Algorithm formulation for adjusting the estimated composition of concrete mixture taking into account relevant properties of the raw materials

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Abstract. This article deals with the research dedicated to the formulation and testing algorithm of water amount adjustment tempering while producing concrete mixtures depending on raw material characteristics. The algorithm is intended for an automated quality control system of concrete mixtures of raw components, providing continuous data collection in real time. The article provides the necessity of automatic quality control implementation and adjusting the calculated compositions of concrete mixtures based on them. There is the discussion of factors discouraging the formulation and implementation of the given systems at the existing production of reinforced concrete products. There were formulated the ways of solving the problems, the scientific significance of the proposed projects was proved. There was revealed the main parameter of the concrete mixture, which provides the concrete quality obtained on its basis and factors influencing it associated with the physicochemical characteristics of raw materials are shown.

1. Introduction
Reinforced concrete products are leading structural materials in modern construction. Manufacturing of these products is the largest technically equipped branch of the construction industry [1-4].

However, in spite of the large-scale productive capacity and the apparent simplicity of the technological lines, concrete mortar units and enterprises for manufacturing of reinforced concrete products currently have the ability to automate only certain technical production areas [5-9]. Most operations requiring increased accuracy are manual. Currently, it is almost impossible to automate the processes associated with the input control of raw materials in particular. In production process, laboratory assistants check raw materials quality, draw up and adjust formulations, adopt production parameters.

Thus, human factor is always the reason for drawback and to a significant extent affects the quality of the finished product. Manual labor excess significantly slowdown the production process, does not exclude the occurrence of errors and data loss.

A universal automated system allows solving the following problems:
• continuously monitor the main raw materials characteristics,
promptly adjust the mixture composition depending on deviation indicators magnitude of controlled characteristics

switch off the production process at a critical deviation of these indicators.

The development of automation systems for the production of reinforced concrete products is complicated by the lack of a working algorithm for adjusting the estimated composition of concrete mixture depending on the characteristics of raw materials. The development of this algorithm taking into account the indicators of controlled parameters can be carried out with the well-known method of "absolute volumes".

Another factor complicating the system development as a whole is the lack of express methods that are acceptable for measuring control performance directly on the production line. The solution to this issue is planned to be carried out by conducting a series of experiments in which the properties of raw materials will be determined both by standard methods and based on several types of proposed express methods.

As a result of the carried-out experiments, it is expected to develop the methods that allow to determine the raw materials properties with a deviation of 5% from the results obtained by standard methods. The simplest techniques from a technological point of view will be used to form units for collecting information.

The scientific significance of solving this problem is mainly aimed at the subsequent prospect of implementing the latest high-tech domestic technologies and developments in the field of building materials science into the production of reinforced concrete products.

The main objectives of this study are to identify a number of parameters determined by the future automated quality control system to adjust the current composition of concrete mixture in the reinforced concrete products manufacturing. This article suggests the part of a general algorithm development for adjusting the composition of concrete mixtures depending on the physic mechanical and physicochemical parameters of raw materials.

2. Materials and methods of research

To test the proposed part of the algorithm, a concrete mixture was made. Portland cement CEM I 32.5 was used as a binder. As a fine aggregate, sand was used with a fineness modulus of Mk 2.5 and a moisture content of 3.2%. Granite crushed stone with the largest NC size of 20 mm and a moisture content of 1% was used as a coarse aggregate.

3. Research part

Classical concrete mixture consists of cement binder, coarse aggregate, fine aggregate and mixing water [10]. The physic mechanical and physicochemical characteristics of each raw material component in one way or another affect the characteristics of heavy concrete obtained on their basis [11-16]. In the general sense, the determining factor affecting the strength of hardened concrete is the ratio of cement to water (C/W) [17].

The strength of heavy concrete and C/W in accordance with the recommendations [18] on the concrete mixtures selection for heavy and fine concrete are related by the formula:

\[
\frac{C}{W} = \frac{R^28 - 0,006 \cdot R^28 + 13}{0,24 \cdot R^28 + 13},
\]

where \( \frac{C}{W} \) is cement to water ratio providing the reliability of concrete; \( R^28 \) is cement hardness (activation) taken equal to class indicator, MPa; \( R^28 \) is the required average strength of the class of concrete (normal hardening at the age of 28 days), MPa.

There is also dependence of concrete strength on the cement-water ratio according to the formula of I. Bolomey - B.G. Skramtaeva [19, 20]. In addition to the cement-water ratio and the activity of cement, it takes into account the quality of the aggregates used, since the strength of the hardened
conglomerate is affected not only by the cement stone strength but also by its adhesion to the aggregate.

For ordinary concrete with $C/W = 1.4 \ldots 2.5$, the strength formula has the form:

$$ R_b = A \cdot R_c \cdot \left( \frac{C}{W} - 0.5 \right), $$

(2)

where $\frac{C}{W}$ is cement to water ratio providing the reliability of concrete; $R_c$ is cement hardness (activation) taken equal to class indicator, MPa; $R_b$ is the demanded average reliability of normal hardening concrete at the age of 28 nights, MPa; $A$ is coefficient taking into account the quality of the aggregate.

With high-quality aggregates (crushed stone from dense igneous rocks, coarse sand with a minimum content of harmful impurities) $A = 0.65$; for ordinary aggregates $A = 0.6$; when using aggregates of reduced quality $A = 0.55$.

For high-strength concrete manufactured with a $C/W > 2.5$, there is the formula:

$$ R_b = A \cdot R_c \cdot \left( \frac{C}{W} + 0.5 \right), $$

(3)

There is $A = 0.43$ for high-quality aggregates, for ordinary $A = 0.4$ in this formula.

This law of strength is common for materials with a conglomerate structure; it is applied to heavy and lightweight concrete, fine-grained concrete and mortar. Only the parameters $A$ included in the strength formula will have different numerical values, depending on the type of material and aggregate. For the further automatic adjustment algorithm development of the heavy concrete composition, we take the Bolomey-Skramtaev characteristics.

It is most obvious from formulas 2 and 3 that the predicted strength of concrete is inversely proportional to the amount of water in the concrete mixture.

In addition to mixing water, introduced in an amount calculated by the laboratory, moisture with coarse and fine aggregates also gets into the concrete mixture. The natural moisture content of aggregates is taken into account when selecting the composition. Only the parameters $A$ will have different numerical values, depending on the type of material and aggregate. For the further automatic adjustment algorithm development of the heavy concrete composition, we take the Bolomey-Skramtaev characteristics.

The moisture content of aggregates can be determined in real time at the time of dynamic movement in thin layer (when moving along the conveyor) using microwave moisture testers.
2. When selecting the heavy concrete composition, the current moisture content of the aggregates $\omega_1$ was not taken into account, it is taken equal to 0, and the actual consumption of aggregates corresponds to the estimated amount of aggregate in the laboratory composition. Water flow adjustment must be carried out according to the formula

\[ W = W_0 - A \left( \frac{\omega}{100} \right), \]  

(5)

where, $W$ is the actual calculation of water, with respect to adjustment; $W_0$ is the calculated water flow rate selected in laboratory conditions; $A$ is estimated amount of coarse/fine aggregate, kg; $\omega$ is unaccounted moisture for aggregate.

3. Since the actual aggregate humidity can be either higher or lower than the calculated one according to the laboratory, the adjustment of the water flow and aggregates can go both in the direction of decreasing and increasing. Consequently, the algorithm must take into consideration both options.

4. First of all, it is necessary to determine how the actual aggregates consumption will change taking into account the changed humidity.

4.1 If the condition is met:

\[ \omega_1 < \omega_2, \]  

(6)

The determination of the actual aggregate consumption is determined by the formula:

\[ A_{\text{eff}} = A \cdot \left( 1 + \frac{\omega}{100} \right), \]  

(7)

where $A_{\text{eff}}$ is the actual amount of coarse/fine aggregate, with the respect to adjustment, kg; $A$ is the estimated amount of aggregate in the laboratory composition, kg; $\omega$ is unaccounted for aggregate moisture.

4.2 If the condition is met:

\[ \omega_1 > \omega_2, \]  

(8)

then the correction of water flow goes according to the formula:

\[ A_{\text{eff}} = A \cdot \left( 1 - \frac{\omega}{100} \right), \]  

(9)

5. Taking into consideration the changed flow rate consumption of the aggregate and its unaccounted humidity, the actual water flow rate can be determined on the formula:

5.1 If condition (6) is fulfilled, then the correction of water flow occurs according to the formula:

\[ W = W_0 - A_{\text{eff}} \cdot \left( \frac{\omega}{100} \right), \]  

(10)

where, $W$ is actual calculation of water, with the respect to adjustment; $W_0$ is the calculated water flow rate matched in the laboratory conditions; $A_{\text{eff}}$ is the actual amount of coarse/fine aggregate, with the respect to adjustment, kg; $\omega$ is unaccounted moisture for aggregate.

5.2 If condition (8) is fulfilled, then the correction of water flow occurs according to the formula:

\[ W = W_0 + A_{\text{eff}} \cdot \left( \frac{\omega}{100} \right), \]  

(11)

An experiment was carried out to test the algorithm. Taking into account the moisture content of coarse and fine aggregates used, the composition of heavy concrete with strength class B25 was
calculated. To obtain heavy concrete, based on the elaborated composition, there were prepared moisture aggregates, aggregates with high humidity and dried aggregates.

Compositions with variable humidity aggregates have been adjusted in accordance with the algorithm proposed above. The definition of the brand for mobility revealed that the concrete mixture of all compositions has the same brand for mobility - P2. Samples of the obtained heavy concrete were tested at the age of 28 days. The strength characteristics of all samples submitted for testing corresponded to the calculated strength class with a confidence level of 95%.

Thus, using the proposed algorithm, the quality controlling system of raw materials and adjusting the concrete mixtures composition will allow to obtain concrete mixtures with calculated mobility and the required strength indicators. In addition to the unaccounted aggregates moisture content, the degree of contamination, as well as the discrepancy between the calculated grain composition and the actual one, can affect the quality of concrete mixtures. The development of the algorithms that take these factors into account is the subject of further research.

4. Conclusions
One of the most unstable indicators of raw materials for concrete mixtures is the moisture content of coarse and fine aggregates. The indicator of unaccounted moisture can significantly change the water amount in the composition of the concrete mixture, lowering the cement-water ratio, and as a result, the strength of concrete based on it.

It is possible to avoid deterioration in the quality of finished products providing the condition of enterprises implementing an automatic quality control system for raw materials capable of promptly adjusting the calculated composition of concrete mix in accordance with actual indicators, including moisture indicators of raw materials.

Ensuring high quality and strict control of the production processes for the production of reinforced concrete products is of high practical importance, since products that do not meet the declared characteristics bring a high risk to humans.

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