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Article

On-site pilot testing of maturity sensors in conjunction with ambient condition monitoring device to get an insight into the concrete strength gain process

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Abstract. The article demonstrates the performance of newly developed concrete maturity sensors on the construction site of residential complex "New Line" in Nur-Sultan. The sensors were mounted on the rebar of reinforced concrete structures to monitor the curing temperature of poured concrete grade M350 during 7 days. Additionally, the sensor device monitoring ambient temperature and relative humidity was set nearby. 14 cubic specimens were molded for compression test to determine the concrete strength. To get an idea on the degrees of influence of considered factors on concrete strength gain, the correlation analysis was conducted. As expected, the curing temperature showed a significant correlation with compressive strength, and its degree of influence amounted 58%. The ambient temperature with influence degree of 36% seemed to affect the concrete strength vividly. The relative humidity affected insignificantly with 6%. Based on conducted investigations the well-enough performance of maturity sensors is concluded. Moreover, there was set plans on the extension of their software solution with colored cross-correlation analysis technique.
Keywords: maturity sensor, construction site, cross-correlation analysis, concrete strength, internal and external factors.

1. Introduction

Monitoring the influence of internal and ambient factors is an important step when constructing a monolithic building frame, especially at early ages of concrete curing. As is known, the cement hydration in the concrete mix is accompanied by the heat release. Sometimes, depending on the composition and type of concrete as well as the massiveness of a structure, the internal temperature during exothermal process of concrete hardening may reach 90 ºC. In majority of cases the dynamics of curing temperature may be describes with a sharp increase at the first few days after pouring, continued by general declining trend with slight fluctuations. Observation of such external factors as ambient temperature and relative humidity may give a certain understanding on the concrete hardening process as well. The external temperature may effect on the curing temperature unfavorably by cooling it. And the relative humidity at the surrounding air may somehow either extend the designed water content in the concrete or reduce it to a certain level interfering with the process of cement hydration [1]. Therefore, real time monitoring of these factors can potentially prevent undesirable consequences with concrete curing process. Previous studies show much of the examples of how these factors may be monitored on site using various sensor devices. One of the most popular devices to monitor internal temperature is a maturity sensor [2]. As of now, different types of maturity sensors have been invented, including embedded ones. Main purpose of the maturity sensors is to help estimating a concrete strength by indirect methods using a certain relationship between the temperature-time factor and strength, which was described in some international standards [3]. This relationship has been thoroughly discussed in previous studies [4], as well as some its modifications were presented. The sensors monitoring ambient conditions also exist and developed in different variations [5]. One common thing that has to be taken into account on the sensors monitoring all the factors affecting certain characteristics of a building structure is a simultaneity of measurements. This must be always set precisely to make fair assumptions on the effect of factors on the concrete strength. In the sensor devices developed during the studies of [6] and [7] the aspect of simultaneity is reached by setting a specific measurement interval programmed to their Arduino microcontrollers in advance. By this moment these sensor devices were tested only on small precast structures, and fulfilled the expectations. However, they were not yet tested on site, on the structures of a monolithic building frame. Therefore, this study is aimed on pilot testing of the newly developed sensor devices as well as monitoring internal and ambient conditions affecting the strength of concrete in the massif structures on site.

2. Methods

The pilot test of sensor devices was held on the construction site of residential complex “New Line” in the city of Nur-Sultan, Kazakhstan. One maturity sensor was installed on the rebar of a raft foundation and another one on the rebar of pillar as shown in Figure 1 below, and the sensor device monitoring ambient conditions was put nearby. The measurement interval was set to 1 hour. So that each hour one reading was obtained.

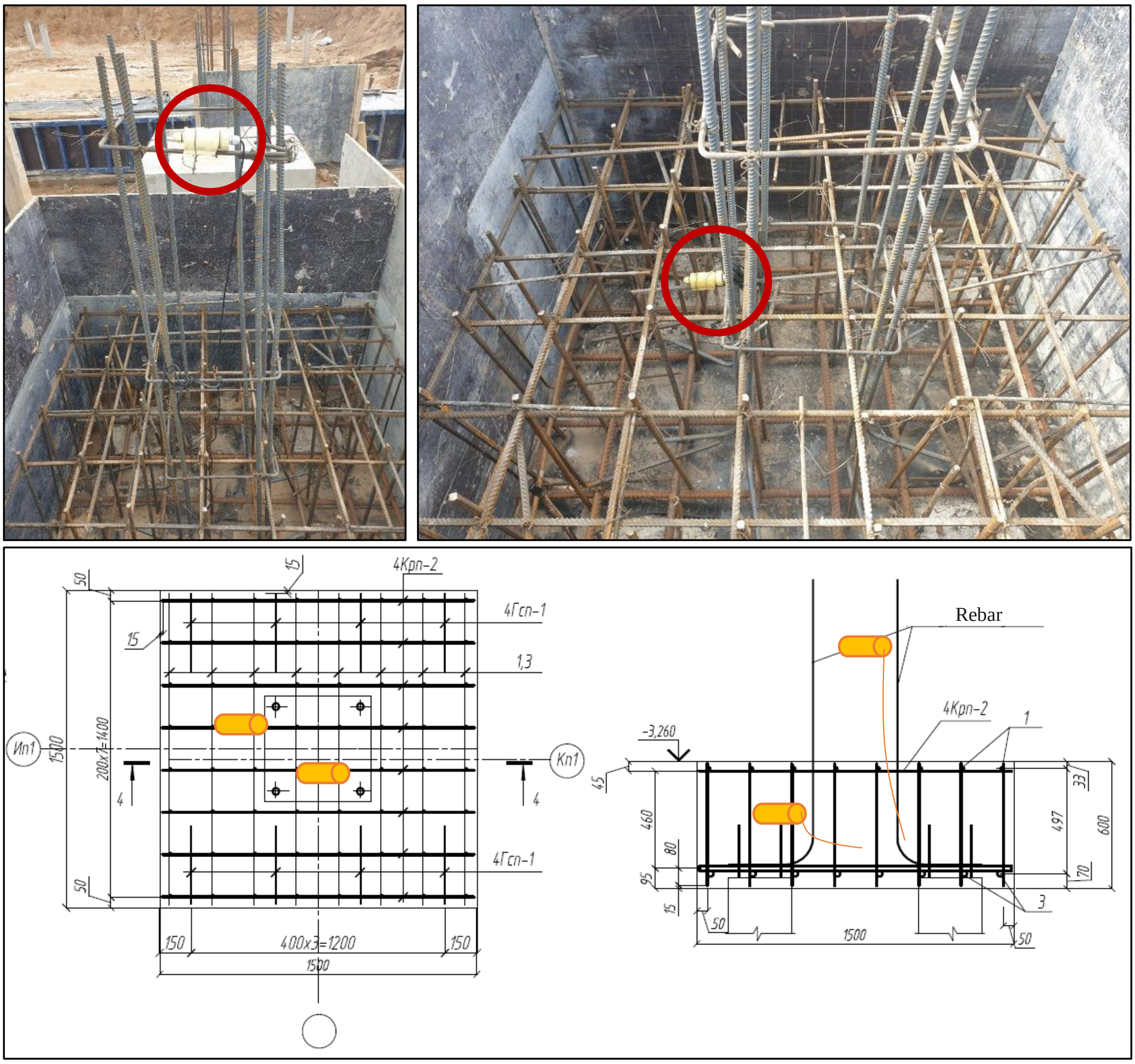

Figure 1 – Maturity sensors installed on rebar

Before pouring a concrete mix grade M350 on the formwork, 14 cubic specimens were sampled to monitor the compressive strength of the concrete of the structures. The monitoring was conducted over one week. The compression tests (Figure 2) were conducted each day on 2 cubic specimens according to [8]. The compressive strength values were averaged for each day.

Figure 2 – Compression test of concrete specimens

At the end of a week the collected measurement data and compression test results were processed and analyzed on Excel. The correlation analysis was conducted to investigate the influence of internal temperature, ambient temperature and relative humidity on the concrete strength gain using classical Equation 1 below:

$$r_{i,a} = \frac{\sum_{a=1}^{7}(F_i - \bar{F_i})\cdot(R-\bar{R})}{\sqrt{\sum_{a=1}^{7}(F_i-\bar{F_i})^2 \cdot \sum_{a=1}^{1}(R-\bar{R})^2}}, \quad (1)$$

where: *i* – considered factors: curing temperature (ºC), ambient temperature (ºC), and relative humidity (%).

a – curing age (day); in current case we considered first 7 days;

F_i and $\bar{F_i}$ – *i* factor and its average value for age *a* respectively;

R and $\bar{R}$ – strength (MPa) and its average value for age *a* respectively.

The degrees of influence of considered factors on concrete strength gain was obtained on via weighting of the modulus of correlation coefficients, so that the sum of obtained values equals one.

3. Results and Discussion

Figures 3 below shows the results of monitoring curing temperature of concrete in the raft foundation and the pillar. Because both structures were poured with concrete mix simultaneously, for the further analysis the average of temperature values from both maturity sensors were taken.

Figure 3 – Internal temperature monitoring results

As is seen from the chart above, the cement setting started 6 hours after pouring the concrete mixture in the structures. Since then, the curing temperature started dramatically rising up to 37 ºC, keeping this level for around 3 hours. Then it dropped sharply, and started fluctuating within the range from 20 to 25 ºC. The fluctuation may be explained with the difference of ambient conditions between day-time and night-time, which is shown in the Figure 4 below.

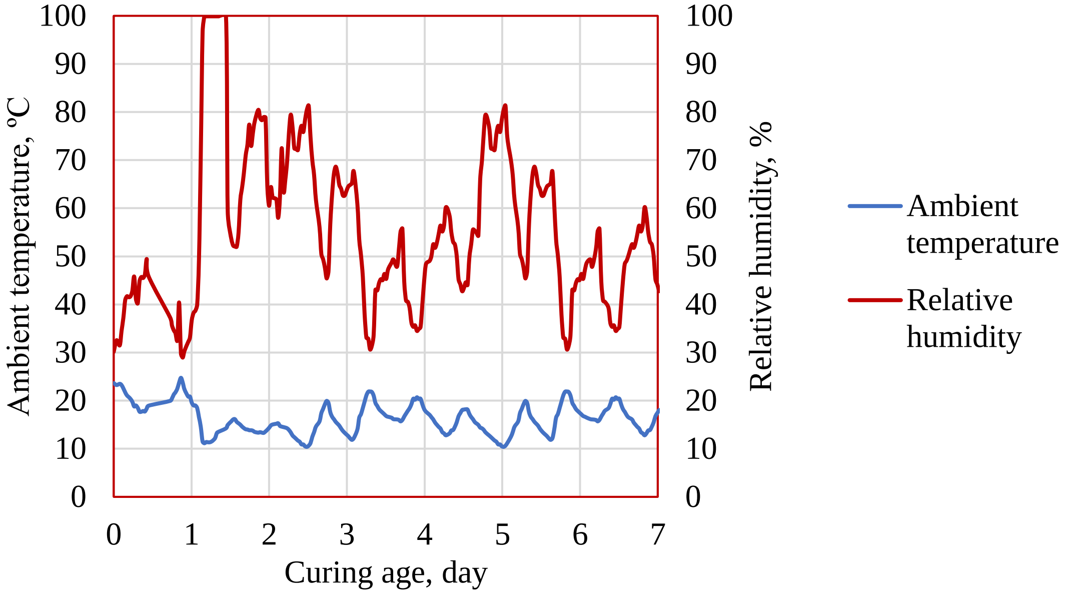

Figure 4 – Ambient conditions monitoring results

From the charts of ambient temperature and relative humidity over 7 days period can be observed that their general trend somehow coincides with those of curing temperature. Another clear trend is that when the ambient temperature is rising, the relative humidity is dropping, as vice-versa. In general, during the monitoring period the temperature outside was ranging between 10 to 25 ºC. The relative humidity of the air at those days was ranging from 29 to 100 %.

The results of compression test of cubic specimens are shown in Figure 5 below. The values of compressive strength presented are those of average between two specimens for each curing day.

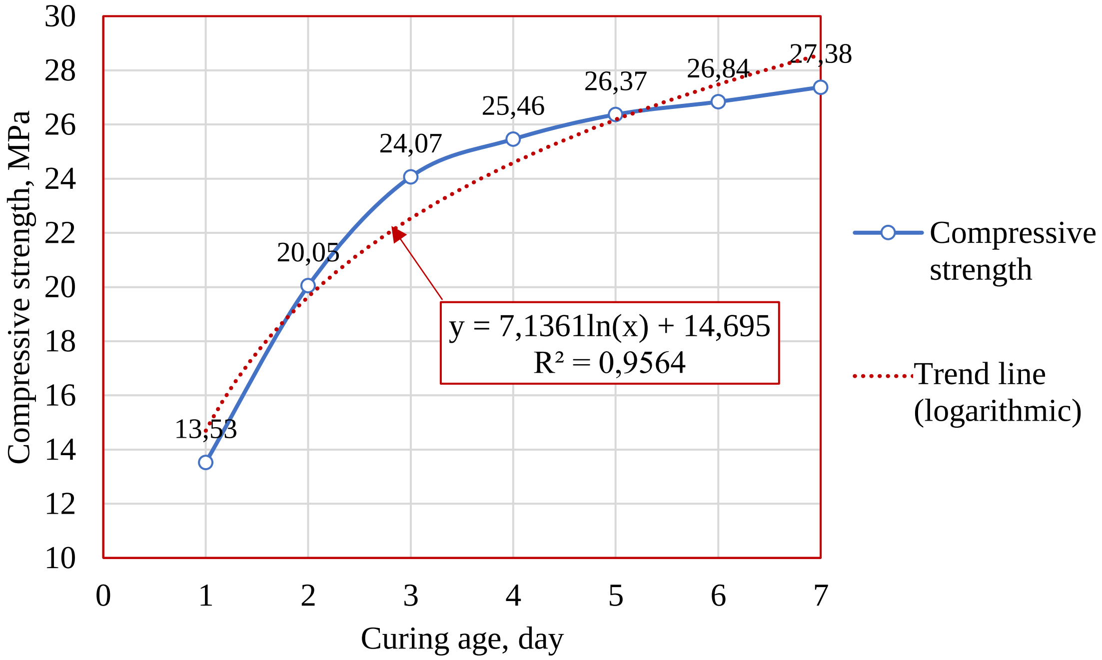

Figure 5 – Compression test results

From the chart above we can observe that over 7 days the concrete gained the strength of more than 27 MPa. This is more than 70% of the projected strength of concrete grade M350. It is seen that the first 3 days the strength is gaining faster than that of following days. In order to conduct correlation analysis, it was necessary to retrieve the hourly strength values. Therefore, the trend line and the strength function were extracted from the existing values for each of 7 days. It was decided to use the logarithmic function describing the trend of concrete strength gain due to for this case it had a highest coefficient of determination (R^2 = 0.9564). Further, using the Equation 1 above, the correlation analysis was conducted between all the considered factors and compressive strength (Table 1).

Table 1 – Cross-correlation analysis

	Compressive strength	Curing temperature	Ambient temperature	Relative Humidity
Compressive strength		-0.465	-0.286	0.046
Internal temperature	-0.465		0.115	0.105
Ambient temperature	-0.286	0.115		-0.872
Relative Humidity	0.046	0.105	-0.872	
Degrees of influence on strength gain:		58%	36%	6%

The cross-correlation above presented in green and blue colors demonstrate clear picture of how significant or insignificant of correlation between considered parameters. From market green cells is seen that the compressive strength has a high correlation with curing temperature; next is ambient temperature, and relative humidity. This is obvious, since the curing process releases a heat and the more the temperature the faster the strength gain. It can be also observed that the ambient temperature and relative humidity are strongly correlated. This proves the trend discussed above. The last line in the table shows the estimates of the degrees of influence of various considered factors on the concrete strength gain; the cells are marked blue. They were estimated taking the weighted modulus of each correlation coefficient. Thus, it can be seen that the curing temperature like always influenced greater than that of other factors. However, 36% of influence degree in this study is taken by ambient temperature. The relative humidity played insignificant role in the strength gain process.

The obtained results clearly show how demonstratively the strength gain process can be presented and used when monitoring the concrete structures. Previous studies [5-6] somewhat have something similar, however the cross-correlation technique in this study seems easier to understand. Moreover, the non-volatile manner of proposed estimations may be straightforwardly integrated to a computer or mobile software for monitoring purposes.

4. Conclusions

This study demonstrated on the basis of sensor devises and compression tests an easy-to-use technique for monitoring the concrete strength gain process, as well as on fly presentation of how various factors may affect it. The proposed technique is replicable and integrable to various computer or mobile programs.

The pilot test where the newly developed sensor devices were used disclosed fairly well performance of the latter. Therefore, it is planned to extend its software with the functionality to visualize the real-time cross-correlation between the internal and ambient factors, and concrete strength values. This may give opportunity to potential users for making better decisions during treatment of freshly poured concrete, as well as its hardening process.

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