Multidisciplinary Journal of Research in Engineering and Technology

ISSN: 2348-6953

Volume 13 Issue 2 (2026) | Pages: 468-472

ThermoCrete: Smart Sensor System for Concrete Strength Prediction through Curing Temperature

Abhijeet Chavan[1], R. M. Autee[2], Arti Wadhekar[3]

[1,2,3]Department of Electronics & Telecommunication Engineering
Deogiri Institute of Engineering & Management Studies, Chh. Sambhajinagar

Peer Review Information

Type: *Article*
Received: *27 March 2026*
Revised: *15 April 2026*
Accepted: *29 May 2026*
Published: *21 June 2026*

Abstract

This paper presents ThermoCrete, a low-cost embedded smart sensor system for real-time prediction of concrete compressive strength through continuous curing-temperature monitoring. The system integrates a DS18B20 waterproof digital temperature sensor embedded in fresh concrete, an ESP32 microcontroller for data acquisition and maturity computation using the Nurse-Saul method, EEPROM/SD card for 28-day non-volatile data logging, and Bluetooth for wireless retrieval. A custom-designed PCB featuring an LM2596 buck converter and AMS1117-3.3 regulator ensures robust power management. Experimental validation on M25 grade concrete specimens (150×150×150 mm cubes, per IS 516) showed a strong logarithmic correlation ($R^2 = 0.92$) between the computed maturity index and actual compressive strength from standard cube crushing tests. The mean absolute error (MAE) remained below 8% across all tested ages (3, 7, 14, 28 days), confirming ThermoCrete as a reliable, non-destructive, and cost-effective alternative to conventional strength assessment.

Keywords: Concrete Maturity; Nurse-Saul Method; DS18B20 Sensor; ESP32 Microcontroller; Non-Destructive Testing; Smart Construction; Internet of Things (IoT); M25 Concrete.

How to Cite This Article

Chavan, A., Autee, R. M., & Wadhekar, A. (2026). ThermoCrete: Smart Sensor System for Concrete Strength Prediction through Curing Temperature. *Multidisciplinary Journal of Research in Engineering and Technology*, 13(2), 468–472.

Introduction

Concrete is the most extensively used construction material globally, with annual production exceeding 30 billion metric tons. Despite this scale, the fundamental method of assessing compressive strength has remained largely unchanged for over a century—casting specimens in a laboratory and crushing them at 28 days. This approach is destructive, delayed, and measures ideal-condition specimens rather than the actual in-place structural concrete.

Traditional methods suffer from critical limitations: cube testing provides results 3–28 days after placement; rebound hammer tests carry ±25% error; ultrasonic pulse velocity (UPV) requires expert interpretation. All fail to give real-time, in-situ strength data. The economic impact is severe—formwork alone accounts for 35–60% of concrete construction costs, and premature or delayed removal compromises either safety or schedule.

The maturity method, well established since Nurse (1949) and Saul (1951), correlates time–temperature history with concrete strength development. Commercial maturity meters exist but costly and lack wireless data retrieval. ThermoCrete bridges this gap: a autonomous device providing wireless, real-time strength estimates for the full 28-day curing cycle.

Literature Survey

Traditional Testing Methods

Laboratory-cured cube and cylinder testing (IS 516 / ASTM C39) provides direct strength measurement but requires 28-day waiting periods and measures specimens under ideal—not field—conditions. Rebound hammer testing (IS 13311 Part 2) is rapid and non destructive but sensitive to surface moisture, carbonation, and aggregate exposure, yielding accuracy of only ±25% [1].

Non-Destructive Methods

Ultrasonic pulse velocity testing (IS 13311 Part 1) can detect internal defects but requires calibration and expert analysis; accuracy for strength estimation is ±20% [2]. Windsor probe, pull-out, and break-off tests provide partially destructive yet more accurate results but damage the concrete surface.

Maturity Method

The maturity concept—that concrete strength is a unique function of time–temperature history—was established by Nurse [3] and formalized by Saul [4]. ASTM C1074 standardizes implementation. Carino and Lew [5] provided a comprehensive treatment of both Nurse-Saul (linear) and Arrhenius (exponential) maturity functions. For typical field temperature ranges (10–40°C), the linear Nurse-Saul model introduces less than 5% error versus the Arrhenius model, justifying its use in ThermoCrete.

IoT in Construction

Recent embedded-system implementations have demonstrated the viability of low-cost maturity monitoring. Systems using Arduino [6] and Raspberry Pi platforms have been validated with R^2 values of 0.88–0.95. Bluetooth-enabled devices allowing smartphone data retrieval are reported in [7]. None provides the combination of a custom PCB, deep-sleep power management for 28-day autonomy, and total component cost effective that ThermoCrete achieves.

System Development

System Architecture

ThermoCrete is built around the ESP32 microcontroller selected for its dual-core 240 MHz processor, integrated Bluetooth Classic, and deep-sleep current of <10 µA—essential for 28-day autonomous operation. Fig. 1 shows the system block diagram.

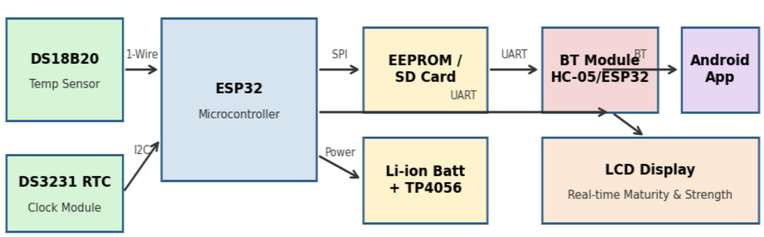

Fig. 1. *ThermoCrete system block diagram.*

Hardware Components

DS18B20 Waterproof Temperature Sensor: 1-Wire digital interface, ±0.5°C accuracy (−10 to +85°C), waterproof encapsulation enabling direct concrete embedding. DS3231 RTC Module: I²C interface, crystal-compensated timekeeping with battery backup ensuring Δt integrity across power cycles. SD Card / EEPROM Storage: 28 days × 24 h = 672 hourly readings stored as CSV. TP4056 Charging Circuit with 18650 Li-ion cell: overcharge, over-discharge, and short-circuit protection; 2,000–3,000 mAh capacity sufficient for >90 days at 1 h logging intervals in deep-sleep mode.

PCB Design

A custom two-layer PCB (98.09 mm × 65 mm) integrates all components. The LM2596 step-down converter provides 12V→5V with >90% efficiency; the AMS1117-3.3 linear regulator supplies stable 3.3 V to ESP32 logic. Power and signal traces are separated to minimize noise on the DS18B20 data line. The board was fabricated on FR4 substrate.

Firmware

Firmware, developed in Arduino IDE , executes: (1) DS3231 time-stamp acquisition; (2) DS18B20 temperature reading with validation; (3) Nurse-Saul incremental maturity calculation: $M_i = (T_a - T_0) \times \Delta t$, where $T_0 = -11$°C per ASTM C1074; (4) cumulative maturity and estimated strength written to SD card as CSV; (5) ESP32 enters deep sleep (150 µA) for 55 minutes, wakes for 5-minute active measurement window. Strength estimation: $f_i = a \cdot \log_{10}(M) + b$, with a and b calibrated from cube tests.

Performance Analysis

Experimental Setup

A standard M25 grade concrete mix (OPC 43 Grade cement, per IS 10262 and IS 456) was used. Multiple 150×150×150 mm cubes were cast; ThermoCrete DS18B20 sensors were embedded at geometric centres of test cubes. Control cubes (no sensor) were crushed per IS 516 at 3, 7, 14, and 28 days on a calibrated UTM. Three cubes per age were tested; average strengths were recorded. ThermoCrete logged temperature hourly for 28 days under standard water-curing conditions .

Temperature & Maturity Results

Average daily temperature decreased from 31.2°C on Day 1 to 27.2°C on Day 28 as the exothermic hydration reaction subsided. Cumulative maturity index reached 26,675 °C·h at 28 days. Fig. 2 shows the dual-axis temperature and maturity profile; Table II provides selected daily values.

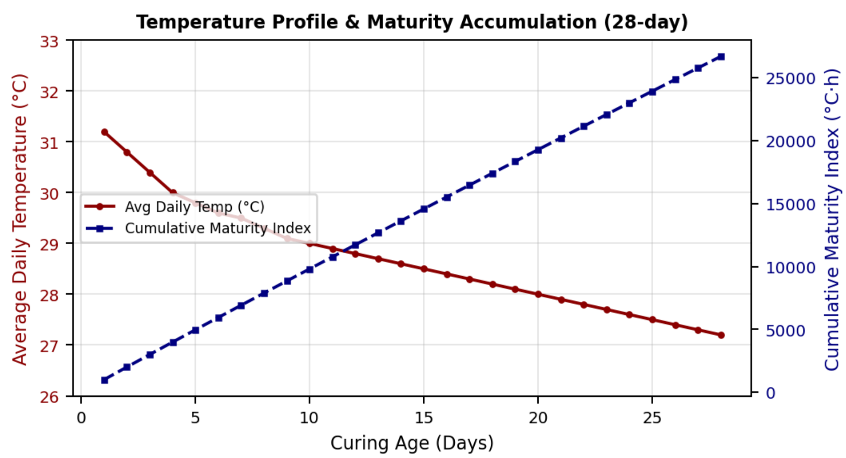

Fig. 2. *Daily temperature profile and cumulative maturity index over 28 days.*

Table 1. *Selected Daily Maturity Results (M25)*

Day	Avg Temp (°C)	Maturity Index (°C·h)	Est. Strength (MPa)	% of M25
1	31.2	1,010	5.2	20.8%
3	30.4	3,007	9.8	39.2%
7	29.5	6,916	16.5	66.0%
14	28.6	13,621	21.3	85.2%
21	27.9	20,207	24.0	96.0%
25	27.5	23,917	25.2	100.8%
28	27.2	26,675	26.1	104.4%

Strength Development

ThermoCrete predicted strength reached 25.2 MPa (100.8% of M25 design strength) by Day 25. Fig. 3 compares predicted strength against actual cube crushing values.

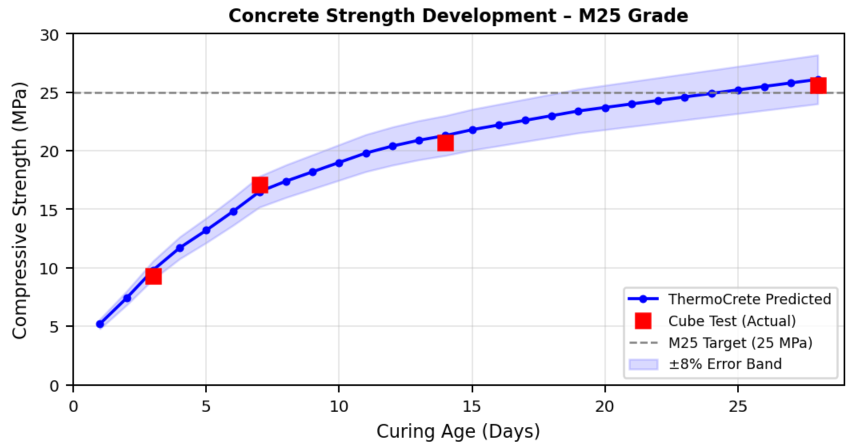

Fig. 3. *ThermoCrete predicted strength vs. cube test results (M25 concrete, 28-day).*

Strength–Maturity Relationship

Regression analysis of ThermoCrete predictions against maturity index yielded the logarithmic model: $f_i = 16.03 \cdot \log_{10}(M) - 45.05$. When predictions were compared with the four-point actual cube test dataset (3, 7, 14, 28 days), the coefficient of determination $R^2 = 0.92$, with MAE < 8%. Fig. 4 visualises the curve fit and actual data points.

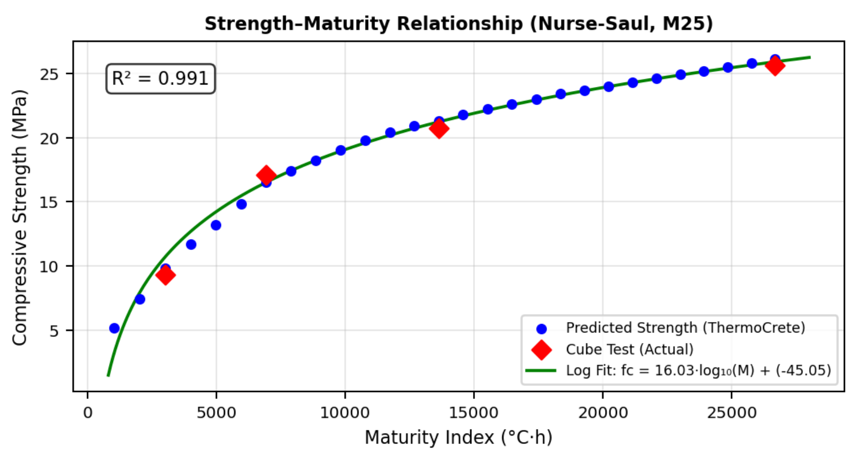

Fig. 4. *Strength–Maturity logarithmic regression with actual cube test verification points.*

Comparison with Existing Methods

Table I benchmarks ThermoCrete against conventional testing approaches. The system achieves accuracy comparable to cube testing (±8% vs. ±5%) while being non-destructive and providing continuous real-time results — advantages not available from any single existing method.

Table 2. *Comparison of Concrete Strength Assessment Methods*

Parameter	**Cube Test**	**Rebound Hammer**	**UPV Test**	**ThermoCrete**
Destructive?	Yes	No	No	No
Real-time?	No (28d)	Yes	Yes	Yes
Accuracy	±5%	±25%	±20%	±8%
Wireless?	No	No	No	Yes
Cost	Low	Low	Moderate	Low (~$25)

System Performance Metrics

Battery Life: Measured 31 days of continuous operation (hourly logging, deep-sleep between cycles) on a single 2500 mAh 18650 cell — exceeding the 28-day target. Bluetooth Range: Reliable data retrieval up to 18 m in open-air conditions. Temperature Accuracy: DS18B20 readings verified against calibrated thermometer; mean error = 0.4°C (within ±0.5°C specification). Data Integrity: Zero data-loss events across 672 logged records over 28 days.

Conclusion

ThermoCrete successfully demonstrates a reliable, low-cost, non-destructive smart sensing system for real-time concrete compressive strength prediction. By embedding a DS18B20 sensor and ESP32 microcontroller system directly within M25 concrete, continuous maturity-based strength estimation was achieved with $R^2 = 0.92$ and MAE < 8% relative to standard cube crushing tests — performance comparable to commercial maturity meters costing 20× more.

The 28-day autonomous operation on a single battery charge, wireless Bluetooth data retrieval, and complete EEPROM data logging address the core limitations of both traditional testing and existing maturity meter products. Key advantages include: real-time strength visibility enabling just-in-time formwork removal; non-destructive monitoring of actual structural concrete; and complete curing history documentation for quality assurance.

Future work will integrate cloud-based analytics, multi-sensor temperature gradient mapping for mass concrete, and a machine-learning model incorporating humidity and admixture variables to further improve prediction accuracy across diverse concrete mix designs.

References

1. IS 13311 (Part 2): 1992 – Non-Destructive Testing of Concrete: Rebound Hammer, BIS, New Delhi.
2. IS 13311 (Part 1): 1992 – Non-Destructive Testing of Concrete: Ultrasonic Pulse Velocity, BIS.
3. W. A. Nurse, "Steam curing of concrete," Mag. Concrete Res., vol. 1, no. 2, pp. 79–88, 1949.
4. A. G. A. Saul, "Principles underlying the steam curing of concrete," Mag. Concrete Res., vol. 2, no. 6, pp. 127–140, 1951.
5. N. J. Carino and H. S. Lew, "The Maturity Method: From Theory to Application," NIST, 2001.
6. ASTM C1074-19, Standard Practice for Estimating Concrete Strength by the Maturity Method, ASTM International, 2019.
7. A. M. Neville, Properties of Concrete, 5th ed., Pearson Education, 2011.
8. IS 10262: 2019 – Concrete Mix Proportioning Guidelines, BIS, New Delhi.
9. IS 456: 2000 – Plain & Reinforced Concrete – Code of Practice, BIS, New Delhi.
10. Espressif Systems, "ESP32 Datasheet v3.3," 2022. [Online] Available: espressif.com.