# USE OF IoT-BASED TECHNIQUE FOR NON-DESTRUCTIVE EVALUATION CONCRETE PROPERTIES AT ITS EARLY AGE.

Abraham Oluseun OLANIYI*[1], Masaya SATAKE[2], Takeshi WATANABE[3], Chikanori HASHIMOTO[4].
***1** & **2**. Graduate Students Tokushima University; Student Member JSCE, **3**. Full Member, JSCE. **4**. Fellow, JSCE*

## 1.0 Introduction and Research Objectives (はじめに)

The temperature-time history of concrete otherwise known as the maturity method has been used to reliably predict the compressive strength of concrete among other properties. For instances where early removal of formworks is desired to safely reduce construction duration without altering the quality performance of concrete structures, reliable maturity functions and simple techniques are important. Monitoring the real-time strength distribution of concrete with the use of simple techniques such as the internet of things (**IoT**) to monitor on-site properties of concrete is therefore very relevant.

## 2.0 Research Background (研究の背景)

The Nurse-Saul maturity index function is one of the widely used models to monitor the temperature-time history of concrete[1];

$$M = \sum_0^t (\mathrm{T} - \mathrm{To})\Delta t \quad \text{--------} \ (1)$$

T = average temperature of concrete, ºC; $T_o$ = the datum temperature, ºC; Δt = time interval (in days or hours).

Based on Eqn. (1), the equivalent age, $t_{en,}$ can be mathematically expressed as:

$$t_{en} = \frac{\sum_0^t (\mathrm{T}-\mathrm{To})}{\mathrm{T}r - \mathrm{T}o}\ \Delta t \quad \text{---------} \ (2)$$

Equation (2) was however found to represent a linear relationship, which may not be valid for concrete samples at elevated temperatures above 60ºC[2]. A new function was developed in 1977 by Freiesleben and Pedersen, based on Arrhenius equation that was used to account for the impact of the temperature on a chemical reaction[1][2].

$$t_{ea} = \sum_o^t e^{\frac{-E}{R}\left(\frac{1}{T} - \frac{1}{Tr}\right)}\ \Delta t \quad \text{------------} \ (3)$$

$t_{ea}$ = equivalent age at ref. temp. (days/hour); $T_r$ = reference temperature, 23ºC;

E = activation energy, J/mol; R = universal gas constant, 8.314J/mol K.

The **IoT** which is a fast-evolving technology refers to the use of intelligently connected devices and systems to leverage data from embedded sensors and actuators in machines

**Fig. 1.0** DS1820b Temperature Sensor and the Raspberry-Pi Micro-controller

## 3.0 Methodology (実験方法)

**Table 1.0**: Experimental Mix Proportion

| W/C | s/a | W(kg) | C(kg) | S(kg) | G1 | G2 | SLP | CT |
|---|---|---|---|---|---|---|---|---|
| 40 | 43 | 4.24 | 10.60 | 12.60 | 10.02 | 6.68 | 6.3 | 22.2 |
| | | 12.72 | 31.80 | 37.80 | 30.06 | 20.04 | 8.0 | 22.1 |

Based on JIS A1101, Table 1.0 shows the mix proportion used in this experiment, using type-I-cement, i.e., OPC. According to ASTM C-1074, a total of 38 cylindrical concrete specimens were cured at 20ºC and 40ºC, (19 samples for each). For each curing condition, the temperature of 2 samples were monitored using the Keyence datalogging device and simultaneously, the DS18b20 temperature sensors wirelessly connected to the raspberry-pi 3b+; **Fig. 1.0**.

Seventeen (17) samples each were subjected to mechanical impedance-based strength test and the uniaxial compressive strength test at ages 1, 3, 7, 14 and 28 days. Using python programming on the raspberry-pi micro-controller, the following were monitored and predicted real-time: temperature-time history of samples; maturity of the concrete specimen; and the strength of concrete samples.

### 4.0 Experimental Results（実験結果）

The slump and concrete temperature (CT) of the concrete at fresh state are shown in **Table 1.0**. Based on equation (1), equation (4) can be used to evaluate concrete strength $F_c$ of concrete samples with maturity M, where A is the slope and B the intercept of the equation[3].

$$F_c = A\log M + B \quad \text{--------}\ (4)$$

Using the equivalent age $t_{ea}$, i.e. equation (4), in place of the curing age t, the modified ACI model was used as shown in equation (5), to evaluate the strength of concrete. The 28-day strength $(fc')_{28}$ and strength revelation factors α and $\beta$; constants 4.0 and 0.85 respectively are applied in this study[4].

$$(F_c)t = \frac{t}{\alpha+\beta t}\,(fc')_{28} \quad \text{--------}\ (5)$$

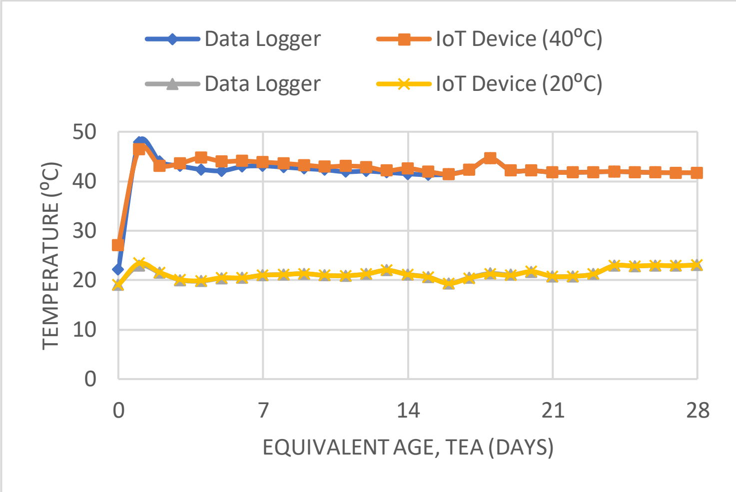


**Fig. 2.0**: Temperature-Time History

Both the data logger and the IoT device gave satisfactory results of the temperature-time history of the concrete samples, as shown in **Fig. 2.0**, but the IoT device was much more effective for monitoring the real-time strength development of the concrete samples, with the use of the mathematical models in computer programs (**Fig. 3.0** and **Fig. 4.0**).

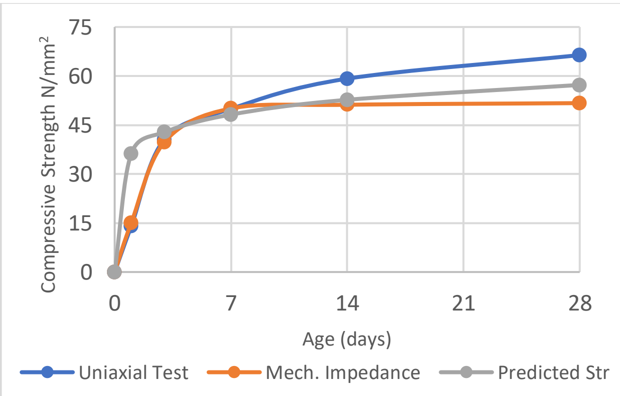


**Fig. 3.0** Strength of Concrete Cured at 20°C

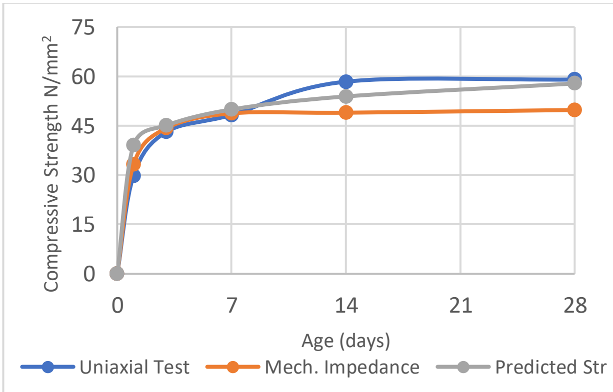


**Fig. 4.0** Strength of Concrete Cured at 40°C

### 5.0 Conclusion (まとめ)

Experimental results showed that the predicted strength and actual strength of concrete specimen tested via conventional crushing techniques are closely related. Based on other modified mathematical models, the elastic modulus of concrete samples was predicted as well and were observed to have a correlating pattern with the actual elastic modulus. In the further studies of this research, these models will be subjected to further investigations.

### References

1. Ilker Bekir Topcu and Cenk Karakurt (2018), "Strength-Maturity Relations of Concrete for Different Cement Types". Proceedings of 3rd International Sustainable Buildings Symposium (ISBS 2017).
2. Gidion Turu'alo (2013), "Early Age Strength Development of GGBS Concrete Cured Under Different Temperatures".
3. Tazawa Eichi, Yonekura Asuo, Kasai Tetsuroo, Ujike Isao, Ooshita Hideki and Hashimoto Chikanori (2002) "Concrete Engineering Handbook". ISBN 978-4-254-26476-0. C 3351, pp. 77.
4. Branson E. Dan and Carreira J. Domingo (1997), "Prediction of Creep, Shrinkage, and Temperature Effects in Concrete Structures". ACI Committee Report 209R-92.