Computers and Concrete, *Vol. 24, No. 2 (2019) 95-102*
DOI: https://doi.org/10.12989/cac.2019.24.2.095

Prototyping an embedded wireless sensor for monitoring reinforced concrete structures

Yelbek Utepov[*1,2], Olzhas Khudaibergenov[1a], Yerzhan Kabdush[1a] and Alizhan Kazkeev[1,2b]

[1]*Department of Civil Engineering, L.N. Gumilyov Eurasian National University, 2 Satpayev, Nur-Sultan 010000, Republic of Kazakhstan*
[2]*CSI Research & Lab (LLP), 2 Kunayev, Nur-Sultan 010000, Republic of Kazakhstan*

(Received January 22, 2019, Revised May 17, 2019, Accepted July 6, 2019)

Abstract. Current article proposes a cheap prototype of an embedded wireless sensor to monitor concrete structures. The prototype can measure temperature and relative humidity concurrently at a controlled through smartphone time interval. It implements a maturity method to estimate in-place concrete strength, which is considered as an alternative for traditional shock impulse method and compression tests used in Kazakhstan. The prototype was tested and adequately performed in the laboratory and field conditions. Tests aimed to study the effect of internal and ambient temperature and relative humidity on the concrete strength gain. According to test results revealed that all parameters influence the strength gain to some extent. For a better understanding of how strongly parameters influence the strength as well as each other, proposed a multicolored cross-correlation matrix technique. The technique is based on the determination coefficients. It is able to show the value of significance of correlation, its positivity or negativity, as well as the degree of inter-influence of parameters. The prototype testing also recognized the inconvenience of Bluetooth control due to weakness of signal and inability to access several prototypes simultaneously. Therefore, further improvement of the prototype presume to include the replacement of Bluetooth by Narrow Band IoT standard.

Keywords: strength; temperature and relative humidity; Arduino; wireless embedded sensor; prototype

1. Introduction

Determination of the true properties of concrete in the element and their change during operation allows solving many important problems associated with the design of reliable, durable and cost-effective buildings and facilities (Kibar *et al.* 2015). Knowledge of the internal and ambient curing parameters of concrete, such as relative humidity and temperature, gives a deep understanding of the nature of the concrete strength gain (Zemajtis 2014). Accurate and timely control of strength allows achieving the highest level of quality and durability of concrete, while providing great economic benefits and reducing construction time (Fick *et al.* 2012). Currently, the most common methods of destructive and non-destructive testing of strength are the test of standard samples by compression and the method of shock impulse (Malek *et al*. 2014). As concerning the testing of standard samples, there is a significant difference between a destructible concrete sample in the laboratory and concrete on the construction site. The hardening conditions in the laboratory differ from the conditions at the site (Thandavamoorthy 2015), where absolutely different values of ambient temperature and air relative humidity are observed, which leads to a distortion of the test results and, consequently, to their bias (Kockal *et al.* 2007). The above disadvantages to a certain extent solved by the shock impulse method in a non-destructive way (Helal *et al.* 2015). This method is based on striking a reinforced concrete structure at the construction site itself. However, because only specific parts of the structure are tapped out, it is possible to obtain reliable results of precisely pointed areas, and not the whole structure. In general, both traditional methods are rather laborious, time consuming and relatively expensive. Modern non-destructive techniques to predict concrete strength are based on up-to-date technologies, such as embedded sensors, machine learning regressions and artificial neural networks (Hannan *et al.* 2018, Erdal *et al.* 2018, Dutta *et al.* 2018, Gazder *et al.* 2017). These techniques are powerful in case of nonlinear relationship between different parameters of a system, as in the behavior of concrete parameters (Ashteyat *et al.* 2018). Unfortunately, despite of their potential benefits, the application of such modern methods for predicting concrete strength in Kazakhstan is limited, due to the absence of corresponding regulating documents and standards.

This paper is focused on the implementation of existing approach for non-destructive concrete testing, based on the temperature-time-strength relationship described in ASTM (1998), the so-called maturity method. The paper also presents the laboratory and field studies of the effect of additional curing parameters on the concrete strength, which are not considered in ASTM (1998), such as internal relative humidity, as well as ambient temperature and relative humidity. The dependence of concrete strength on

∗Corresponding author, Associate Professor
E-mail: utepov-elbek@mail.ru
[a]M.Sc.
[b]M.Sc. Student

http://www.techno-press.org/?journal=cac&subpage=8 ISSN: 1598-8198 (Print), 1598-818X (Online)

various parameters of curing has been proven in previous works (Ge *et al.* 2009, Anwar *et al.* 2009, Chen *et al.* 2009, Zhang *et al.* 2016, Farzampour 2017). The approach presented in ASTM (1998) is most effectively implemented by the use of specialized embedded temperature sensors that are wirelessly controlled. The main positive feature of this solution (i.e. sensors) is the ability to monitor the concrete's actual strength in real time (Hannan *et al.* 2018). This allows making timely decisions on the loading of reinforced concrete structures, thereby reducing construction time and overhead costs (workers' wages, rental of machines and mechanisms, etc.) at least for one day for each stage of pouring the concrete structures. This time-save can be explained by the rarity of performing tests with traditional method described in the standard by NIIZhB (2012) - on the 3rd, 7th and 28th day after concrete pouring. The principles of current standard were justified for the concrete strength classes up to B20 (i.e., mark of M250) and were not adapted to mostly used currently concretes of B25 (M350) and B30 (M400) in Kazakhstan, which gain strength significantly faster. Consequently, it may gain necessary strength of 70% between the 3rd and 7th day of its life.

Various foreign manufacturers present analogs of this solution. Sensors “CS100” and “CS200”, produced by the British company Structural Health Systems, “SmartRock”, manufactured by the Canadian company Giatec, and others (Walsh 2016, ConcreteSensors 2018, SmartRock 2018) are known. All of the above sensors have similar functionality and principle of operation: the sensor is mounted in the body of concrete on the reinforcement by means of a clamp just before the start of pouring. After that, the device starts measuring the temperature in the concrete body at a specified interval and transmits the results to the smartphone using Bluetooth wireless transmission protocol. A specially designed mobile application in the smartphone analyzes the data and issues a report on the actual strength of concrete. A specific feature of the sensors is a preliminary laboratory analysis of the curing conditions of in-place concrete, by conducting a set of tests of standard concrete samples (Walsh 2016, ConcreteSensors 2018, SmartRock 2018). As a result, the effectiveness of the application of existing foreign analogues of sensors on local construction sites raises certain doubts. Since to pick up the same concrete as on the construction site, in a remote laboratory from completely different inert materials is practically impossible. And the approximation of the chemical and granulometric composition of concrete by methods of equivalent materials adds a certain unreliability in the results of the strength determination. Moreover, due to the high cost for local consumers (from $80 and above (Walsh 2016, ConcreteSensors 2018, SmartRock 2018)), the use of existing analogs is not economically feasible. The cost of sensors is also composed of the cost of laboratory tests, which are much higher abroad than in local laboratories of Kazakhstan. These inconveniences led in current work to the development of more efficient solution to monitor concrete structures, based on a number of parameters that influence strength gain of freshly laid concrete.

2. Methods

The concept of maturity method is to use combined effect of concrete curing time and internal temperature to estimate its actual strength. It requires establishing the strength-maturity relationship in the laboratory and registration of internal temperature history of the concrete. According to ASTM (1998), there are two functions expressing maturity index:

1) Temperature-time factor (TTF), the so-called *Nurse-Saul* maturity function;

2) Equivalent age at a specified temperature.

Current study considers only the first function, based on TTF as follows

$$M(t) = \sum (T_a - T_0)\Delta t \tag{1}$$

where: $M(t)$ - the TTF at age t, degree-hours; Δt=a time interval, days or hours; T_a=average concrete temperature during time interval Δt, °C; T_0=datum temperature (taken as -10°C).

To derive the strength-maturity relationship, at least 17 cylindrical specimens must be prepared. 15 specimens are used for compression tests at the ages of 1, 3, 7, 14 and 28 days (three specimens per test age), where the average compressive strengths must be taken. Other 2 are used to record the history of their internal temperature at the center of the specimens, where their averaged history is taken. It is recommended to record temperature at intervals of ½ hours for the first 48 hours (in general, the shorter the interval, the more accurate the result will be). At each test age the average TTF is computed. Then, the average compressive strengths at each age are plotted on a graph as a function of the corresponding average TTFs. The best-fit curve drawn through retrieved points is the strength-maturity relationship that is used to estimate the in-place strength of concrete cured under other temperature conditions. Thus, in-place strength at specific age will be equal to its value corresponding to the TTF determined at the same age and plotted on the strength-maturity curve.

ASTM (1998) does not guarantee the accuracy of strength estimation, due to several factors influencing the strength gain are not considered. Therefore, current work additionally aims to study the effect of such factors as internal relative humidity, ambient temperature and relative humidity. The new procedure would require preparation of at least one more specimen in the laboratory to record internal relative humidity. The ambient temperature and humidity close to the specimen (within 1m distance) would be also recorded. Recordings of all the three new parameters should be taken concurrent to the recording of internal temperature (i.e., with the same interval throughout 28 days). Retrieved recordings allow a better understanding of the nature of concrete strength gain. Hypothetically, it may help improving the maturity method proposed in ASTM (1998) by means of developing new functions of the interdependence of considered parameters. Onwards, the retrieved functions may be validated with the results of recordings at in-place conditions.

Fig. 1 Prototype architecture

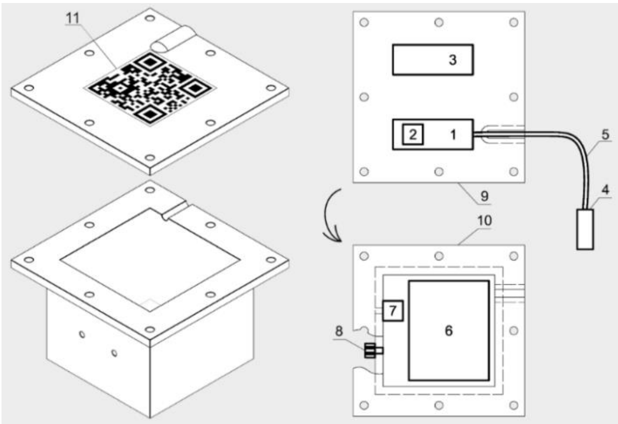


Fig. 2 Prototype components

where: 1-Microcontroller; 2-Memory; 3-Wireless network module; 4-Temperature sensor; 5-Connecting cable; 6-Power supply; 7-Relative humidity sensor; 8-Switch; 9-Bottom element of the case; 10-Top element of the case; 11-QR identification code

3. Prototype architecture and components

The prototype architecture (Fig. 1) is based on the concept of Internet of Things (IoT). IoT architecture includes two things. On the one hand, it is a large number of peripheral devices with low computing power, low power consumption, high speed of reaction to events and on the other hand - cloud servers with high computing power for processing large amounts of data, storing them and classifying, often with elements of machine intelligence and analytics (Sethi *et al.* 2017).

According to the architecture, the prototype performs measurements that are collected on a smartphone by Bluetooth request. The accumulated measurement data are transmitted via Internet to a personal computer, where they are processed in Excel. The prototype components (Fig. 2) are selected to meet its main functional requirements: measurement of internal temperature and relative humidity, collection and storage of measurement data, transfer data to a smartphone via Bluetooth.

The prototype case was printed on a 3D printer with a material of acrylonitrile butadiene styrene (ABS). It consists of the lower and upper parts (cap). The cap is mounted to the lower part of the case by means of a bolt connection, impermeability of which is provided by a rubber gasket. The overall dimensions of the case are - 86×86×49 mm.

The functionality of the prototype is realized with an Arduino Nano 3.0 microcontroller with the connection of additional modules to it. Arduino has significantly simplified and accelerated the development process with built-in modules

Fig. 3 Prototype

Table 1 Cost ratio of the prototype components

№	Components	Number	Proportion, %
1	Microcontroller Arduino Nano 3.0 with memory	1	24
2	Bluetooth module	1	15
3	Temperature sensor with 100 cm cable	1	12
4	Relative humidity sensor	1	12
5	AA batteries	3	3
6	Switch	1	5
7	Case printed in a 3D printer	1	29
8	QR identification code	1	free

that can be used at will, as well as expansion slots that allow connecting additional components. The temperature sensor is connected to the microcontroller by means of a 100 cm cable. The humidity sensor is integrated from inside of the case and connected to the microcontroller. The memory module is built into the microcontroller. Its memory of several megabytes is satisfactory for the temporary storage of measurement data for months. For communication with a smartphone, a Bluetooth wireless data module is connected to the microcontroller. Microcontroller with its components is located in the upper half of the case (Fig. 3). The prototype is powered by three AA batteries located in the bottom of the case.

The prototype cost amounted to KZT 10200 (or around $27.6[1]) and was made up of the cost of the components in the proportion presented in Table 1 below.

It should be noted that in the particular case, the labor cost is not counted and was free of charge. In general, it is expected that the net cost of the industrial models of the sensor at production in batches will decrease considerably.

4. Testing

Laboratory and field tests were conducted according to the procedures described in chapter 2 at the L.N. Gumilyov Eurasian National University (Astana, Kazakhstan).

4.1 Laboratory testing

Concrete mixture B25 M350 was adopted for testing. In total, 18 cylindrical specimens were prepared. 15 specimens

[1]370.03 KZT for one USD dated 15.10.2018 according to: https://prodengi.kz/valuty/kurs_valut_15_10_2018/

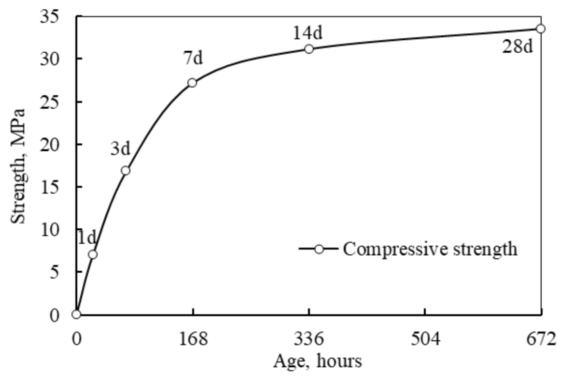


Fig. 4 Compression test results

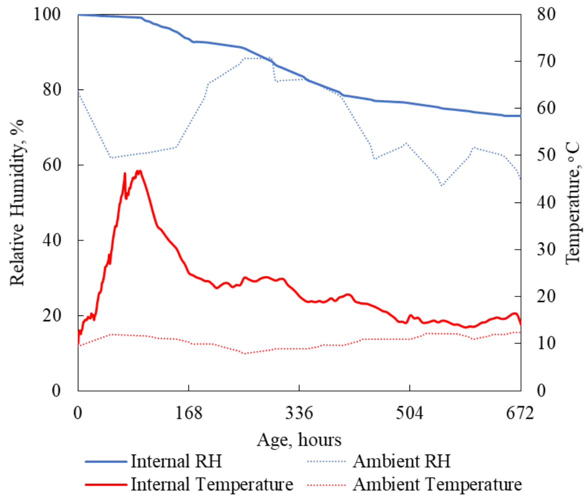


Fig. 5 Recordings of internal and ambient parameters at the laboratory

were used for compression test at the curing ages of 1, 3, 7, 14 and 28 day. The internal curing temperature was recorded in two specimens, and the internal humidity was recorded in the last specimen. Both internal parameters along with the ambient temperature and relative humidity were recorded concurrently with the intervals of 1 hour for the first 4 days (96 hours), and 6 hours for the rest of time until 28 day passed. Such intervals were set because the knowledge of the curing conditions in the first 3-4 days is very important at construction sites. This helps making proper decisions to unmold formwork from the concrete structure. The results of compression test (Fig. 4) shown that the majority of the strength concrete specimens gained within the first 7-8 days of curing (around 30 MPa). At the age of 28 days, the strength gain was 33.53 MPa, which indicates that the concrete matches its class of B25 and mark of M350.

Results of recordings (Fig. 5) showed interesting behaviour of the internal and ambient parameters. Within the first 3-4 days, the internal temperature rashly grew exceeding 45 degrees (cement hydration period). It stood on its peak of about 47 degrees for couple of hours, then almost abruptly went down with little fluctuations up to 22 degrees. For the rest of time, the temperature cavorted several times with an amplitude of up to 5 degrees until it reached the air temperature in the laboratory. In contrast, the ambient temperature was relatively stable between 8 and 12 degrees. Two slightly noticeable peaks

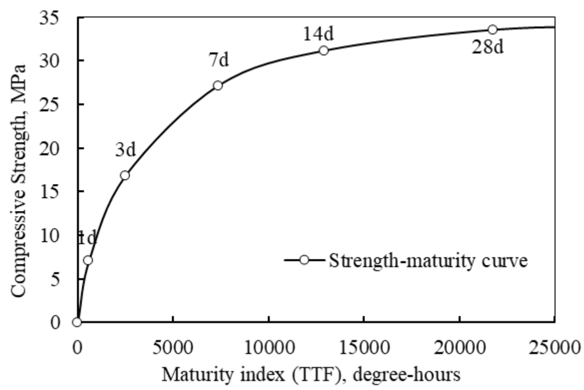


Fig. 6 Strength-maturity relationship of concrete B25 M350

were observed - the lifting peak on the 2nd day, and the lowering peak in the middle of the 10th day. Contrary, the ambient relative humidity fluctuated with high amplitude between 54 and 88 percent, and its peak times coincided the peak times of ambient temperature, but with opposite logic. When the temperature increased, the relative humidity decreased, and vice versa. During the period of cement hydration, the internal relative humidity was almost stable and very close to the 100 percent. Then it began gradually declining. At the age of 28 days, its value was slightly more than 70 percent.

To establish the strength-maturity relationship of concrete mixture under study, the TTFs calculated by Eq. (1) and the values of compressive strength at the ages of 1, 3, 7, 14 and 28 were plotted on a graph (Fig. 6).

According to the estimates, the value of TTF at the age of 28 days was equal to 21792 degree-hours, which corresponds to the strength gain of about 33.53 MPa. The strength-maturity curve presented above was further used to estimate concrete in-place strengths at different ages.

4.2 Field testing

For field testing, a timber formwork was built outside on the dry surface. The formwork was poured with 0.4 cubic meters of the same concrete mixture as in the laboratory tests. When the formwork was half-poured, the switched-on sensor prototype was embedded in the center, and then the other half of concrete immured the prototype. Before activating the prototype, the same time intervals of recording internal parameters were set, as in the laboratory tests. Similar intervals were set on the electronic device to record ambient parameters near the formwork. Then, the prototype and electronic device were simultaneously activated and started collecting records. 28 days later, the recordings were stopped. All the collected measurements were retrieved wirelessly through smartphone, and uploaded into the Excel for further processing. The results of field recordings are shown in Fig. 7 below.

According to the recordings above, the internal and ambient parameters behaved more or less predictably. At the beginning of the test and for about 108 hours, the ambient temperature was below zero. In general, throughout the whole 28 days the temperature was unstable, fluctuating between minus15 and plus18 degrees. Nevertheless, an

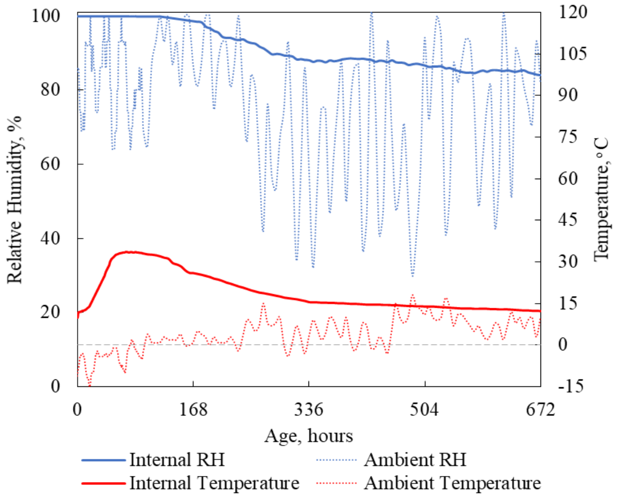


Fig. 7 Recordings of internal and ambient parameters at the field

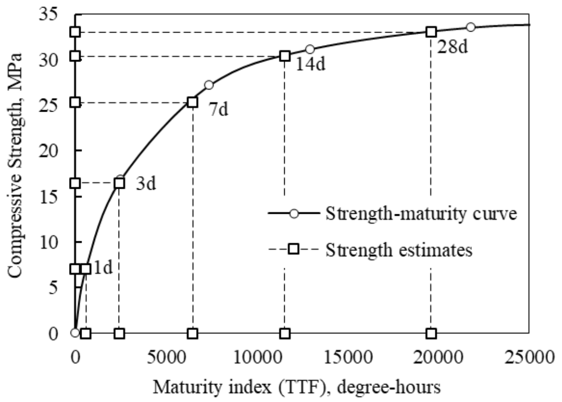
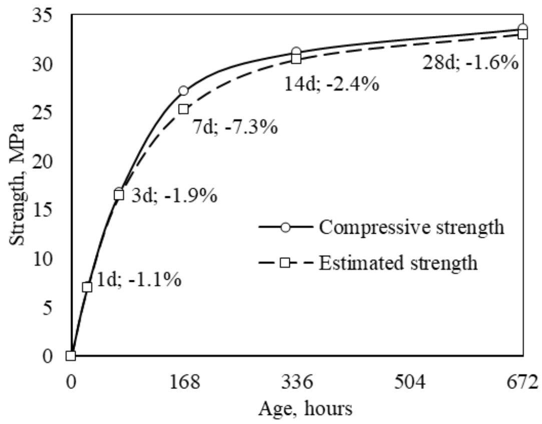


Fig. 8 Estimation of in-place concrete strength

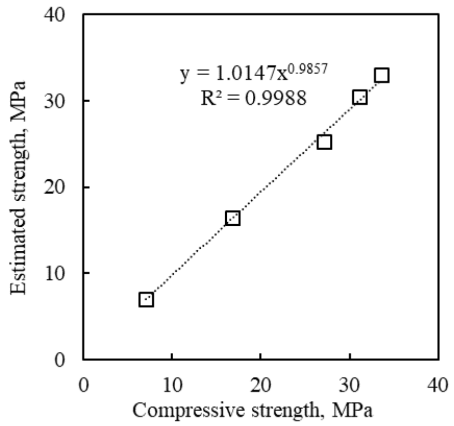
overall trend show that it was growing. Perhaps, this unstable behavior influenced the cement hydration process to some extent. Because the highest point of internal temperature of the concrete barely reached 33.6 degrees at the age of 3 days, and stood for only few hours. After that the temperature almost smoothly descended throughout the remaining time. The ambient relative humidity was cavorted with great frequency between 30 and 100 percent. Still it can be noticed that as in the laboratory recordings, the logic of contrariety of ambient temperature and relative humidity preserves. The internal relative humidity was steadily 100 percent for 5 days. Ever since, it moderately decreased to the value of 84 percent at the age of 28 days, with the small fluctuations.

After the test and data processing completed, the in-place TTFs were computed using Eq. (1) for each curing ages of 1, 3, 7, 14 and 28 days. The obtained TTFs were plotted on the previously drawn strength-maturity curve (Fig. 6) to estimate the corresponding in-place concrete strengths at different ages as shown in the Fig. 8 below. As expected, the values of in-place concrete strength were lower than those obtained from compression tests.

5. Results and discussions



(a) Comparison of strength curves



(b) Superimposition of strength values

Fig. 9 Behavior and relationship of the compressive and estimated strengths

The comparison of the obtained results of compressive and estimated strengths (Fig. 9(a)) at different ages shows that the ambient conditions made themselves felt. Thus, the reduction of the values of estimated strength observed in the range of 1.1 and 7.3 percent throughout the whole period. Nevertheless, the estimated strength at the age of 28 days reached 33 MPa, which proves the match with the type of concrete B25 M350. Moreover, the superimposition of the strength values demonstrated a high correlation (Fig. 9(b)).

Thereby, the compressive and estimated strengths relationship expressed by the exponential function, showed the value of determination coefficient very close to one. This function can be declared as follows.

$$R_e = 1{,}0147 \cdot R_c^{0{,}9857} \tag{2}$$

where: R_e and R_c correspond to the values of estimated and compressive strengths respectively.

It is important to note that the Eq. (2) is not universal and refers only to the concrete of B25 M350 tested in current work. Tables 2-3 provide a better insight of this outcome.

Tables above show the cross-correlation of different parameters that influence the concrete strength gain by means of coefficients of determination. The correlation-matrices were created using all the recordings obtained from the laboratory and field tests. Here, the effects of parameters on the strength are given in percent and were

Table 2 Correlation matrix of the parameters recorded at the laboratory

	Internal temperature	Ambient temperature	Internal RH	Ambient RH	Compressive strength
Internal temperature	1				
Ambient temperature	0.626822	1			
Internal RH	0.191260	-0.030362	1		
Ambient RH	-0.597220	-0.996134	0.085961	1	
Compressive strength	0.491281	0.281002	-0.728847	-0.302717	1
Effect on strength:	27%	16%	40%	17%	

Table 3 Correlation matrix of the parameters recorded at the field

	Internal temperature	Ambient temperature	Internal RH	Ambient RH	Estimated strength
Internal temperature	1				
Ambient temperature	0.234854	1			
Internal RH	0.280957	-0.859996	1		
Ambient RH	0.096232	-0.939692	0.970773	1	
Estimated strength	0.406305	0.981393	-0.746935	-0.860990	1
Effect on strength:	14%	33%	25%	29%	

expressed through normalization of absolute values of the coefficients of determinations. For a better understanding of trends, cells were colored according to the values they contain. The color scheme in the matrices is chosen in such a manner as to emphasize the values of significant correlations, meaning that the darker the colors the higher the correlation. Here, the blue and red colors refer to the positive and negative correlation between parameters. To note, the positive correlation indicates that the higher the first parameter the higher the second one, or vice versa. On the contrary, the negative correlation indicates that the higher the first parameter, the lower the second one, or vice versa.

Tables also show that all the considered parameters influence the concrete strength gain to some extent. According to laboratory recordings (Table 2), the highest influence to the strength is observed from the internal relative humidity (40%), with the significant negative correlation in between. This is logical due to the cement hydration process (when concrete is hardening) is accompanied by the consumption of water, including in vapor state of aggregation. This reduces the value of relative humidity. The effect of internal temperature takes a second place (27%), with less significant positive correlation. This is because the chemical process of curing in the concrete at first releases the heat and then the temperature drops. This bounce influenced the value of the coefficient of determination. The influence of ambient temperature and relative humidity is moderate (around 16% and 17% respectively). Concerning the interrelationship between the parameters, following recognized patterns exist:

1) Ambient temperature highly influences the internal temperature; a significant positive correlation is observed;

2) Ambient relative humidity and internal temperature are inversely related, with negative correlation in-between;

3) Ambient relative humidity has a strong inverse relationship with the ambient temperature; the significant negative correlation exists. Other relationships are not significant.

The effect of parameters on the strength gain observed at the field tests vary from those observed at the laboratory tests. Thus, the more severe (especially subzero temperature (Fig. 7)) ambient parameters played a significant role. As expected, the ambient temperature has a highest influence (33%) to the strength, with a significant positive correlation. In this regard, it is logical that the ambient relative humidity has close value of influence (29%), with a significant negative correlation. Such behavior is understandable from previous paragraph. Other parameters has less influences. From interrelationship of parameters, it is seen that the ambient temperature has strong inverse effect on the ambient and internal relative humidity, with significant negative correlations. Most likely, this effect explains the low velocity of water vaporizing, and therefore the slow decrease of internal relative humidity.

In general, the proposed (Tables 2-3) technique to visualize the inter-influence of different internal and ambient parameters provides deep understanding of the nature of concrete strength gain. Therefore, the combination of this technique with the prototype developed in current work may produce valuable results for further related studies.

Concerning the prototype, it showed adequate performance when measuring different parameters. During the tests, no functional deficiencies of prototype were identified. Nevertheless, current state of the prototype needs improvement. Further improvements may include the following changes and actions:

1) Molded case with a smaller size and different shape.

2) New system architecture. Due to the use of Bluetooth to collect measurement data, the smartphone is able to access not more than one devise. Similar issue is observed in the analogues. The Narrow Band IoT may fix this shortage.

3) Developing an application for mobile devices to control many sensors concurrently.

4) Performing more field tests on different ambient conditions.

6. Conclusions

Today in Kazakhstan there is no production of embedded sensors for wireless control of concrete strength. Application of existing analogues raise certain inconveniences, as follows:

- The maturity method used to estimate in-place concrete strength is not regulated in Kazakhstan.
- Analogues monitor limited number of parameters that may influence the concrete strength gain; some monitor only internal temperature, some internal temperature and

relative humidity.

• The strength-maturity relationship is derived at remote laboratories, where it is complicated to reconstruct the same concrete mixture used in Kazakhstani construction sites, which leads to inaccuracy of estimations and to the increase of costs.

Identified shortcomings of analogues to some extent may be filled by the developed in current work prototype. The prototype implements the maturity method (ASTM 1998) to estimate in-place concrete strength gain. Its system architecture is based on the IoT concept, but partially implemented: the sensor takes measurements and transmits them via Bluetooth to the receiving device (smartphone), bypassing the server. In the further improvement of the prototype, Bluetooth is likely to be changed to the Narrow Band IoT, to enable concurrent data acquisition from many sensors.

To observe the performance of prototype, conducted a set of laboratory and field tests aimed to record the internal and ambient parameters that may influence concrete strength gain. The list of considered parameters are as follows: internal temperature, internal relative humidity, ambient temperature, and ambient relative humidity. As expected, test results showed that the values of in-place concrete strength estimated by the maturity method were lower than the values of compressive strength due to the presumable influence of the listed parameters. For a better understanding of this effect, it was decided to search for the patterns in the behavior of all the parameters, both from the laboratory and field tests. This led to the calculation of cross-correlations between the parameters, and to the representation of its results in a multicolored matrix manner. Such matrix is intended to understand the interrelationships between the parameters and to estimate the degree of inter-influence. The degree of inter-influence shows how strongly one parameter affects the other relative to all other parameters. The correlation matrix has a set of properties, which are as follows:

1) It uses two colors to distinguish the negativity or positivity of correlation.
2) The darker the colors of cells, the more significant the correlation is, and opposite, depending on the value of determination coefficient that the cells contain.
3) The degree of inter-influence is estimated by normalization of the absolute values of determination coefficients to the scale of 0-1. So that the sum of scaled values must be equal to one.

The method to estimate in-place concrete strength is currently not regulated in Kazakhstan. In this regard, the acceptance of concrete structures with their use is not yet possible. However, the developed prototype or its further improvements, as an alternative, can be useful for a timely response in reaching up the strength of concrete (e.g. 40% and 70%), necessary for loading the structure, and thus may bring a positive economic impact by reducing the construction time. Moreover, the proposed matrix-technique for cross-correlation of monitored parameters allows obtaining a complete picture of how one parameter or another influenced the curing of concrete.

Authors obtained a Kazakhstani intellectual property represented by a patent for a utility model №3575 dated 21.01.2019, application №2018/0562.2 for the developed prototype.

Based on the knowledge and experience gained during the development of the prototype, one can assume the relevance and need to develop a new Kazakhstani standard regulating the maturity method to estimate in-place concrete strength.

Acknowledgments

CSI Research & Lab (LLP) fully supported the research described in this paper financially and managerially.

The construction materials laboratory of the L.N. Gumilyov Eurasian National University headed by Prof. Rauan Lukpanov provided necessary equipment and laboratory rooms to conduct tests within the research.

Assembly of the prototype was made by Mr. Altynbek Kalitanov.

References

Anwar, H. and Khandaker, M. (2009), "Influence of extreme curing conditions on compressive strength and pulse velocity of lightweight pumice concrete", *Comput. Concrete*, **6**(6), 437-450. https://doi.org/10.12989/cac.2009.6.6.437.

Ashteyat, A.M. and Ismeik, M. (2018), "Predicting residual compressive strength of self-compacted concrete under various temperatures and relative humidity conditions by artificial neural networks", *Comput. Concrete*, **21**(1), 47-54. https://doi.org/10.12989/cac.2018.21.1.047.

ASTM C1074 (1998), Standard Practice for Estimating Concrete Strength by the Maturity Method, ASTM International, West Conshohocken, Pennsylvania, USA.

Chen, H.J., Yang, T.Y. and Tang, C.W. (2009), "Strength and durability of concrete in hot spring environments", *Comput. Concrete*, **6**(4), 269-280. https://doi.org/10.12989/cac.2009.6.4.269.

ConcreteSensors (2018), Our Sensors are Designed for the Unique Challenges of Concrete, ConcreteSensors, Cambridge, England, UK. www.concretesensors.com/durable-wireless-sensors/.

Dutta, S., Samui, P. and Kim, D. (2018), "Comparison of machine learning techniques to predict compressive strength of concrete", *Comput. Concrete*, **21**(4), 463-470. https://doi.org/10.12989/cac.2018.21.4.463.

Erdal, H., Erdal M., Şimşek O. and Erdal H. (2018) "Prediction of concrete compressive strength using non-destructive test results", *Comput. Concrete*, **21**(4), 407-417. https://doi.org/10.12989/cac.2018.21.4.407.

Farzampour, A. (2017), "Temperature and humidity effects on behavior of grouts", *Adv. Concrete Constr.*, **5**(6), 659-669. https://doi.org/10.12989/acc.2017.5.6.659.

Fick, G., Taylor, P., Christman, R. and Ruiz, J.M. (2012), "Field reference manual for quality concrete pavements", U.S. Department of Transportation, Austin, Texas, USA.

Gazder, U., Al-Amoudi, O.S.B., Saad Khan, S.M. and Maslehuddin, M. (2017), "Predicting compressive strength of blended cement concrete with ANNs", *Comput. Concrete*, **20**(6), 627-634. https://doi.org/ 10.12989/cac.2017.20.6.627.

Ge, Z. and Wang, K. (2009), "Modified heat of hydration and strength models for concrete containing fly ash and slag", *Comput. Concrete*, **6**(1), 19-40.

https://doi.org/10.12989/cac.2009.6.1.019.

Hannan, M.A., Hassan, K. and Jern, K.P. (2018), “A review on sensors and systems in structural health monitoring: Current issues and challenges”, *Smart Struct. Syst.*, **22**(5), 509-525. https://doi.org/10.12989/sss.2018.22.5.509.

Helal, J., Sofi, M. and Mendis, P. (2015), “Non-destructive testing of concrete: A review of methods”, *Elec. J. Struct. Eng.*, **14**(1), 97-105.

Kibar, H. and Ozturk, T. (2015), “Determination of concrete quality with destructive and non-destructive methods”, *Comput. Concrete*, **15**(3), 473-484. https://doi.org/10.12989/cac.2015.15.3.473.

Kockal, N.U. and Turker, F. (2007), “Effect of environmental conditions on the properties of concretes with different cement types”, *Constr. Build. Mater.*, **21**(3), 634-645. https://doi.org/10.1016/j.conbuildmat.2005.12.004.

Malek, J. and Kaouther, M. (2014), “Destructive and non-destructive testing of concrete structures”, *Jordan J. Civil Eng.*, **8**(4), 432-441. https://doi.org/10.12816/0025889.

NIIZhB (2012), GOST 10180-2012 Concretes. Methods for Strength Determination using Reference Specimens, NIIZhB, Moscow, Russia.

Sethi, P. and Sarangi, S.R. (2017), “Internet of things: Architectures, protocols, and applications”, *J. Elec. Comput. Eng.*, 1-25. https://doi.org/10.1155/2017/9324035.

SmartRock (2018), Real-time Temperature and Maturity Monitoring of Concrete, Giatec Scientific Inc., Ottawa, Ontario, Canada. www.giatecscientific.com/products/concrete-sensors/smartrock-maturity-meter/.

Thandavamoorthy, T.S. (2015), “Determination of concrete compressive strength: A novel approach”, *Adv. Appl. Sci. Res.*, **6**(10), 88-96.

Walsh, D. (2016), IoT Hero from Giatec Develops “SmartRocks”, with Bluetooth, Giatec Scientific Inc., Ottawa, Ontario, Canada. www.silabs.com/community/blog.entry.html/2016/01/18/iot_hero_from_giatec-Av1P.

Zemajtis, J.Z. (2014), *Role of Concrete Curing*, Portland cement association, Skokie, Illinois, USA.

Zhang, B., Cullen, M. and Kilpatrick, T. (2016), “Spalling of heated high performance concrete due to thermal and hygric gradients”, *Adv. Concrete Constr.*, **4**(1), 1-13. https://doi.org/10.12989/acc.2016.4.1.001.

CC