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Development and testing of the concrete maturity sensor housing

Abstract. The two types of custom housings for the maturity sensor made of two-component plastic were proposed and subjected to durability testing in this study. The first rectangular housing was made of two parts connected by 6 screws and waterproofed with rubber. The second housing was made keg-shaped with a cylindrical keg and screw-on cap. The housings were tested for water resistance, integrity when dropped, and load resistance on three sides using an electromechanical press-machine. At compression tests, both housings demonstrated fairly acceptable resistances, ranging from 0.6 to 2.11 kPa. If referring to the weight applied, it may be supposed that the housings may bear from 65.3 to 165.3 kg depending on the sides, on which the loads are applied. The integrity tests did not cause notable damage on both types of housings, while the water-resistance test revealed the weakness of rectangular housing that failed the test at 3 days of submerging. Comparatively, the cylindrical housing turned out to be more reliable, since its average resistance deviation on all sides appeared to be twice less than those in rectangular one. Moreover, the keg-shaped housing turned out to be waterproof, less material, and labor-intensive.
Keywords: non-destructive testing, maturity sensor, housing, durability, plastic.

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Introduction

The hardware and software products bring advanced smart testing technologies and real-time data collection to the forefront of every job site, driving innovation throughout concrete's lifecycle [1]. Monitoring of the internal processes occurring in the concrete body during the hardening helps to make timely decisions to reduce equipment and formwork rental time, as well as labor costs [2-3].

Electronic devices are subjected to various mechanical effects in the process of operation. Therefore, special attention is focused on its mechanical properties. The mechanical properties of the device include tensile properties, compression properties, flexural properties, static and dynamic friction coefficients, etc. The mechanical properties also have an impact on the areas in which they can be used. For example, iButtonLink Technology, the developer of the iButton sensor, has taken a big step forward by teaming up with Rhodium Scientific. Industrial temperature sensor - iButton was sent into space for high-precision research, where it will measure and transmit temperature information. Another benefit, the implementation of wireless sensors by Giatec's 2020 report, was the ability to quickly collect, analyze and share important data without having to be in close contact with other workers on the construction site. Particularly noted is the use of the sensor as a signal, which gives confidence in the absence of power failures, turning off heaters, or the other way left on. The worldwide practice of using sensors has shown their superiority [4–6]. One of the common key points for expanding the usage areas of electronic devices is the suitability of its enclosure for the external influences it is being subjected to. Therefore, a great deal of attention must be paid to the design of the housing. Developers of electronic equipment are used to designing the enclosure after the completion of the internal part, which is a serious mistake [7]. Firstly, it does not allow selecting an efficient and cheap solution, due to which the dimensions grow, ergonomics, and appearance of the device are reduced. Secondly, in the case of consecutive development of the electronic stuffing and the housing, the launch of the device in serial production can start much later than in the process of parallel development, since there are risks of non-compliance of the housing with the exploitation conditions.

Maturity sensors are becoming widely used nowadays, surpassing traditional techniques in many aspects and enabling real-time monitoring of concrete strength and curing temperature. Embedded into the concrete body, these sensors must have durable and waterproof housing. The current study is aimed at durability testing of the housing for the modernized version of the maturity sensor previously developed by [8]. Along with the data collection station, and the server software, the new version of the maturity sensor represents an integral component of a measuring complex BDM-1. To date, BDM-1 has become the first Kazakhstani product that allows real-time monitoring of the concrete curing temperature and the strength wirelessly. Since the maturity sensors are embedded into the concrete body and subjected to mechanical impacts when the concrete is poured, their internal electronic components must be securely protected with robust housing and waterproofed according to IP68 international standard [9]. To follow such requirements, the housing design was constructed in two configurations (by shape). The next chapter describes the development and experimental procedures performed.

Materials and methods

As mentioned, the maturity sensor housings were built in two configurations: 1) Two parts rectangular; 2) Keg-shaped cylindrical. Two-component liquid plastic from the company Kimpur - Kimteks Kimya Tekstil Ürünleri ve Ticaret A.Ş. formed the basis of the housings. Both components are manufactured in Turkey and are available in packs ranging from 2 to 200 kg. This type of plastic is characterized by its hardness, resistance to mechanical influences, and short setting time. The components of this plastic are mixed in a 1:1 ratio by weight [10].

The maturity sensor housing was initially designed as a combined (upper and lower parts) rectangular housing with 6 screw connections and rubber for waterproofing.

Each part of the housing went through several iterations of molding the silicone formwork, pouring the liquid plastic, and polishing. The formworks were made of the two-component silicone HY-520 produced by the Shenzhen Hong Ye Jie Technology Co. [11], in the ratio by weight of the hardener and silicone of 1:40. Both components are manufactured in China and are available in packs ranging from 1 to 5 kg. To mold the silicone formwork, there were used handy tools and materials.

The poured molds were kept at a room temperature of 20°C and 95% humidity. Every iteration took 1 day till the formwork was ready for the liquid plastic pouring. The setting time of the plastic was around 30 min, after which the housing was polished with abrasive paper. As a result, the master model of the housing was obtained and used to mold a master formwork made of silicone. The final formwork was then used to replicate the housings (Figure 1).

a b c

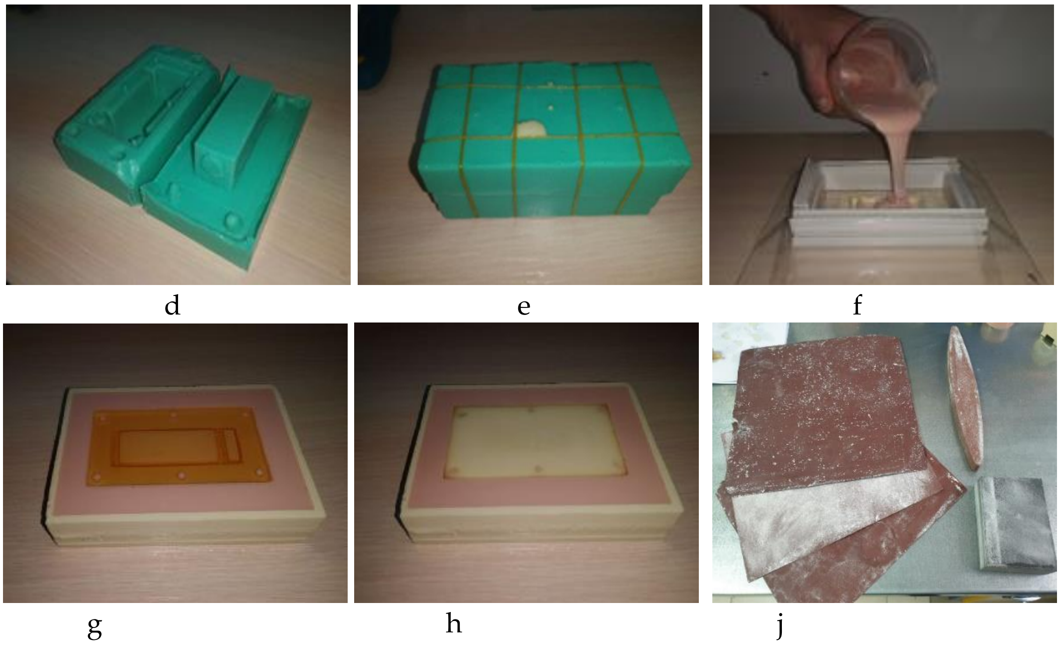


Figure 1. Design and fabrication of a silicone mold for a rectangular housing: a) 3D design; b) prototypes; c) the pouring of silicon for upper part master-form; d) prepared silicone mold; e) cured upper part in the silicon master-form; f) the pouring of silicon for lower part master-form; g) the curing process of plastic in a silicone mold; h) cured lower part in the silicon master-form; j) polishing tools

Since the rectangular housing design was characterized by various elements (metal screws, washers, nuts, and a rubber gasket), its assembly turned out to be complicated. Therefore, the cylindrical housing was based on the screw-cap keg concept. This type of housing was developed to simplify the design and thereby make it cheaper. The cylindrical housing passed through similar stages as the rectangular one (Figure 2).

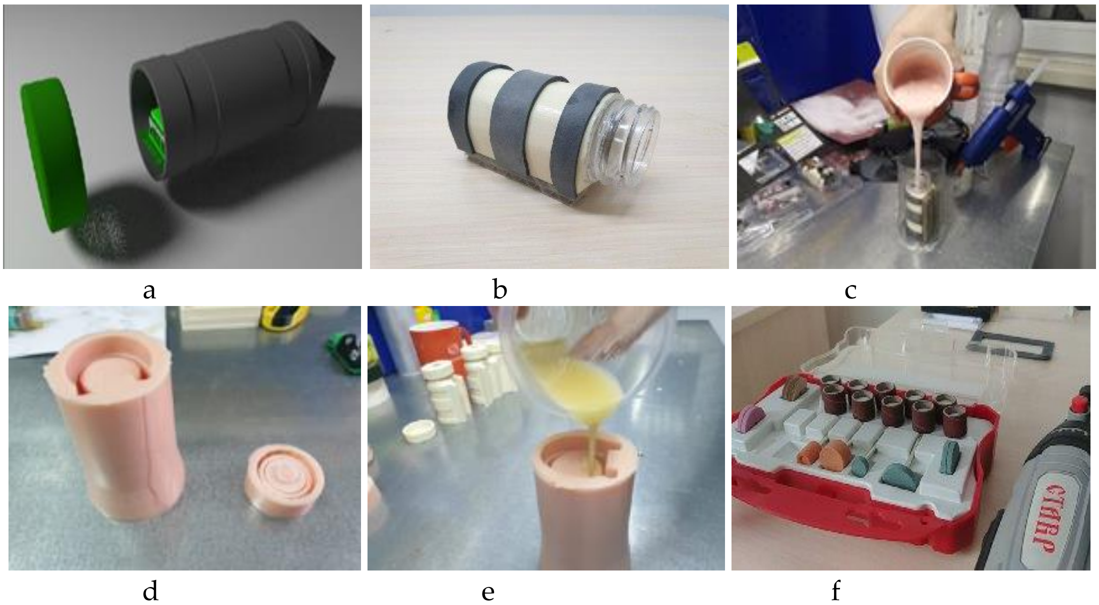
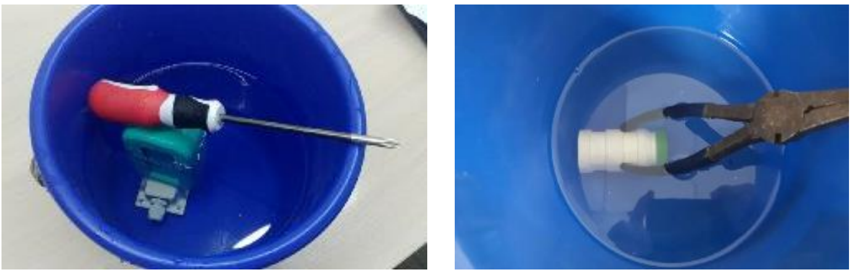


Figure 2. Design and fabrication of a silicone mold for the cylindrical housing: a) 3D design; b) prototype; c) the pouring of silicon for master-form; d) prepared silicone master-form; e) pouring of plastic; f) polishing tools

To argue the durability of the housings, the experimental procedures included the testing of their waterproofness, integrity, and load resistance.

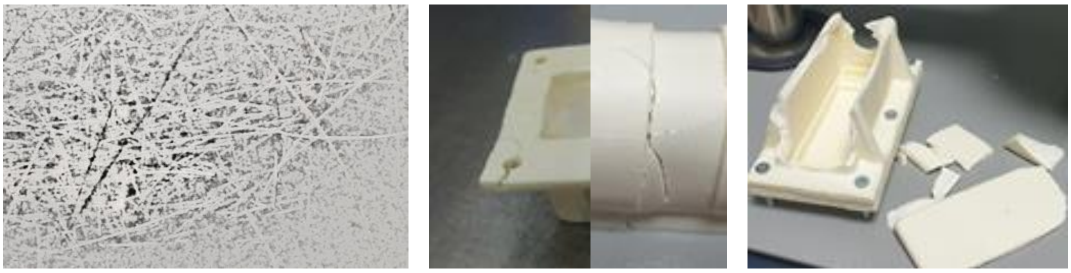
To test for water resistance, both types of housings were sealed with tissue paper inside and prepared for complete submerging in a tank of water, where they had to remain for 1 month. The tissue paper was planned to be used as an indicator of waterproofness. To prevent them from floating to the surface, they were loaded with weights (Figure 3).



a b

Figure 3. Water resistance tests: a) rectangular housing; b) cylindrical housing

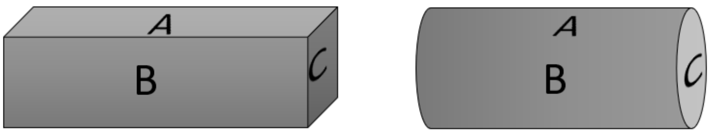
The integrity of the housings is tested by a procedure of free-fall from the different heights (1, 1.5 and 2 m) according to [12]. Three samples of each type of housings were used for testing. Due to the complexity of the technical evaluation after dropping, a visual determination of the samples condition was performed according to the [13] principle. For further classification of the tested samples figure 4 presents the examples of possible breach of integrity (visual indicators).



a b c

Figure 4. Visual indicators of housings integrity: a) scratches; b) cracks; c) spalls

Load resistance determination of the maturity sensor housings structure was carried out on an electromechanical press-machine UNIFRAME 70-T1182 with a load range up to 50 kN and displacement speed ranging from 0.05 to 51 mm/min [14]. The loads on the sides of the housings during the test are conventionally marked by capital letters (Figure 5).



a b

Figure 5. Compression load sides: a) rectangular housing; b) cylindrical housing

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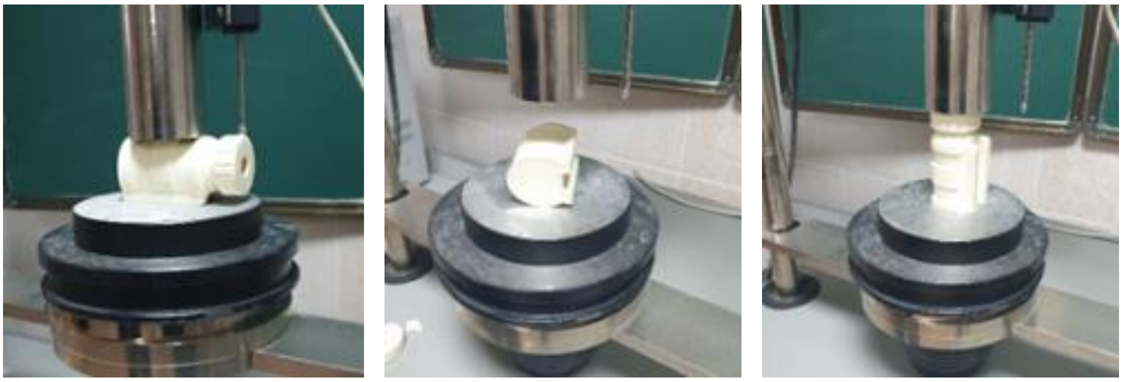
Three rectangular (Figure 6) and three cylindrical (Figure 7) housing samples were destroyed during the compression tests. The different nozzle area of the press piston was taken into account in the compression results.

a b c

Figure 6. Rectangular housing compression test: a) side A; b) side B; c) side C



a b c

Figure 7. Cylindrical housing compression test: a) side A; b) side B; c) side C

Results and Discussion

The housing water-resistance and integrity tests were evaluated visually. The water-resistance test revealed the weakness of rectangular housing that failed the test at 3 days of submerging, which was confirmed by the blotting of the tissue paper. Meanwhile, the cylindrical housing remained in the tank of water for 1 month, turned out to be completely waterproof, since the tissue paper after the inspection still remained dry (Figure 8).

a b

Figure 8. Water-resistance test results: a) wet tissue paper in the rectangular housing; b) dry tissue paper in the cylindrical housing

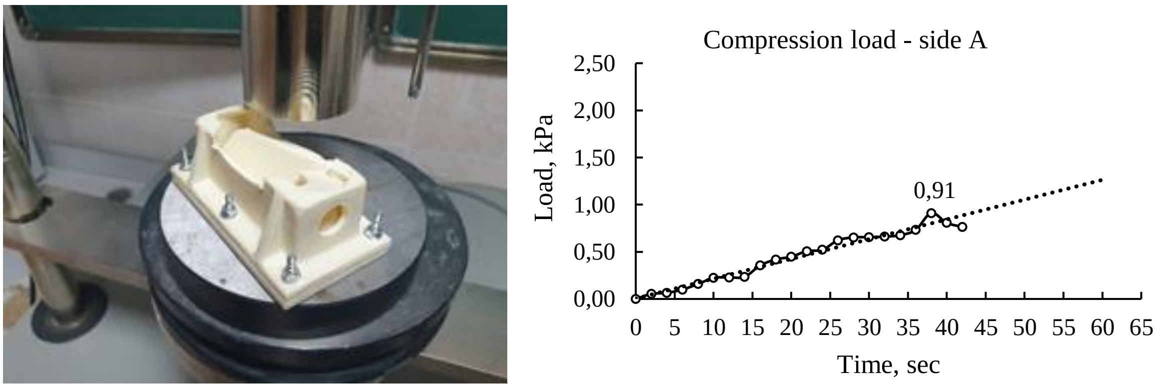
The integrity tests did not cause notable damage on both types of housings as shown in Table 1. There were minor scratches on the surface of both cases, as well as a single crack after the fall of the sample No. 2 of rectangular housing at a height of 2 m. The rectangular housing was cracked at the screw connection part, which may be reasoned by the fact that the screw holes are located close to the edge of the housing.

Table 1

Integrity test results of housings

Sample No.	Height, m	Visual indicators of housings integrity					
		Rectangular			Cylindrical		
		Scratches	Cracks	Spalls	Scratches	Cracks	Spalls
1	1						
	1.5	✓					
	2	✓			✓		
2	1						
	1.5	✓					
	2	✓	✓		✓		
3	1						
	1.5	✓					
	2	✓			✓		

The results of the housings compression tests are demonstrated below. The diagrams show the maximum uniaxial compression load in kPa for each side of the housings (Figures 9 and 10). It is worth noting that the load was performed with the same displacement speed and time.



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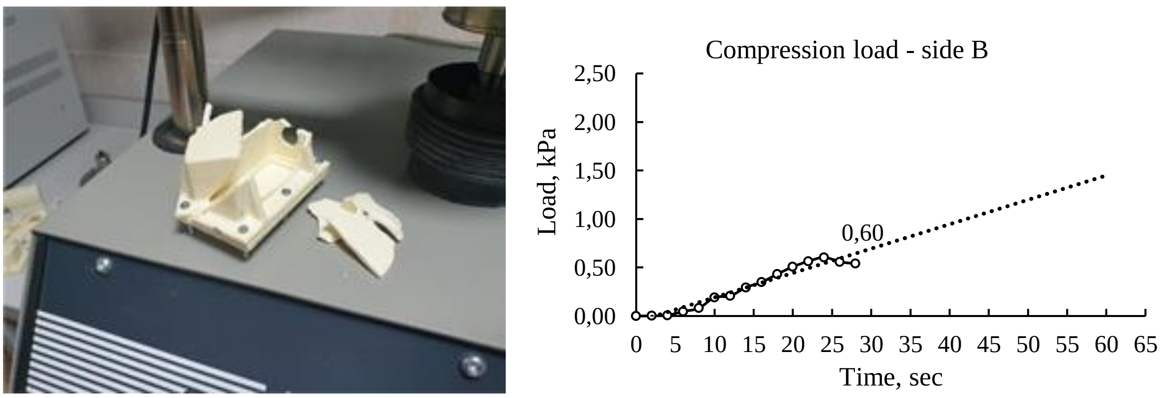

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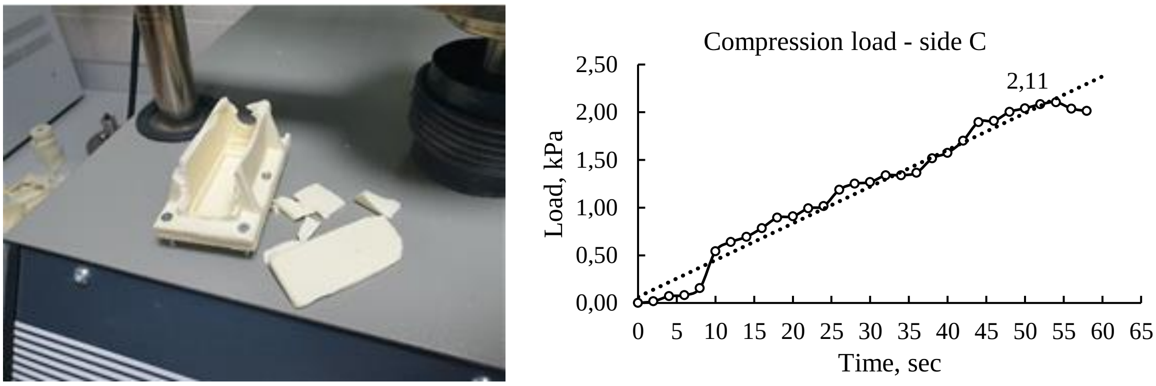
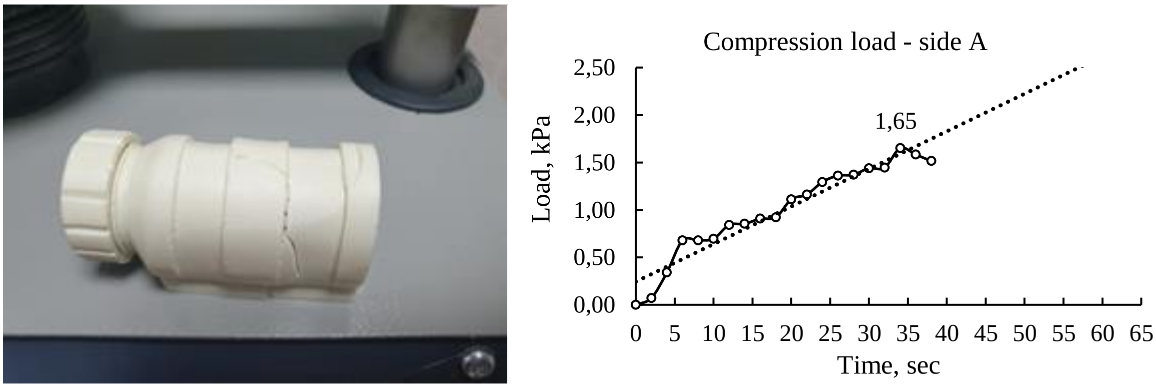


c

Figure 9. Compression load diagram of the rectangular housing: a) side A; b) side B; c) side C



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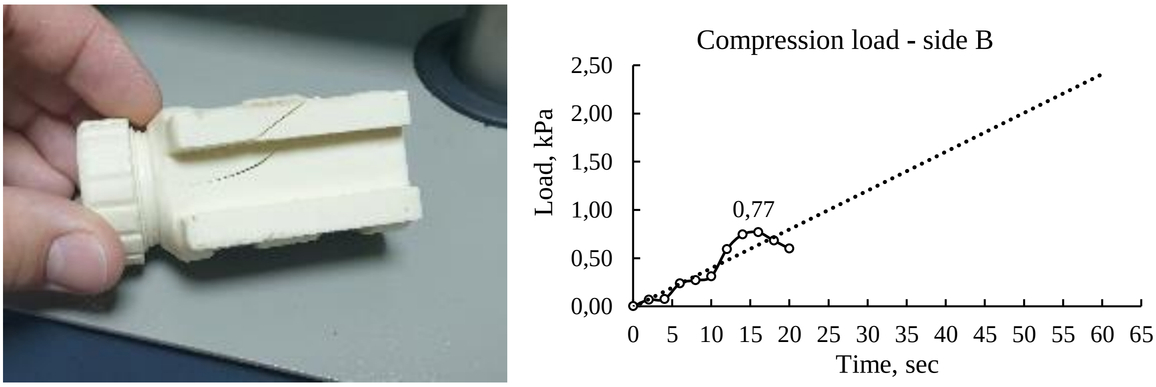

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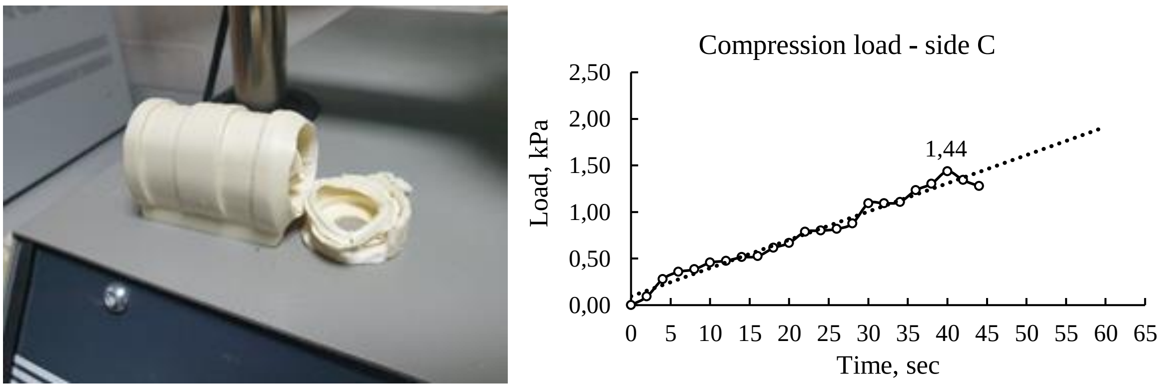

c

Figure 10. Compression load diagram of the cylindrical housing: a) side A; b) side B; c) side C

According to the results of tests of rectangular and cylindrical-shaped housings, the B-side of both types of housings turned out to be the most sensitive to the loads. Whereas the C-side of the rectangular and the A-side of the cylindrical housings withstood the maximum loads. Thus, the sides of the housing when ranked by bearing load may be given the following comparison: B < A < C for the rectangular shape, B < C < A for the cylindrical shape.

To sum up, both housings demonstrated fairly acceptable durability. However, the cylindrical housing turned out to be more reliable since its average resistance deviation on three sides deviate from the average resistance to 26%, as opposed to rectangular housings of 49% (the difference is almost twice). Moreover, the keg-shaped housing turned out to be 100% waterproof according to the test results, less cost and labor-intensive due to the exclusion of screw connections and rubber for waterproofing.

Conclusion

A review of existing modeling techniques, pouring methods, and housing materials were performed. Two varieties of maturity sensor housings by shape were manufactured – the rectangular and cylindrical one. Both types of housing were tested in the laboratory for waterproofness, integrity after falling from a height, and compression load from three sides.

According to the test results, the cylindrical housing appeared to be more reliable than those of rectangular one in several parameters. Moreover, the cylindrical design is more efficient in terms of material and resource consumption in contrast with the rectangular design.

As a result of the process of creating a housing for an electronic device, the following can be highlighted:

- the shape of the housing plays an important role in the development of an electronic device;
- the monolithic design and the small number of parts in the assembly gives more robustness;
- the specifications and operational requirements of the device have a direct impact on the cost of the product;
- the significant part of the production cost lays on the expenses for the development, testing, and serial production of the housings.

The new version of the maturity sensor was represented in the construction market of Kazakhstan. The formation of the local manufacturer along with foreign analogs is focused on the development of the domestic market of instrumentation. The use and implementation of the foreign standard and method of concrete strength control in Kazakhstan is an additional contribution of the research. Laboratory tests confirmed the requirements for the operation of the BDM-1 measuring complex components.

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Бетонның жетілу сенсорының корпусын жасау және сынау

Аңдатпа. Мақалада екі компонентті пластиктен жасалған, беріктікке сыналған жетілу сенсорына арналған корпустың екі түрін ұсынды. Бірінші тікбұрышты корпус 6 бұрандамен және су өткізбейтін резеңкемен қосылған екі бөліктен жасалған. Екінші корпус цилиндрлік бөшке мен бұрандалы қақпағы бар бөшке түрінде жасалды. Корпустар су өткізбейтіндігіне, құлау кезіндегі тұтастығына және электромеханикалық пресс-машинаның көмегімен үш жағынан жүктемелерге төзімділігіне тексерілді. Сығымдау сынақтарында екі корпус та 0,6-дан 2,11 кПа-ға дейін жеткілікті қарсылықты көрсетті. Егер қолданылатын салмақ туралы айтатын болсақ, онда корпустар жүктеме әсер ететін тараптарға байланысты 65,3-тен 165,3 кг-ға дейін көтере алады деп болжауға болады. Тұтастық сынақтары корпустың екі түріне де айтарлықтай зиян тигізбеді, ал суға төзімділік сынағы 3 күндік сүңгуірден кейін сынақтан өтпеген тікбұрышты корпустың әлсіздігін анықтады. Салыстырмалы түрде цилиндрлік корпус неғұрлым сенімді болды, өйткені оның барлық жағынан қарсылықтың орташа ауытқуы тіктөртбұрышқа қарағанда екі есе аз болды. Сонымен қатар, бөшке тәрізді корпус су өткізбейтін, аз материалдық және уақытты қажет ететін болып шықты.

Түйін сөздер: бұзылмайтын бақылау, жетілу сенсоры, корпус, беріктік, пластик.

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Разработка и тестирование корпуса датчика зрелости бетона

Аннотация. В данном исследовании были предложены и подвергнуты испытаниям на прочность два типа нестандартных корпусов для датчика зрелости, изготовленных из двухкомпонентного пластика. Первый прямоугольный корпус был изготовлен из двух частей, соединенных 6 винтами, и гидроизолирован резиной. Второй корпус был выполнен в форме бочонка с цилиндрическим бочонком и завинчивающейся крышкой. Корпуса были испытаны на водонепроницаемость, целостность при падении и устойчивость к нагрузкам с трех сторон с помощью электромеханического пресса. При испытаниях на сжатие оба корпуса показали вполне приемлемое сопротивление в диапазоне от 0,6 до 2,11 кПа. Предположительно корпуса могут выдержать от 65,3 до 165,3 кг в зависимости от сторон, к которым прикладывается нагрузка. Испытания на целостность не вызвали заметных повреждений на обоих типах корпусов, в то время как испытание на водонепроницаемость выявило слабость прямоугольного корпуса, который не выдержал испытания при погружении в воду в течение 3 дней. Для сравнения, цилиндрический корпус оказался более надежным, так как среднее отклонение сопротивления по всем сторонам оказалось в два раза меньше, чем у прямоугольного. Кроме того, корпус в форме бочонка оказался более водонепроницаемым, менее материалоемким и трудоемким.

Ключевые слова: неразрушающий контроль, датчик зрелости, корпус, долговечность, пластик.

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