The engineering of the reinforced concrete products manufacturing business process as a guarantor of the buildings and constructions’ operational reliability

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Abstract. The article highlights the problems associated with ensuring the quality of products and structures manufactured at the reinforced concrete complex enterprises. The article substantiates the dependence of the finished products’ formed quality parameters on the ability to control the “levers” of the process parameters’ quality control. The questions of the industrial complex facilities engineering significance are raised, an assessment of technological production as a sequential, interdependent process is given. An example of the introduction of innovative technologies with digitalization elements in the manufacturing process of the reinforced concrete products and structures is given.

Introduction
The modern market for construction products is more and more saturated with a variety of materials, products and designs that meet both the updated requirements for technical characteristics and the growing demand of the consumer market.

Modern requirements for residential and public buildings, elements of organized infrastructure more and more relate to security issues reflected in the Federal Law “Technical Regulation on the Safety of Buildings and Structures” [1]. In order to implement the Federal Law [1], the Federal Agency for Construction and Housing and Communal Services of Russia developed and agreed with the concerned authorities a draft regulatory system [2], the hallmark of which is the transition to the new methodological principles based on technical regulations (TR), which become more widespread in the practice of building standards and standardization in the developed countries.

Similar methodological principles are implemented in the scientific research process. The level of such research work aimed at solving the scientific, technical, technological solutions with a goal to improve the source material quality, the level of the organizational and production process, product quality control at all stages starting with research and development work and ending with the implementation and transition the mass production with the required quality parameters [3].

There is no technical base for the widespread implementation of the scientific developments’ results, which makes it possible to introduce and provide the positive results and possible advantages of innovative methods for the production of the reinforced concrete products relative to the existing and operating in modern conditions.

The withdrawal of existing capacities for the production of the reinforced concrete products and...
structures to a fundamentally new technical level is much more than economically feasible, regarding the construction of new capacities and in time and cost, which justifies the prospects of this direction in the construction industry development.

**Analysis of the problem, goals and objectives of the work**

The currently existing enterprises in the construction industry for the production of reinforced concrete products and structures (as well as most materials and products for construction purposes) are for long morally and physically obsolete production facilities. The technical potential of these enterprises is comprised of the equipment and production lines in the best case of semi-automatic control and the main productive force in these factories is a human. And accordingly, the entire technological process with its features, difficulties and inconsistencies with modern standards and requirements depends on the human factor.

At the same time, it is not right to say that the construction industry products are often produced in inadequate quality. This is not true. Many enterprises producing concrete and reinforced concrete products supply their products to the construction industry and finished buildings and structures constructed on their basis, pass the acceptance stage and are subsequently reliably operated for a long time.

Is everything so clear in this situation? Let us consider some aspects of this problem. First of all, the technical requirements of construction norms and rules in force were initially introduced at the time enterprises’ designing. This was taken into account, implemented and ensured. But at the same time, previously existing standards do not meet modern requirements for materials and structures. Simultaneously with these conditions, the enterprises should keep up to date and provide the construction industry with the products that meet the requirements of the consumer demand in the modern market.

If we analyze the features of modern construction projects, it becomes obvious that buildings of high storeys dominate on it, which is generally inherent in densely populated megacities.

Evaluating modern buildings and structures, we can definitely say that during their design all modern requirements are taken into account, designed to ensure technical safety and operational reliability of the newly constructed buildings and structures.

The variety and expressiveness of architectural, spatial and constructive solutions of the buildings created on the basis of monolithic and precast monolithic reinforced concrete allow solving the complex urban problems and improving the aesthetic buildings’ qualities.

However, this situation makes us take a completely new look at the commercial products of the construction industry enterprises used in this case, and specifically at the commercial concrete mixes.

As already noted, the security requirements and operational reliability of buildings and structures imposed the need to increase the quality and technical properties of the monolithic structures’ main component - concrete. If earlier, concrete class B20-B22.5 (under special conditions B25) was the working class of concrete used in the construction of monolithic load-bearing structures with a height of up to 14 floors, then concrete of a class not lower than B25-B30 is used for the construction of buildings with 18 or more floors (in special conditions B35).

These requirements form other approaches to ensure the compliance with the initial regulatory requirements both to the quality of the freshly prepared concrete mixes themselves and to the preservation of these properties in the period from the time of manufacture until the formation of the concrete structure in the formwork at the construction site.

This period of time is largely unpredictable, since currently construction is mainly carried out on the newly developed territories of megacities, which are often located at a sufficient distance from the construction site.

At the same time, it is necessary to take into account other problems, such as the manufacturability of the work when receiving concrete mix at the construction site, moving it to the place of laying into the formwork, forming the concrete structure during concrete work, and most importantly, over the entire period of time spent on these works maintain the technological properties given to concrete...
mixtures to the maximum.

In addition to the high construction pace of the buildings with the increased number of storeys and complexity, the modern construction complex erects the complex and responsible structures of increased length inherent in modern conditions for the traffic flows’ organization.

The provision of reinforced concrete structures, on the basis of which the construction of the transport facilities is built, lies at the reinforced concrete complex enterprises. This, in turn, imposes the special requirements on the very approach to organizing the production process. Regardless of whether new or reconstructed production is considered, the products and designs are manufactured on domestic or foreign technological equipment manufactured by the machine-building plants or machine shops of enterprises, the ongoing technological process should ensure the manufacture of products that meet the requirements of standards, design documentation and technological maps for these products [4].

The products’ manufacturing regulated by this set of rules should include the following technological processes:

- concrete components’ warehousing and storage;
- production (or a complete set delivered centrally) of reinforcing and embedded products;
- concrete preparation;
- products’ molding;
- products’ thermo treatment;
- products’ formwork, finishing, storage and transportation.

Each of the regulated technological processes must be controlled and controllable. In this case, it is necessary to focus on the process approach. The present operations in the form of business processes, i.e. the transition of raw materials, requirements, technological regimes into finished products. The positive results’ stability of the production activities largely depends on the production manufacturing the entire technological process management, taking into account the results’ analysis of the monitoring operations and output quality control of the finished product.

At the present stage of the production capacities’ development, this is achievable only with the widespread introduction of technological innovations in the production process [5]. In general, technological innovations are present at all enterprises of the construction complex, but their effectiveness varies for each individual enterprise, which ultimately forms the competitiveness of the products at these enterprises on the sales market.

As already noted, for today, it is economically feasible to consider modernization or technical re-equipment as a decisive factor in increasing the economic efficiency of business processes regarding the construction of new facilities. In this case, a business process is understood to mean a system of consistent and targeted actions by means of which the originally invested resources are transformed into the final result (finished products of the enterprise). In other words, this concept includes the totality of the “steps” of a manufacturing enterprise, in particular the construction complex, the implementation of which leads to the creation of finished products for the construction purposes that fully satisfy the requirements and expectations of the consumer. Out of the whole set of the business processes types (managing, operating and supporting) from the point of view of ensuring the technological process quality, the most significant are operational, i.e. the processes associated with the implementation of the construction complex enterprises’ main activities - the finished products production of the required quality parameters.

Improving and increasing the efficiency of business processes without fundamentally changing them lies in the field of engineering. An analysis of the enterprise reorganization engineering methods’ results showed that when they are used, the company’s performance indicators increase on average from 10 to 50%, while they are mainly aimed at rationalizing the old business processes.

The next step in improving production efficiency should be considered the business processes digitalization process, which consists in the transition of the enterprise to electronic platforms. The business processes’ digitalization can reduce the number of steps required to complete a specific task, reduces the amount of work with documents and the influence of the human factor. In the future,
digital transformation provides for a qualitative change in the entire business model, starting from the enterprise strategy and ending with the production processes digitalization.

**Research part, recommendations to the industrial enterprises**

Current requirements for industrial complexes for the reinforced concrete products and structures production [4] are the introduction of automation of individual operations for the reinforcing elements’ manufacturing, concrete preparation, processes for the concrete structure and thermo and moisture treatment of products’ formation, as well as the instruments for operational control and non-destructive methods of product quality control.

During the new plants’ construction, the certain main technological stages’ automation introduction is provided:

a) preparation and transportation of concrete mixtures;

b) thermo and moisture treatment in various units;

c) operational process quality control;

d) quality control of finished products, including evaluation of measurement results.

And if the methods of automating the processes of manufacturing reinforcing elements for the reinforced concrete products and structures are widely implemented in production, the rest of these positions are significantly inferior to the first in terms of implementation efficiency.

To implement the basic requirements for ensuring the finished products’ quality parameters, a comprehensive program was developed, which should be tested as a part of the engineering reorganization measures’ implementation in relation to the operational type of the business process.

In order to increase the technological security of design solutions, the new generation concretes with high technological and operational properties are used. They are equipped with guaranteed quality indicators, which play an important role in complex engineering structures of the 21st century.

As an example, let us consider an enterprise manufacturing reinforced concrete structures for the construction of transport structures (in particular, bridges, overpasses, etc.).

If concrete of class B30-B35 was earlier used in the span beams’ manufacturing, then the changed requirements for the organization of traffic required changes in the requirements for structures on the basis of which the transport structures are being constructed. Today, the production of beams span concrete class B45 is used.

The materials used for the high-strength concrete preparation (which includes concrete of class B45) are subject to the increased requirements to ensure that concrete is obtained with the necessary strength at the maximum possible cement saving. The increased requirements are also imposed on the accuracy parameters of the materials’ batching process for preparing concrete mixtures and determining the workability of the prepared concrete mixture [6-9].

In this situation, the ability to control both the process of preparing materials for kneading and the process of mixing the components to obtain a homogeneous mass is of great importance.

The basic requirements for the concrete industry and for the concrete mixture preparation process continuous monitoring possibility were considered repeatedly in the previous authors’ works [5, 10-11].

Particular attention is paid to the dosing accuracy of the concrete mixture components. The following requirements for this process are established: dosing of cement and aggregates is carried out only by weight; dosing of water and additive solution by volume is allowed.

The accuracy of the constituent materials’ dosage for the concrete mixture per batch of the concrete mixer should not be lower than: cement, water and additive solutions ±1 %, each fraction of aggregates ±2 %.

Particular attention is paid to the actual workability compliance of the obtained concrete mixture with the requirements of the technological regulations for the production process of the product or structure. And in this case, timely accounting of the actual moisture content of the aggregates in calculating the composition of materials per batch is of great importance.

The introduction of automatic concrete mixing systems with software control using a computer
allows you to ensure a stable quality of concrete. To ensure the implementation of this task, based on experimental data, a program that allows for online adjustment of the concrete mix composition taking into account the express analysis of the actual moisture content of aggregates (using, for example, probe sensors of universal moisture meters (type SIMS-2.2) installed in storage bins) has been developed. The programs algorithms for adjusting the concrete mix composition by the moisture aggregates content (Algorithm A) and calculating the materials consumption per batch volume (Algorithm B) are presented in Figure 1-2.

**Figure 1.** Algorithm for adjusting the concrete mix composition by the aggregates’ humidity

After dosing and mixing the concrete mixture, express control of the freshly prepared concrete mixture workability is carried out

**Figure 2.** Algorithm for calculating the concrete mixture components’ consumption for the batch volume
The appearance of the window for adjusting the concrete composition is shown in Figure 3.

![Concrete Composition Adjustment Window](image)

**Figure 3.** Concrete Composition Adjustment Window

The workability express monitoring is carried out in the bunker of the paver using one of the measuring devices: C188 Waltz consistometer, C189 Electric plastometer, etc. Assessment of the concrete mixture actual workability is necessary to adjust the vibration compaction process during the formation of the concrete structure in the product.

Experimentally, based on the known empirical dependencies of V.N. Shmigalsky, establishing the concrete structure’s formation duration in the product from the concrete mixture vibrations and workability intensity, the modes that allowed to obtain the certain composition of the concrete mixture required compaction degree with various combinations of vibration intensity and different duration of vibration compaction were worked out. This value should be correlated with the vibration compaction duration obtained by the calculation taking into account the required specific power of compaction \( P \), cm\(^2\)/s\(^2\) and the specific work of compaction \( W \), cm\(^2\)/s\(^3\), which is adopted according to the regulatory documents.

The consideration of the parameters in the reinforced concrete products’ manufacturing is presented in the form of a technological scheme shown in Figure 4.

Freshly formed products arrive at the thermo treatment post, where the operating mode of the thermo unit is controlled using a multi-channel TMT concrete control system. This multichannel system can vary the reinforced concrete products’ thermo treatment mode depending on the characteristics and workability of the concrete mixture on the basis of which they are made. The algorithm for regulating the TMT mode is presented in Figure 5.

The feasibility of the automation systems’ use for controlling the thermo treatment processes based on the automation tools’ use, for example, the PTM-5 System, is justified by the possibility of reducing defects in this redistribution by 0.3 ... 0.4%, and will also provide the additional steam savings of 10 ... 15%.
Quality control of the finished products and structures involves checking the geometric dimensions and shapes of the products, the quality of the outer surface, the size of the protective layer, the position of the fittings and embedded parts, the correspondence of strength, frost resistance, water tightness, density, thermal conductivity, etc., as well as the rigidity and crack resistance of the structure as a
whole project requirements.

The requirements for these parameters, their list and test conditions are given in the normative documents for the products.

In general, operational control automation leads to the defect reduction by about 0.5 ... 0.6% and will reduce the repairing products’ cost.

Summary

Analyzing the foregoing, we can conclude that by introducing the engineering methods of reorganizing the business process by operational type into the production implementation, the reinforced concrete products can be transferred from the category of assuring the finished products’ quality to the category of production organization with the controlled process parameters and with the finished products’ established parameters quality.

At the same time, the operational control automation of the technological processes and product quality, transfer of their management to an electronic platform, will significantly improve the production culture at enterprises, establish the causes of defects and improve the products’ quality.

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