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Prototyping of a concrete maturity sensor with a hermetically sealed housing made of two-component plastic

The construction industry, traditionally considered quite conservative, is now going through a marked change. With competition intensifying, companies have begun to gradually adopt various digital technologies to reduce construction costs, such as the wireless concrete monitoring sensors, which implement a temperature-strength monitoring method for concrete. Each device has its technological features, which are taken into account in the development of the concepts. Enclosure design is the most important stage of product development. An enclosure made in-house has many advantages and disadvantages. The most important part of the design of an electronic device enclosure is the preliminary research stage. This article presents features of wireless monitoring sensor enclosure design. A data acquisition station (DAS), also referred to in the network topology as a "gateway", will be used to collect data from the wireless monitoring sensor over the selected protocol. The server application was created based on HTML, PHP, CSS, JavaScript. Testing of the wireless monitoring sensor, SDS, and the server application working together showed full functionality. A study is also given on the determination of concrete strength using the developed sensor according to the ASTM method and using the IPS MG 4.0 by GOST.

Keywords: enclosure design, strength, sensor, software, concrete curing temperature, requirement, non-destructive testing of concrete, monitoring.

Introduction

The concrete strength is the main characteristic that establishes the ability of concrete or reinforced concrete structure to bear the design loads. Standards specify that there are four steps in the use of the method of calculating the current strength of concrete by its maturity: establishing the maturity-strength relationship in the laboratory; embedding maturity sensors inside the formwork at the construction site; sensor reading of concrete maturity at the construction site; data analysis [1–3]. The first phase involves the development of a housing for a wireless concrete strength monitoring sensor.

All electronic devices are quite different in their functionality and set of tasks. Despite this, there is a common set of rules that can be applied to the design of a product enclosure. Enclosure development consists of several stages [4]:

– Creation of the product concept. At this stage the idea goes through a commercial success analysis. Competing products are identified and a technical level map is drawn up. The technical level map is a comparative table that identifies the unique combination of product functionality and business model to ensure the commercial success of the device being created. Specialists and experts in the required industry prepare a technical and commercial proposal and a product concept design describing the functional features and benefits. In parallel, business analysts create a business plan based on the selected business model and expert assessments. As a rule, the result of this stage is a finished product [4];

– Technical development of the product. At this stage, a conceptual design (PD) is created, terms of reference (TOR) are developed, specifications are created, and product use cases are analyzed. A device feasibility study is carried out, often culminating in the assembly and testing of a product prototype. The selected software, and hardware solutions are evaluated, and the problem areas from the point of view of further technical implementation, platform performance, and other important characteristics are studied. The result of the technical study of the product is a decision on the correctness of the chosen platform and the justification of technical solutions;

– Development of an electronic device, including the specification of the list of components to be used, the design of the circuit diagram, and the creation of a list of components. The interface is designed, the function tree is built and the control concept is created. Simultaneously with the development of the schematic diagram, the design of the device enclosure is completed. Based on the sketch, a model and design of the device are developed. The software architecture developed in the previous stage is implemented and the software is adapted and finalized. All kinds of tests are developed to check the correctness of both software and hardware;

– At this stage prototypes are created to test their performance and to eliminate possible errors made in the previous design stages. Prototypes have the advantage of solving marketing problems. At this stage, components are procured, and production is placed on the manufacture and assembly of printed circuit boards. After the assembly of the sample PCBs, the operating system and bootloader are ported, drivers, low-level procedures, and application software are finalized. All product components are assembled and integration testing is performed. The result of this stage is the production of working prototypes and changes to the design documentation based on the results of integration testing;

– At this stage, the device class and the need for testing are determined. Based on the preliminary results of the certification, the protocols with the results of the measurements are generated and, if necessary, changes are made to the design documentation;

– Preparation for production and release of a pilot batch. A pilot batch is the starting point for serial production and a check on the manufacturability of the device in real production. At this stage, product defects that were not detected on a small number of prototypes are identified and minor adjustments are made to the circuit, enclosure design, and printed circuit board;

– Full support by the developer for an industrial product that is ready for implementation.

The next step is to verify that the software works and to determine the "strength-maturity" relationship obtained in advance by laboratory testing of the concrete composition chosen, according to the ASTM C1074 maturity method.

Features of hull design

One important feature is the design of the enclosure after the stuffing has been completed [5]. In general, plastic parts are produced on special machines — injection moulding machines (IMMs), on which moulds corresponding to the parts are installed [6]. Molten plastic is injected under pressure into the mould cavity of the mould, after which it is cooled and opened to remove the part [7].

The faster and cheaper production of moulds has led to maximum standardization of the elements. As a result, mould making is essentially reduced to the creation of mould inserts. A high proportion of the cost of the moulds is made up of high-grade steel, which accounts for around 80 % of the cost of the moulds. The quality of the steel used in the molds determines the lifetime of the mold [8]. The leading mold maker is China. The price of moulds in China varies greatly from manufacturer to manufacturer, although it is several times cheaper than in Europe. On the mould production time, Europe is inferior to China. The main problems when dealing with Chinese manufacturers are the difficulty of controlling delivery times and quality [9].

The main material used for enclosures in the electrical industry is plastic. It is widely used because of its good appearance, shiny surface, sufficient plasticity, and ability to retain its properties over a wide temperature range. It should be noted that parts with special properties require more careful selection of material. In addition to ABS plastic, materials such as polystyrene, polycarbonate, glass-filled polyamide are often used [10]. The aforementioned materials are colored by adding a pigment of a certain color. This way any color can be obtained, but the coloring technology requires the use of specialized equipment. To avoid such problems, super concentrates (plastic granules dyed with excessive amounts of pigment) are used [11]. Plastic injection moulding may seem a simple enough process, and with the emergence of inexpensive Chinese and Taiwanese machines it has become even more affordable. However, the efficiency and reliability of such production will be very low, no better than casting the body in a polyurethane or silicone mould of your own making [8]. Polyurethane and silicone moulds are often used in the production of various products. Not only plastic but also plaster and even concrete can be poured into them. A silicone mould can also be made by hand. The base ingredient for the mould is a silicone ingredient. It is a set of liquid silicone and catalyst, i.e. hardener. The working principle is simple: the 2 components are mixed in certain proportions and the resulting mixture is poured over the object to be removed from the mould.

Development of the Reinforced Concrete PM enclosure

The development of the enclosure was carried out for a wireless sensor for monitoring reinforced concrete structures. Computer-aided design (CAD) software was used for visualization. There are many analogs of such programs on the market, the classification is presented in Table 1 [9].

Table 1

Classification of CAD programs

№	Program	The complexity of the task to be performed	User level	Not recommended for use
1	Google SketchUp	Simple enclosures	Newcomer	Projects for series production
2	Blender	All enclosures	Beginner and above	Projects with complex geometry or surfaces
3	COMPAS-3D	All enclosures	Beginner and upper	Projects with complex geometry
4	SolidWorks	All enclosures	Beginner and upper	Projects with a complex surface or design
5	Inventor	All enclosures	Specialist	-
6	NX	All enclosures	Specialist	-
7	CATIA	All enclosures	Beginner and upper	-

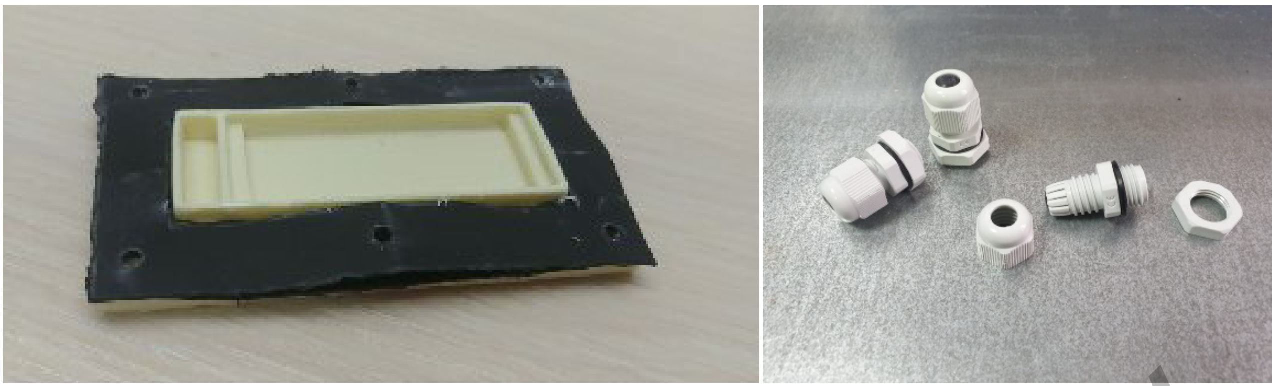
After selecting the computer visualization software, the board and the main components of the device are modeled in 3D. Around the resulting 3D model the enclosure is built. An important role at the stage of construction of the 3D model is played by dimensions of parts, which should be envisaged in 2D. Accuracy of measurement excludes possible alterations [12]. To check the dimensional accuracy at an early stage of the 2D sketch a ream is made on heavyweight paper (Fig. 1).

Figure 1. The reamer from the 2D drawings

Blender [13] is used to visualize the future model of the sensor housing in 3D. In Blender, the construction of the enclosure starts around the board from the largest dimensions and gradually progresses to smaller ones (Fig. 2) [12].

Figure 2. The 3D model of building a square enclosure around the board

According to the initial sketch, the activation mechanism and cable entry hole are provided on the top of the enclosure, with a rib through which a clamp will be passed to hold the transducer in a stationary position. Rubber gaskets (Fig. 3, a) and a gland for the hole through which the cable enters the sensor housing are used to seal the housing. The gland consists of the body, gasket, gasket nut, gasket, and fixation nut (Fig. 3, b). The gasket and gasket are made of neoprene. The body, packing nut, and retaining nut are made of nylon. The gland is installed using a pipe wrench (gas wrench).



(a) (b)

Figure 3. Elements for sealing the enclosure: a) rubber gasket; b) gland for PG7 cable.

The 3D model in STL format is transferred to the 3D printer software. The software allows the model to be automatically or manually positioned in the virtual workspace [14]. All auxiliary elements are then generated and the amount of consumables, as well as the printing time, is calculated (Fig. 4).

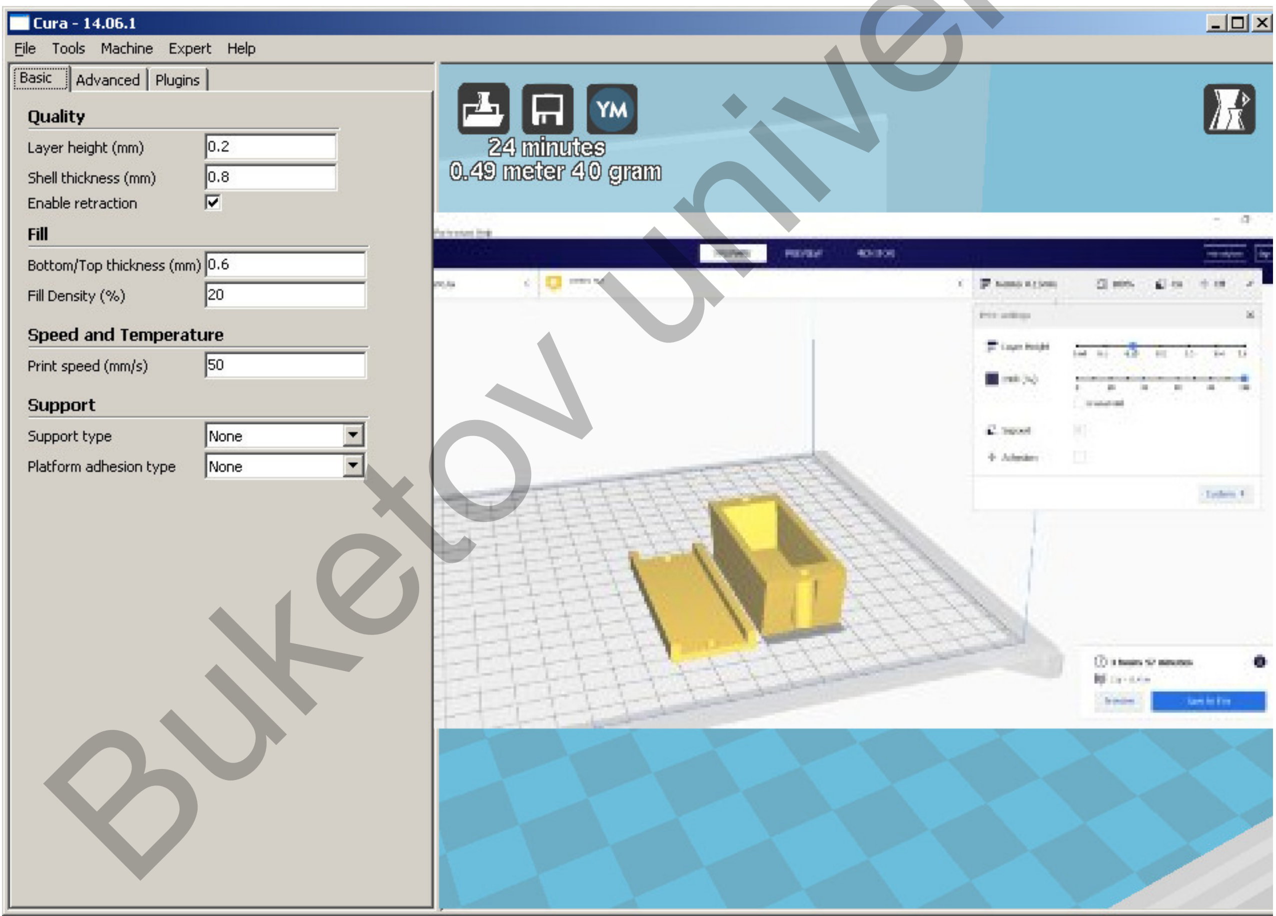


Figure 4. 3D printer software for calculating the number of consumables and time to print

Print auxiliaries are considered to be materials to support the parts as they are positioned over the printing area. Before the printing process begins, the model is automatically divided into horizontal layers and the paths of the printhead are calculated. The 3D printing process then starts: a heating head with spinnerets (extruder) melts thin plastic filament (fishing line) and layers it according to the data in the mathematical 3D model (Fig. 5) [15].

Figure 5. The process of printing on a 3D printer

Once the product has been printed, auxiliary structures are removed by hand or dissolved using a special solution. As a result of the printed model, it is possible to see flaws in the construction and design of the enclosure. When attempting to assemble the enclosure, insufficient rigidity of the enclosure walls was detected. Therefore, the next solution is to return to the previous stage and make corrections to the model. You can modify the finished model by using improvised materials, for example, using liquid plastic, plasticine, or cardboard to increase the thickness of the part or add a new element. The more prototypes produced, the more flaws will be identified and the final product will be as well thought out as possible (Fig. 6, a, b).

(a) (b)

Figure 6. Refinement of the printed model: a — refilling the plastic on the edges of the upper body, b — increasing the height of the bottom body rim with paper

When pouring the silicone, the moulds must be able to fit together smoothly. The first part of the mould must have holes and the second part must have protrusions.

The curing time of the plastic after printing is about 20 minutes. During the design and casting process the hull underwent no small amount of modification. At the time of the virtual model the edges of the hull were enlarged so that the joint between the top and the bottom was tight, and after 3D printing rigidity ribs were added (Fig. 7).

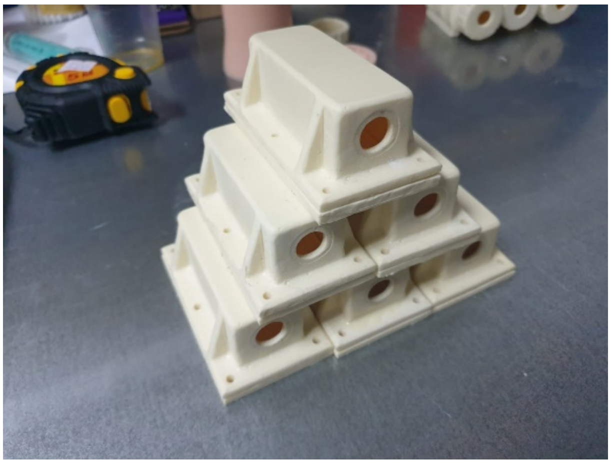


Figure 7. Prefabricated sensor housing

Once the enclosure is ready, testing should be carried out to check the performance.

User interaction with wireless sensor

User interaction with the wireless sensor measurement suite begins with the software (Fig. 8). The user accesses the software via the browser on a mobile device or personal computer. The user selects an existing project or creates a new one, where they specify its name, location, and, if necessary, additional information. Once the project has been fully created and the project data verified, the required number of temperature gauges is added. The concrete composition to be monitored on-site is then selected. It is to be noted that a concrete composition has a concrete strength-maturity curve obtained by performing concrete tests based on the ASTM C1074 maturity method. This dependency is entered into the database by the administrator of the wireless sensor's owner.

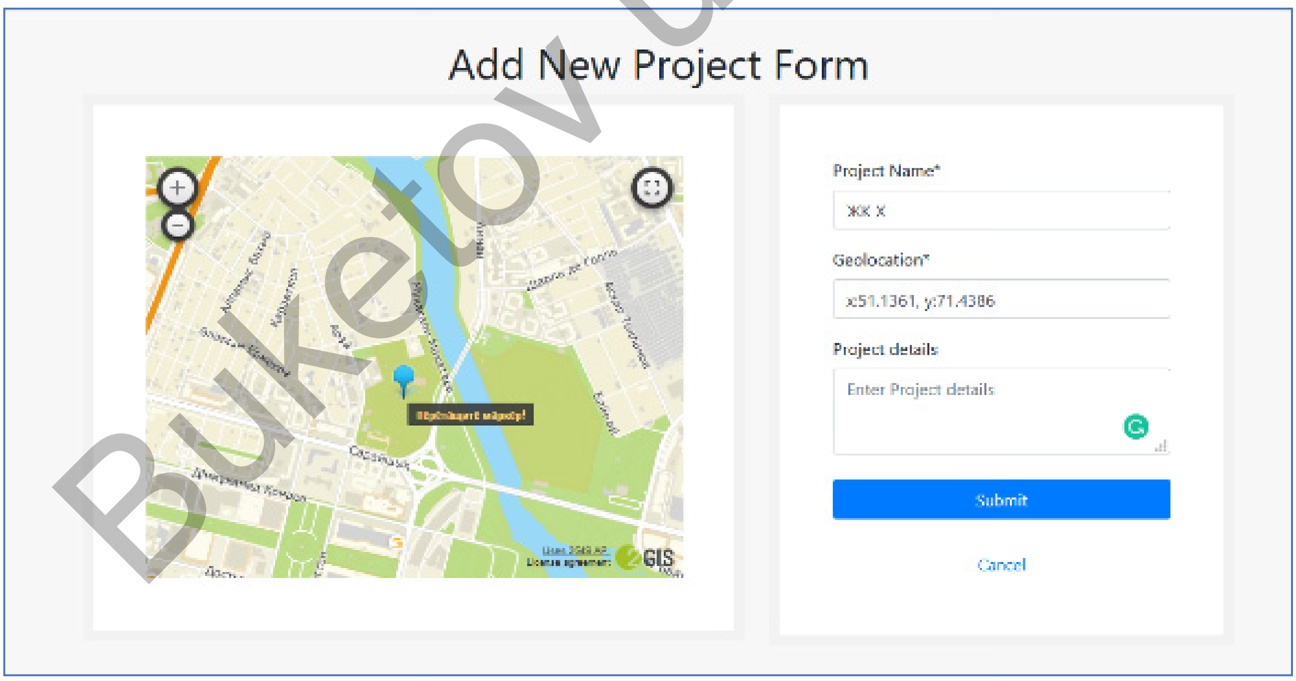


Figure 8. New project creation page

Experimental studies of the selected concrete composition

A series of tests was carried out to check the operation of the wireless sensor: two 50x50x50 cm cubes were prepared by ASTM C 1074, in which the sensors were immersed and the hardening temperature of the concrete was measured for 28 days at 0.5-hour intervals (Fig. 9).

Figure 9. Experimental studies

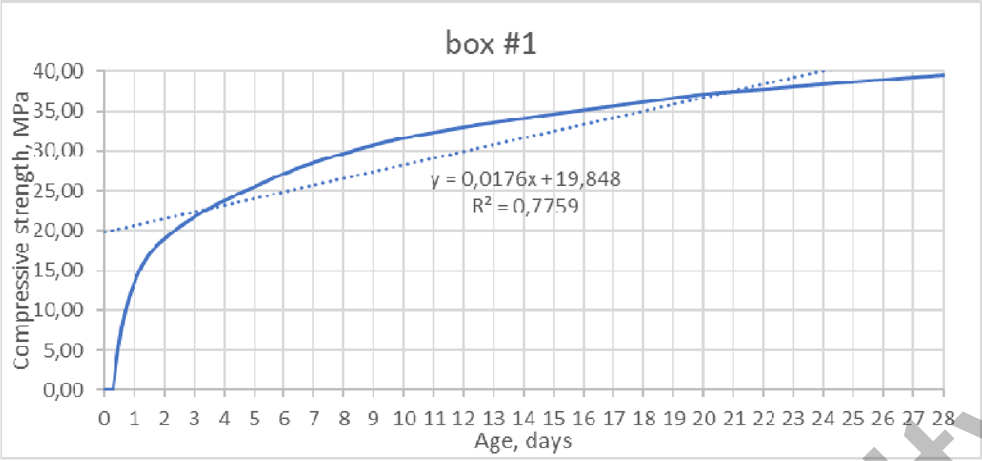
The strength tests of the specimens by the nondestructive control method were performed using a shock-pulse device IPS MG4 [16–17] (Fig. 10).

Figure 10.The strength tests by IPS MG4

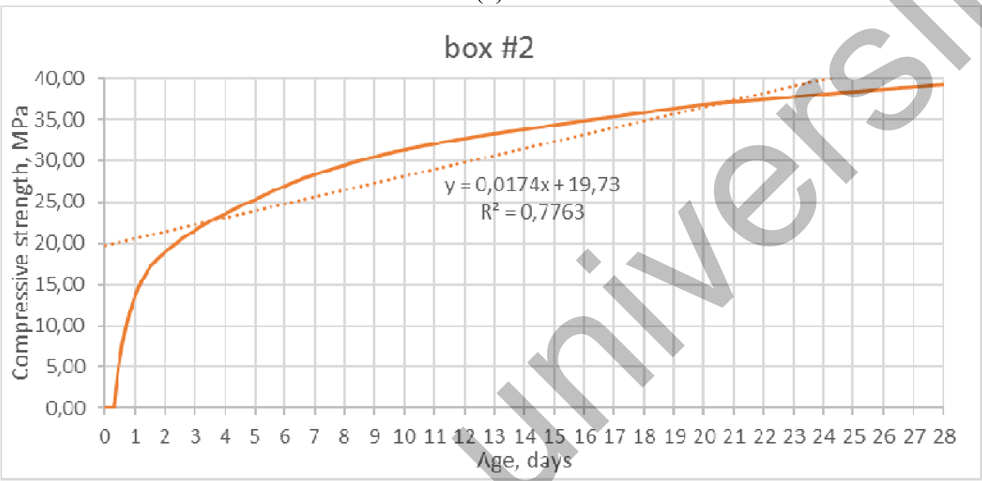
The strength values were then calculated according to the standards [1, 16, 17].

Results and Discussion

The maturity function by ASTM C 1074 is a mathematical expression that uses the measured temperature history of the cement mix during the curing period to calculate an index indicating maturity at the end of that period. Using the calculated maturity index and the strength to maturity ratio, the strength of the concrete is estimated. So the results of concrete strength by ASTM are presented in Figure 11 a, b and by GOST in Figure 12.



(a)



(b)

Figure 11. Results of determination of concrete strength by ASTM: a) box 1; b) box 2

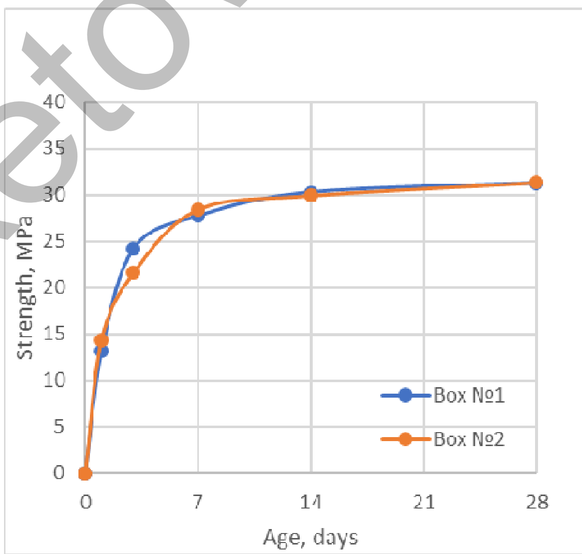


Figure 12. Concrete strength by GOST

To verify the operation of the wireless monitoring sensor two boxes with the sensor were tested by ASTM C 1074; the determination of strength using the IPS MG 4.0 by GOST [16–17] was performed as well. The results showed that the convergence of the values obtained in the tests with the wireless monitoring sensor and by IPS MG 4.0 was satisfactory.

The following conclusions can be made based on the results of the studies: the received data of strength by the sensor has a high degree of reliability, as evidenced by results that were received by the national standard. A slight difference is observed at the initial stage of concrete curing, on the second day the temperature regimes specimens are aligned.

Also based on the results of the work it has been revealed that the shape of the enclosure plays an important role in the design of an electronic device. The specifications and operational requirements of the device have a direct impact on the cost of the product, with the design, testing, and serial production of the enclosure accounting for a significant part of the cost. Each stage in the development of an enclosure is a critical moment, and one of these is the construction of the 3D model, where several basic rules must be observed: there must be no collisions and overlapping parts; all parts must assemble and fully match each other; use uniform dimensions for enclosure walls and repeating parts; and use symmetry and mirror placement of parts. Once the enclosure is ready, testing must be carried out to check the performance with software.

Conclusions

The development of new materials, equipment, and quality control techniques makes it possible to obtain products with high strength, durability, and resistance to wear and tear. In addition to high product quality in the form of building structures, construction companies are also aiming to make a profit. For example, by optimizing the removal cycles of the formwork, time can be saved and overhead costs and labor can be reduced. Timely detection of the point of maturity of a reinforced concrete structure and the decision to load it can generate additional profits by reducing the construction time. There are alternative methods of calculating and predicting the strength of concrete based on modern technology, such as embedded sensors and sensors. The presented embedded wireless sensor for monitoring reinforced concrete structures has no analogs in Kazakhstan. To further verify the performance of the solution, laboratory tests of concrete samples were conducted, the results of which will be used as an initial matrix to be loaded into the server application.

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Екікомпонентті пластиктен жасалған герметикалық корпусы бар бетонның жетілу сенсорының прототипін жасау

Дәстүрлі түрде консервативті деп саналатын құрылыс индустриясы қазір айтарлықтай өзгерістерден өтуде. Бәсекелестіктің күшеюі жағдайында компаниялар құрылысқа жұмсалатын шығындарды төмендету үшін әртүрлі цифрлық технологияларды біртіндеп қолдана бастады, бұл бетонның температуралық-беріктік бақылау әдісін іске асыратын темірбетон конструкцияларының (ТБК) мониторингтік сымсыз датчигі болып табылады. Әр құрылғының өзіндік технологиялық ерекшеліктері бар, олар тұжырымдамаларды әзірлеу кезінде ескеріледі. Корпустың дизайны — өнімді дамытудың маңызды кезеңі. Өз өндірісінің корпусы көптеген артықшылықтарға да, кемшіліктерге де ие. Электрондық құрылғы корпусин дамытудың маңызды бөлігі — алдын-ала зерттеу кезеңі. Мақалада ТБК корпусин дамытудың ерекшеліктері берілген.

Таңдалған хаттама Бойынша ТБК-дан деректерді жинау үшін желілік топологияда «шлюз» деп аталатын деректерді жинау станциясы (ДЖС) қолданылған. Серверлік қосымша HTML, PHP, CSS және JavaScript негізінде құрылды. ТБК, ДЖС және серверлік қосымшаның бірлескен жұмысын тетілеу толық функционалдылықты көрсетті. Сондай-ақ, ASTM C1074 стандартына сәйкес таңдалған қоспаның «беріктік жетілу» тәуелділігін анықтау бойынша зерттеулер келтірілген, оны пайдаланушы сенсордың бағдарламалық жасақтамасына енгізеді.

Кілт сөздер: корпустың дизайны, беріктігі, сенсоры, бағдарламалық жасақтамасы, талаптары, бетонның қатаю температурасы, бетонды бұзбай бақылау, мониторинг.

Е. Утепов, А. Тулебекова, С. Ахажанов, Ш. Жарасов, Д. Базарбаев

Разработка прототипа датчика зрелости бетона с герметическим корпусом из двухкомпонентного пластика

Строительная индустрия, традиционно считающаяся достаточно консервативной, сейчас проходит через заметные изменения. В условиях усиления конкуренции компании начали постепенно применять различные цифровые технологии для снижения затрат на строительство. Таким и является беспроводной датчик мониторинга железобетонных конструкций (БДМ), реализующий метод температурно-прочностного контроля бетона. У каждого устройства свои технологические особенности, что учитывается при разработке концептов. Дизайн корпуса — важнейший этап разработки изделия. Корпус собственного изготовления обладает как многими преимуществами, так и недостатками. Важнейшая часть разработки корпуса электронного устройства — этап предварительных исследований. В статье представлены особенности разработки корпуса БДМ. Для сбора данных с БДМ по выбранному протоколу будет использоваться Станция сбора данных (ССД), именуемая в топологии сети как «шлюз». Серверное приложение создавалось на основе HTML, PHP, CSS и JavaScript. Тестирование совместной работы БДМ, ССД и серверного приложения показало полную функциональность. Кроме того, приведены исследования по определению зависимости «прочность – зрелость» выбранного состава смеси согласно стандарту ASTM C1074, которые затем пользователь заносит в программное обеспечение датчика.

Ключевые слова: конструкция корпуса, прочность, датчик, программное обеспечение, температура твердения бетона, требование, неразрушающий контроль бетона, мониторинг.

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