained, on, for example, days 1, 2, 3, 7, 14, and 28, the strength curve can be extrapolated- *A* and *B* help fit the logarithmic curve to the data points.

The maturity method, as a whole, follows ASTM STD. C1074. There are currently 33 state DOTs that accept the maturity method in their specifications (Giatec, What is Concrete Maturity?, 2019).

SmartRock

The SmartRock device is comprised of two temperature sensors, one at the end of a cable and one in the body of the device. It is designed to be strapped onto the top layer of a rebar mat and sit less than 2” from the surface of the concrete. It has a battery life of 4 months, and during that time it can transmit data via Bluetooth, up to 40’ away, to a smartphone every 15 minutes. The temperature information automatically informs strength calculations based on a calibrated mix design in the mobile app on the phone. The sensors should be placed every 100 yards of placed concrete (Giatec, Monitor Your Concrete, 2018). They remain embedded in the concrete permanently.

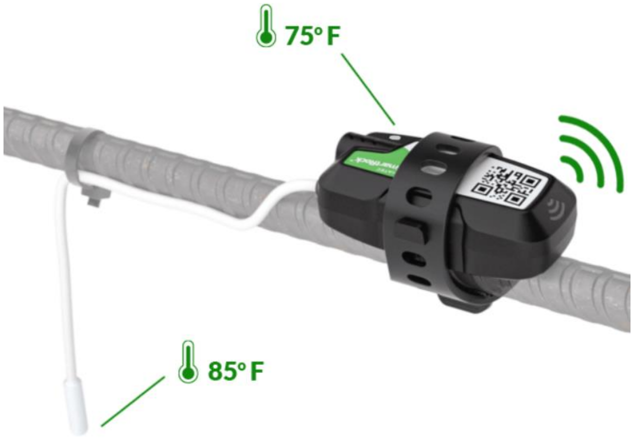


Figure 1. SmartRock Temperature Sensor.

Methods

To test whether there was a difference in the strength of field- or lab-cured concrete, 6x12 cylinders and a 6” cube were prepared using CM 114 Mix A. There were 5 cylinders- one to be broken on days 7, 14, 21, and 28, respectively, and one that would not be broken and instead had a SmartRock sensor embedded in it. These 5 cylinders were cured in a bathtub inside the lab, and a 6” cube cured with wet burlap was left outside as in-situ concrete. The cube also had a SmartRock sensor embedded in it. On the 28th day, the cube was also broken, to confirm that the sensor readings matched the actual strength in the field. The cylinders were prepared following ASTM STD. C31.

Table 1

CM 114 Mix A Design Proportions

Material	Coarse Aggregate (3/4”)	Fine Aggregate	Type II/V Portland Cement	Water
Weight (lbs.)	90	70	40	18

On break days, the compressive strength of the broken cylinders was compared to readings from both sensors. This was required to establish that the sensors were correctly predicting the lab cylinder strengths before being able to compare those readings to the in-situ cube. A difference in the readings from the SmartRock and the lab cylinders was not expected because the sensors had previously been calibrated to that specific mix design, per the direction of the Giatec Support Team. Giatec’s calibration guide states that up to a 10% difference in the strength readings is acceptable.

Data and Results

The 28-day strength of the cylinders, according to the temperature sensor, reached 5,876 PSI. Pictured below is the strength curve, maturity index, and temperature readouts of the cylinder, provided through Giatec360.

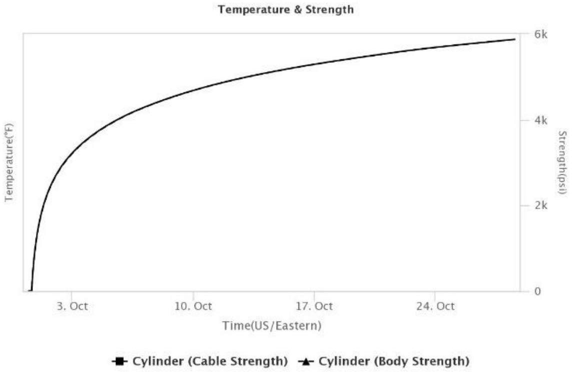


Figure 2. Cylinder strength over time.

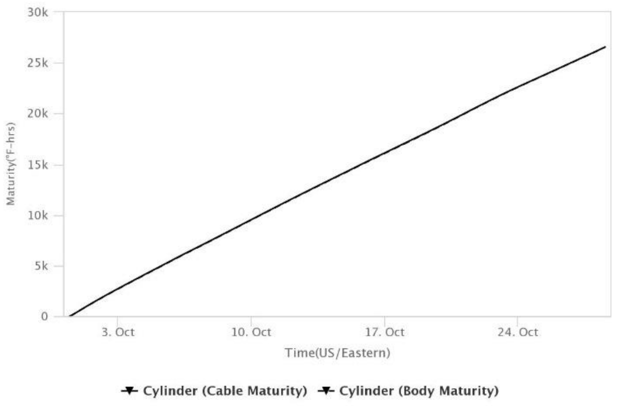


Figure 3. Cylinder maturity over time.

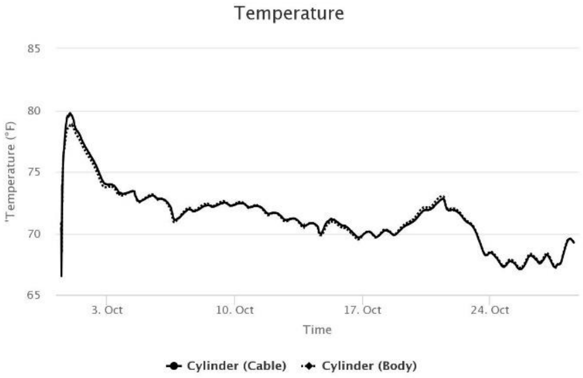


Figure 4. Cylinder temperature over time.

The 28-day strength of the cube reached 5,764 psi. Pictured below are the cube’s strength curve, maturity index, and temperature readouts, provided through Giatec360.

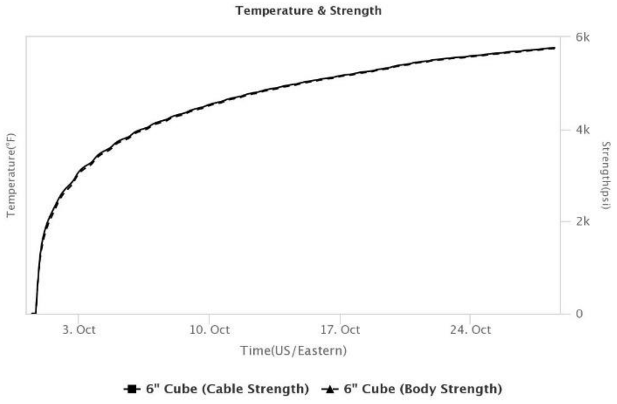


Figure 5. Cube strength over time.

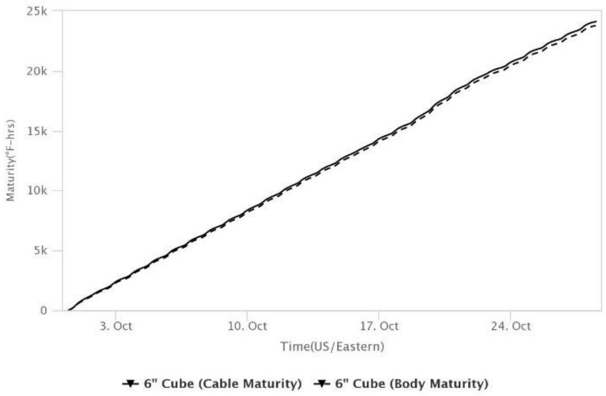


Figure 6. Cube maturity over time.

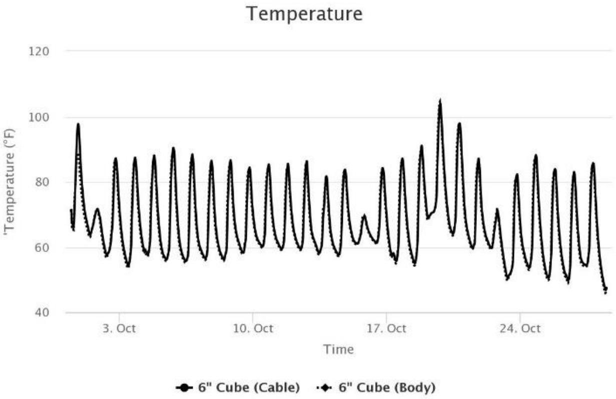


Figure 7. Cube temperature over time. Temperature differences due to heating up during the day and cooling off at night.

As far as temperature differences are concerned, the cylinder temperature ranged from 67.15 °F to 79.77 °F. The cube temperature, left at the mercy of the elements, ranged from 45.9 °F to 104.76 °F. The cylinder acquired 26,600 °F-hrs on the maturity index, and the cube reached 24,100 °F-hrs.

Table 2 contains the actual break results from the cylinders on days 7, 14, 21, and 28. Also included are the sensor readouts for both the cube and cylinder.

Table 2					
Day	Broken Cylinder Compressive Strength (psi)	Sensor Cylinder Compressive Strength (psi)	Cube Sensor Compressive Strength (psi)	Cylinder Difference vs. Breaks (psi)	Cube Difference vs. Breaks (psi)
7	4,531	4,341	4,183	-190 (-4.2%)	-348 (-7.7%)
14	4,824	5,112	4,971	288 (6.0%)	147 (3.0%)

21	5,534	5,564	5,469	30 (0.5%)	-65 (-1.2%)
28	6,023	5,876	5,764	-147 (-2.4%)	-259 (-4.3%)

As seen in the table, the largest difference in the results occurred on Day 7 in the cube, which was 7.7% off the break test result. The smallest differences occurred on Day 21, when both sensors were within 1.2% of the break test. Even though 7.7% seems high, it is well under the 10% acceptable margin put forward in Giatec's calibration instructions.

Table 3 relates the lab-cured and field-cured compressive strengths to each other.

Table 3				
Day	Sensor Cylinder Compressive Strength (psi)	Cube Sensor Compressive Strength (psi)	Difference (psi)	Difference (%)
7	4,341	4,183	-158	-3.6%
14	5,112	4,971	-141	-2.8%
21	5,564	5,469	-95	-1.7%
28	5,876	5,764	-112	-1.9%

The two sensors were much more tightly grouped to each other than to the break tests. The largest difference occurred at the 7th Day of curing at 3.6%, but by the last 2 weeks of curing the difference was less than 2%.

Because the differences between the sensors were less than 10%, there was no significant difference in the values between sensors and breaks, or between lab-cured and field-cured concrete.

When the 6" cube was broken into the Universal Test Machine, it broke after being loaded with 70,750 pounds. Given the 6" by 6" surface area, this means that it broke at 1,965 psi, when it was expected to break at 5,764 psi. The sensors in both the cylinder and the cube were fairly accurate to each other and to the broken cylinders. This raises an area of future research that there may be a local weakness in the concrete wherever these sensors are placed. The weakness could also possibly be caused by user error caused by unfamiliarity with the larger testing machine required to break a cube of that size.

There was an issue that arose during the testing process. The sensors were calibrated to the mix using ¾"-1" coarse aggregate. When the next batch was prepared, the aggregate size on hand had been reduced to ½". It is possible that the change in aggregate size interfered with the sensor's ability to calculate the actual compressive strength of the new concrete, although the readings were already very close to the broken cylinders. It is recommended to recalibrate the sensors to the smaller size of aggregate and repeat the testing process, as well as design a test to explore the possibility of local weaknesses where the sensors are placed. Repeating the field test at a different time of year or in a different location where the temperature difference is more extreme could yield different results between the field and lab cured concrete.

Conclusion

SmartRock temperature sensors are very accurate in estimating the compressive strength placed concrete. Test results show there is not a significant difference in the strength of concrete cured in the field or in the lab. The tests should be redone after recalibrating the sensors to the new, smaller aggregate mix. Further experimentation is required to determine if there is any weakness in compressive strength associated with the area of concrete directly surrounding an embedded sensor.

References

Bagheri-Zadeh, Seyed-Hassan, et al. “Field Study of Concrete Maturity Methodology in Cold Weather: Journal of Construction Engineering and Management: Vol 133, No 11.” *Journal of Construction Engineering and Management*, American Society of Civil Engineers, 1 Nov. 2007, https://ascelibrary.org/doi/full/10.1061/%28ASCE%290733-9364%282007%29133%3A11%28827%29.

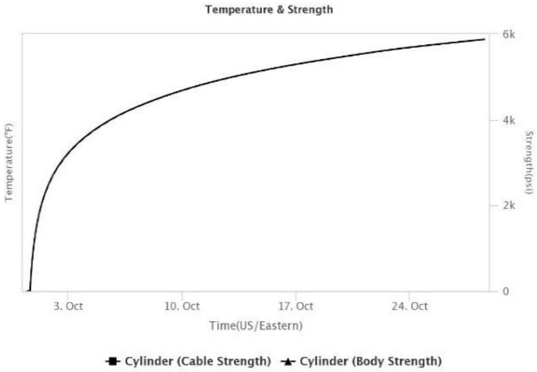
“Free Ebook - Maturity Method: A Guide to Concrete Strength.” *Giatec Scientific Inc.*, 30 June 2022, https://www.giatecscientific.com/strength-maturity/#.

Giatec Scientific Inc. “Test Your Concrete Slab Temperature with SmartRock: GIATEC Scientific.” *Giatec Scientific Inc.*, 18 May 2022, https://www.giatecscientific.com/education/want-to-check-on-that-concrete-slab-you-just-poured-now-theres-a-smartphone-app/#:~:text=The%20company%20suggests%20embedding%20one,100%20cubic%20yards%20of%20concrete.

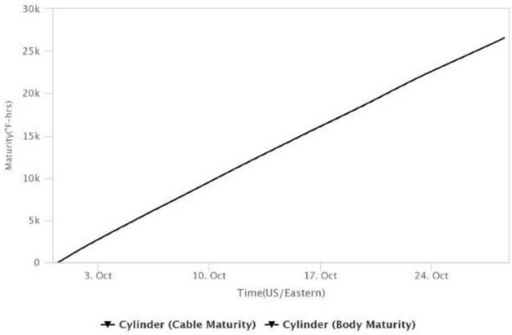
Giatec Scientific Inc. “What Is Concrete Maturity?” *Giatec Scientific Inc.*, 17 Feb. 2022, https://www.giatecscientific.com/education/concrete-maturity-in-situ-compressive-strength/.

Helal, J., et al. *Non-Destructive Testing of Concrete: A Review of Methods*. Journal of Structural Engineering, 2015, https://www.researchgate.net/publication/282938427_Non-Destructive_Testing_of_Concrete_A_Review_of_Methods.

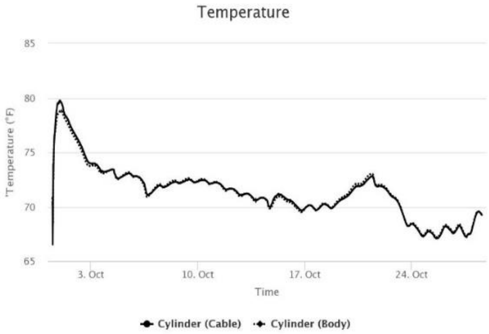
Appendix



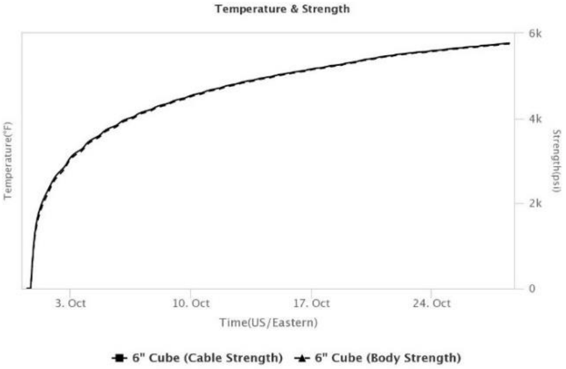
Appendix A. Cylinder Strength Curve



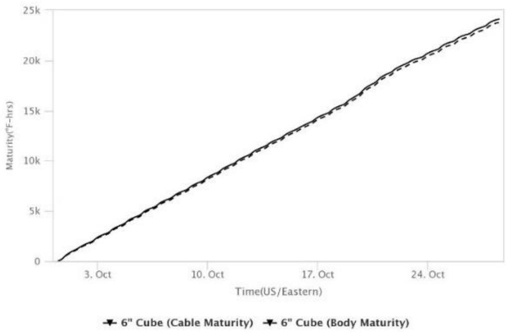
Appendix B. Cylinder Maturity Index



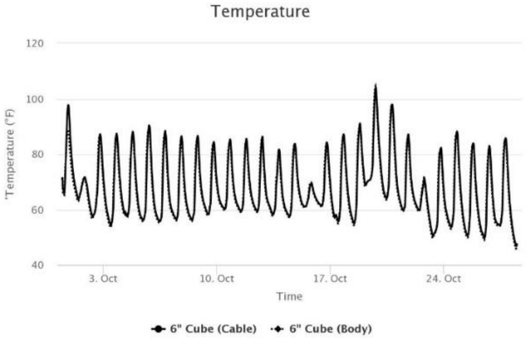
Appendix C. Cylinder Temperature Over Time



Appendix D. Cube Strength Curve



Appendix E. Cube Maturity Index



Appendix F. Cube Temperature Over Time