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# A multi-criteria analysis of sewer monitoring methods for locating pipe blockages and manhole overflows

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**Abstract.** This article is devoted to the aggregation of existing methods for monitoring sewerage systems into a single symbiosis, in particular methods for identifying the locations of clogged pipes and manhole overflows. Clogging of sewers is a frequent problem in large cities, entailing overfilling of manholes with sewage and disruption of the whole sewage system. Today, there are several methods for monitoring sewers: visual, acoustic and laser. Each method is represented by a wide range of devices with different characteristics and applications. The analysis identified the main technical and economic characteristics for each solution presented. Then, on the basis of the data obtained, a multi-criteria analysis was made according to several parameters: measurement accuracy, maximum diameter of the inspected pipe, type of pipe, cost. For the most objective selection, each parameter was given its own weight, and all parameters were normalized for their objective comparison. On this basis, all solutions were sorted by maximum values for each criterion, taking into account the selection by weights. As a result of the multicriteria analysis, five combinations of solutions were built, including several monitoring methods.
**Keywords:** multicriteria analysis, sewer sensors, pipeline inspection, sewage clogging, siltation, solution aggregation.

## 1. Introduction

Despite the fact that sewers are hidden from view, they play an important role in the life of every person. In existing terminology, the sewage system should be understood as technical facilities and networks of pipelines designed for the collection and disposal of solid and liquid waste products of human activity, domestic and rainwater generated in settlements for the purpose of cleaning them from contamination [1].

With the increasing level of urbanization, the load on the sewage system inevitably increases, and as a consequence, there is its increased wear and tear and violations in the work. Typical manifestations of such loads are overfilling of sewer manholes, clogging of pipelines due to their silting, accumulation of dangerous gases for humans at the bottom of cells, as well as unpleasant odor [2]. Such a malfunctioning sewer system leads to many costs. Direct costs include the cost of inspecting the piping and repairing problems. Indirect costs include the costs associated with removing the consequences of clogging: cleaning of streets and municipal property. All this not only interferes with the normal functioning of the urban system, but also affects the lives and comfort of people, which belongs to the category of social costs [3]. In addition, floods and rainwater overflowing into sewage drains pose a threat, as a result of which this water can mix with sewage and enter open water bodies. Urban wastewater is known to contain many hazardous substances and pathogenic bacteria, making it unacceptable to overfill wells with this water [4].

The trend of urbanization around the world continues to grow. Thus, today more than 4 billion people live in cities. Moreover, the number of urban dwellers is expected to reach about 7 billion by

2050, which means that the load on sewers will only increase [5]. Such conditions necessitate competent management of the existing assets of pipe systems, one of the most important factors of which is condition assessment.

There are many solutions aimed at monitoring and controlling the current state of sewers [6-9]. At the same time, each technology has its advantages and disadvantages, which should be considered when choosing. Based on world practice, all methods can be divided into traditional and modern [10]. The presence of a sewer blockage is usually established and eliminated by the fact of its occurrence. This is the easiest approach in application, which does not require serious costs for equipment, but it is not suitable in large cities with a complex system of pipelines due to the high labor intensity of the process. Also, based on the essence of this method, the probability of flooding wells and clogging of pipelines cannot be predicted [11]. Another approach is using special float sensors, indicating about exceeding of permissible liquid level in a well [12]. In this case human participation in monitoring is minimal; however, effectiveness of the method can be reduced in winter time when water in the well will freeze. These methods are considered to be traditional and the most commonly used in a large number of cities. Modern solutions offer a more flexible system for monitoring the state of sewers through the use of a set of different sensors and technologies [13-14]. Thanks to them, it is possible to predict and prevent failures in the pipeline system, and most importantly - without direct human intervention, that is, remotely. Such solutions include: visual methods using cameras; acoustic, using ultrasonic and acoustic sensors; laser; temperature and others. It is worth noting that not all of them are equally suitable and effective for use in different conditions. The diameter of the pipe, the number of its turns and the size of the well play an important role in choosing one or another method of monitoring. The most common types of pipes include:

– Self-flow lines - inclined sewage pipes that transport wastewater under the action of gravity;

– Mainlines - pressure pipelines used for pumping and transporting wastewater;

– Drainage (diversion) canals - pipelines designed to transport wastewater from buildings to mainlines.

Depending on the type and purpose of the pipes, the material from which they are made can also vary. These days, gravity lines are made of plastic, cast iron or reinforced concrete. Large mainlines are more often made of ferrous metals such as cast iron or steel, while small ones are made of PVC and HDPE plastic. PVC and HDPE plastic are also commonly used for bends [15].

Due to the differences in the size of devices and equipment, it is also worth considering the diameter of the pipes. For example, too large a pipe can interfere with the visual monitoring of its internal condition due to the technical limitations of the camera and poor lighting. As in the case of traditional solutions, modern methods of sewer monitoring are not without disadvantages. The main disadvantage is the impossibility of obtaining objective data using only a particular method or sensor. To get a complete picture of the condition of sewers requires the use of multiple solutions and technologies.

Unfortunately, sometimes the wrong selection of monitoring solutions leads to unreliability of the information obtained. For example, using only visual monitoring methods, it is impossible to obtain digital data on volumes. If we talk about traditional methods, float sensors allow an objective assessment of the situation through detailed data on the water level, but may be useless when it freezes, consequently the float sensor will be fixed in a certain position and will transmit incorrect measurements. Theoretically, in a particular case, both methods listed above could be combined into a single system, where each component would solve the disadvantage of the other. Such a symbiosis of solutions can be aggregated based on the conditions and objectives of a particular sewer system based on a variety of other methods and technologies. In this regard, the question of careful analysis of the technical and economic parameters of each solution to implement the most optimal selection of the combination into a single symbiosis is relevant.

In this paper, the object of the study are methods and technologies aimed at detecting siltation, clogging, overfilling of sewage wells, collectors and pipelines.

The purpose of this paper is to aggregate existing methods for monitoring sewerage systems into a single symbiosis.

## 2. Methods

The measures to monitor the condition of sewers include a wide range of works: detection of leaks, corrosion sites, cracks, deformations, as well as blockages. For the convenience of further aggregation, technical and economic parameters of existing solutions and technologies for monitoring were collected, their key criteria (parameters) were established and compared, as well as a multi-criteria analysis was performed.

### *2.1 Data collection*

A summary of existing solutions for sewer monitoring is shown in Table 1.

Table 1 – Methods and technologies for sewer monitoring

| Method | Applied devices, sensors and technologies | Short description |
|---|---|---|
| Human inspection | - | Visual inspection of the internal condition of wells, collectors with the direct participation of a person |
| Visual observation | Cameras, camera probes, zoom cameras, digital scanners | Using different types of cameras to obtain visual images, with which you can assess the condition of the sewer |
| Acoustic method | Sonars, ultrasonic level meters | Using sound waves to detect defects, presence of clogging in the pipeline |
| Laser method | RedZone Robotics, Sima Environmental, CUES, Envirosight, R&R Visual | Using a laser to create a profile of the inner surface of the pipe, which makes it possible to assess the degree of siltation, the level of wastewater in the well |

*Visual Monitoring.* Monitoring with cameras is one of the most common methods of assessing the internal condition of pipes (Figure 1). It provides an opportunity to inspect the sewer when the size of the pipeline is too small or the working conditions are dangerous for humans [16-17]. This approach to monitoring allows identifying almost all required parameters of the state of the sewer: the presence of cracks, the formation of silt and other contaminants, the formation of clogging and overfilling of the manhole. The main disadvantages of such a solution are that the camera system alone cannot provide an objective assessment of the internal condition and requires an operator who could draw conclusions based on the visual information obtained. Also, because of the way the cameras work and the nature of the method, pipe surfaces can only be inspected above the water level, which also limits the scope of their application. In general, this method can be used as the basic one for sewerage monitoring due to providing the most complete range of data used in inspection and its economic efficiency; however, it is recommended to use it as an auxiliary tool.


Figure 1 – Example of internal pipe condition monitoring with cameras

The technology of visual observation of internal condition of pipelines is represented by a wide range of devices: zoom cameras, digital scanners, mobile cameras. Each type of cameras is also represented by a variety of devices from different manufacturers, each of which has its own characteristics of operation (Table 2).

Table 2 – Brief information about zoom cameras

| | |
|---|---|
| Pipe type | Self-flow lines |
| Piping material | Any |
| Pipe size | ~ up to 150 mm |
| Detectable defects | Leaks, cracks, siltation, general condition of the pipe surface |
| Advantages | Ease of use, relatively high efficiency and low cost |
| Disadvantages | The need for an operator, restrictions on the type and size of the pipeline, limitations on the resolution of the lens, the likelihood of missing hidden underwater defects |

*Digital scanners*. Digital scanners are a system of two cameras pointing in opposite directions and taking wide-angle photos of the inner space of the pipe (Figure 2). [18-19]. During the initiation of the inspection, the cameras simultaneously begin to capture images, which are then stitched together into a single whole image with a 360-degree view. In addition to dual, there are also scanners with a single camera having a wide angle of image capture. The principle of operation in this case is identical to dual-camera scanners. The advantage of digital scanning is that the possibility of missing a defect is minimized. In contrast to zoom cameras, where fixation of defects is carried out by the operator controlling the camera rotation, with digital scanning an overall picture of the whole inspected surface is taken [20]. As a result of scanning a digital model can be obtained, on the basis of which digital measurements will be carried out. It is also possible to sweep the image into a single plane.  Thanks to this the probability that the operator will not point the camera to the necessary part of the pipe and will miss a defect is reduced to zero.

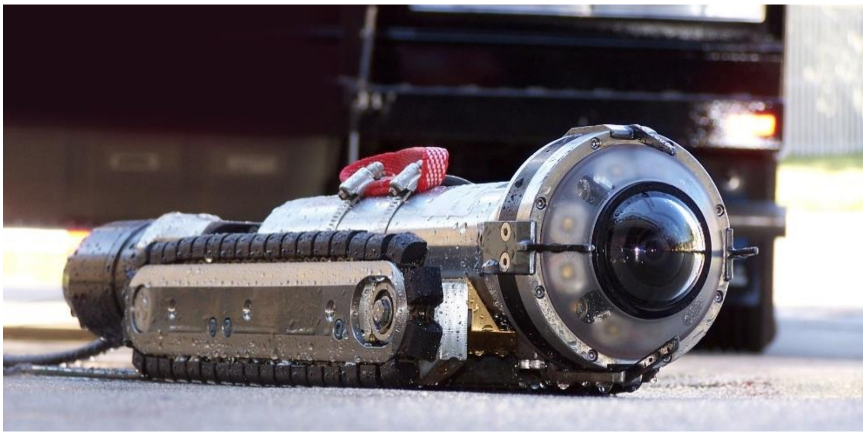

Figure 2 – Digital scanner on a crawler

Digital scanners have similar limitations to zoom cameras. Because the entire surface of the pipe is being scanned, it needs to be dry. Access to some pipes is also a significant limitation. Digital scanning technology is mostly used for gravity flow pipe diameters from 150 mm up to 1500 mm due to its easy accessibility. A brief summary of the zoom cameras is presented in Table 3.

Table 3 – Brief information about digital scanners

| | |
|---|---|
| Pipe type | Self-flow lines, limited applicability for main and service pipelines |
| Piping material | Any |
| Pipe size | 150-1500 mm |
| Detectable defects | Leaks, cracks, siltation, general condition of the pipe surface |

| | |
|---|---|
| Advantages | High efficiency, higher accuracy than conventional cameras, the ability to obtain a digital model of the section of the pipeline, the possibility of digital measurement of defects |
| Disadvantages | The cost of the equipment is higher compared to conventional cameras, the inability to work in water |

*Acoustic method*. The essence of the acoustic method is the use of special measuring devices - sonars, recording the reflection of the ultrasonic signal [6]. They consist of a scanning head, connected with a wire to the processor and monitor. The devices emit an ultrasonic wave, which reaches the area where the defect is observed. When the signal reaches the walls of the pipeline or any other obstacle, the sonar head records its reflections. The reflection varies depending on the material and working medium, allowing the type of surface and therefore the type of contamination, its hardness, to be accurately determined. This method is suitable for detecting various defects in pipelines, including blockages [21]. Also, the time spent on sending and receiving the signal can be used to determine the distance between the sonar head and the pipe wall. From this data, a detailed profile of the pipe can be created, which can then be used for other purposes (Figure 3). In complex branched pipelines, sonars can be mounted on a self-propelled cart.

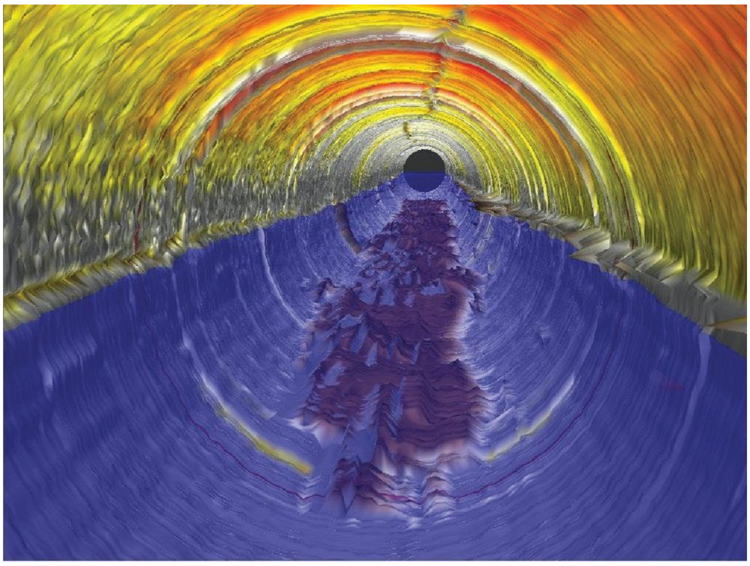

Figure 3 – Example of a pipe profile obtained with the sonar

A significant advantage of the acoustic monitoring method is that it is highly accurate and versatile. When using this method, not only blockages, but also cracks, deflections of pipe walls, corrosion and cavities can be detected. However, it should be taken into account that some defects may be hidden by a layer of grease deposits and debris, so that their detection will be impossible. Also, as described above, signal reflection and reception are affected by the environment in which the sonar will be located. Sonars can work both in dry environment and in water, but the survey cannot be performed in partially filled pipes. This problem is partially solved by installing cameras that record the condition of the pipes in the area above the water level. Brief description of existing sonars on the market is presented in Table 4.

Table 4 – Sonar summary

| Device | Pipe diameter | Type of pipe | Features |
|---|---|---|---|
| A-SIS | up to 300 mm | Any | Includes sonar and camera |
| Envirosight | up to 300 mm | Self-flow lines | Addition to video surveillance system |

| | | | |
|---|---|---|---|
| PipeEye | up to 250 mm | Mainline, Self-flow lines | |
| RVS2 | up to 250 mm | Any | |
| Sonar Profiler System | up to 300 mm | Any | Includes sonar and camera in semi-submerged pipes |
| Sonar Sewer Profiling Attachment | up to 900 mm | Mainline, Self-flow lines | |
| Sonar Sweep Attachment | up to 900 mm | Mainline, Self-flow lines | Includes sonar and camera |

*Laser method.* The essence of the laser method of monitoring consists in creating an internal profile of the pipeline wall using special laser devices that project laser lines (Figure 4). This method is also called laser profilometry [22].

Figure 4 – Example of using lasers to monitor the internal condition of pipes

The disadvantage of this method is the necessity to put the inspected pipeline out of operation, since laser monitoring can only be carried out in dry sections of the pipeline. Video cameras or sonars are also usually used in combination with lasers. A brief summary of lasers is presented in Table 5.

Table 5 – Brief information on lasers

| | |
|---|---|
| Pipe type | Self-flow lines, Mainline |
| Piping material | Any |
| Pipe size | Depends on the size of the device |
| Detectable defects | Deformation, siltation, corrosion |
| Advantages | Relatively high scanning accuracy compared to cameras, the data can be used to create a 3D model of the pipeline |
| Disadvantages | Failure to detect defects in pipes filled with water |

*2.2 Multicriteria analysis*

Due to the fact that all the solutions under consideration have different operating principles, devices and purposes, not all technical and economic parameters can be used in the multi-criteria analysis. For example, some monitoring systems can detect the location of cracks and leaks in the pipeline, but this study only considers defects related to well flooding and clogging.

For optimal selection of methods for monitoring sewer systems into a single symbiosis, all technical and economic parameters were combined into a single table (Table 6). These include such data as: measurement accuracy; cost; the maximum diameter of the investigated pipe; the type of pipeline.

Table 6 – Technical and economic parameters of the devices

| Method | Device | Accuracy | Pipe diameter | Pipe type* | Cost** |
|---|---|---|---|---|---|
| Visual | CrystalCam | 60 m | up to 50 mm | Self-flow lines | $1250 |
| | Flexiprobe | 150 m | 25 - 200 mm | Self-flow lines | $1000 |
| | Hydrus | 50 m | up to 50 mm | Self-flow lines | $350 |
| | Orion | 50 m | up to 100 mm | Self-flow lines | $800 |
| | Orion L | 70 m | up to 100 mm | Self-flow lines | $850 |
| | Push Camera | 90 m | 25 - 300 mm | Self-flow lines | $6000 |
| | IBAK LISY 150-M | ~ 200 m | up to 150 mm | Self-flow lines, partially mainline | $12000 |
| | LAMP | ~ 800 m | 150 - 600 mm | Self-flow lines, partially mainline | $3000 |
| | Lateral Evaluation Television System | ~ 240 m | up to 200 mm | Self-flow lines, partially mainline | $850 |
| | Lateral Inspection System | ~ 1000 m | 200 - 600 mm | Self-flow lines, partially mainline | $1000 |
| | ELK T100 Mini | 150 m | 100 - 250 mm | Self-flow lines, Mainline, Drainage canals | $1500 |
| | KRA 65 | 150 m | up to 100 mm | Self-flow lines, Mainline, Drainage canals | $5000 |
| | Mighty Mini Transporter | 150 m | 100 - 300 mm | Self-flow lines | $2000 |
| | Rovver 100 | 200 m | 100 - 300 mm | Self-flow lines | $5000 |
| | Versatrax 100 | 180 m | up to 100 mm | Self-flow lines, Mainline, Drainage canals | $2250 |
| | Xpress Silver-Bullet Crawler | 180 m | 100 - 380 mm | Self-flow lines | $4620 |
| | Versatrax 300 VLR | 1828 m | up to 300 mm | Self-flow lines | $10000 |
| | Responder | 1600 m | up to 900 mm | Self-flow lines, Mainline | $15000 |
| Acoustic | A-SIS | 0,8 mm | up to 300 mm | Self-flow lines, Mainline, Drainage canals | $7500 |
| | Envirosight | 1 mm | up to 300 mm | Self-flow lines | $8000 |
| | PipeEye | 0,6 mm | up to 250 mm | Self-flow lines, Mainline | $9850 |
| | RVS2 | 0,5 mm | up to 250 mm | Self-flow lines, Mainline, Drainage canals | $15000 |
| | Sonar Profiler System | 0,5 mm | up to 300 mm | Self-flow lines, Mainline, Drainage canals | $13200 |

| | | | | | |
|---|---|---|---|---|---|
| | Sonar Sewer Profiling Attachment | 1,4 mm | up to 900 mm | Self-flow lines, Mainline | $5750 |
| | Sonar Sweep Attachment | 2 mm | up to 900 mm | Self-flow lines, Mainline | $7000 |
| Laser | Active 3D Laser Scanning | 2 mm | 1200 - 2500 mm | Self-flow lines, Mainline | $7700 |
| | Coolvision | 0,5 mm | 100 - 2500 mm | Self-flow lines, Mainline | $10000 |
| | Laser Profiler – CUES | 0,3 mm | 150 - 1800 mm | Self-flow lines, Mainline, Drainage canals | $15000 |
| | Laser Profiling Tool | 1 mm | 100 - 4000 mm | Self-flow lines, Mainline, Drainage canals | $10000 |
| | Laser Profiler – R&R Visual | 1,5 mm | 150 - 4000 mm | Self-flow lines, Mainline, Drainage canals | $12000 |

* Each type of piping is equivalent to 1 point
** The cost is per set

In order to objectively compare sewer monitoring solutions according to the identified criteria, it is necessary to perform data normalization. The value of each criterion is divided by the sum of all values in a particular criterion. The final sum of values after normalization should be equal to 1.

Each criterion was then given a weight. Each criterion was weighted by the following logic: "Accuracy" criterion will have the biggest weight (0,4) because it is the most important factor for any measuring device; "Pipe diameter" criterion will have the weight of 0,3 because the pipe diameter plays big part in measurement accuracy; "Type of pipeline" criterion will have the weight of 0,2 because not all the solutions considered are applicable for the specific type of the pipeline; "Cost" criterion will have the smallest weight (0,1) because high cost of the equipment can be justified by the accuracy of the measurement

Based on the weights for each criterion several combinations (symbioses) of devices will be selected. For convenience, all normalized values for each criterion were highlighted using color scales, where the darkest color corresponds to the highest value, and the lightest - the lowest.

The final result will be a few of the most optimal combinations of solutions for sewer monitoring.

## 3. Results and Discussion

The normalized data were sorted based on the parameters of the weights for each criterion (Tables 7-9). The devices with the maximum values for each criterion, taking into account the selection by weights, are displayed at the beginning of the list. Thus, the best solutions were obtained for each of the three presented monitoring methods.

Table 7 – Data normalization for visual observation methods

| Device | Accuracy | Pipe diameter | Pipe type | Cost |
|---|---|---|---|---|
| Criterion weight | 0,4 | 0,3 | 0,2 | 0,1 |
| Versatrax 300 VLR | 0,25573587 | 0,071770335 | 0,037037037 | 0,137988133 |
| Responder | 0,223838836 | 0,215311005 | 0,074074074 | 0,2069822 |
| Lateral Inspection System | 0,139899273 | 0,09569378 | 0,055555556 | 0,013798813 |

| | | | | |
|---|---|---|---|---|
| LAMP | 0,111919418 | 0,107655502 | 0,055555556 | 0,04139644 |
| Lateral Evaluation Television | 0,033575825 | 0,04784689 | 0,055555556 | 0,011728991 |
| Rovver 100 | 0,027979855 | 0,04784689 | 0,037037037 | 0,068994067 |
| IBAK LISY 150-M | 0,027979855 | 0,035885167 | 0,055555556 | 0,16558576 |
| Xpress Silver-Bullet Crawler | 0,025181869 | 0,066985646 | 0,037037037 | 0,063750517 |
| Versatrax 100 | 0,025181869 | 0,023923445 | 0,111111111 | 0,03104733 |
| Mighty Mini Transporter | 0,020984891 | 0,04784689 | 0,037037037 | 0,027597627 |
| Flexiprobe | 0,020984891 | 0,041866029 | 0,037037037 | 0,013798813 |
| ELK T100 Mini | 0,020984891 | 0,035885167 | 0,111111111 | 0,02069822 |
| KRA 65 | 0,020984891 | 0,023923445 | 0,111111111 | 0,068994067 |
| Push Camera | 0,012590935 | 0,065789474 | 0,037037037 | 0,08279288 |
| Orion L | 0,009792949 | 0,023923445 | 0,037037037 | 0,011728991 |
| CrystalCam | 0,008393956 | 0,011961722 | 0,037037037 | 0,017248517 |
| Orion | 0,006994964 | 0,023923445 | 0,037037037 | 0,011039051 |
| Hydrus | 0,006994964 | 0,011961722 | 0,037037037 | 0,004829585 |
| TOTAL | 1 | 1 | 1 | 1 |

Table 8 – Data normalization for acoustic methods

| Device | Accuracy | Pipe diameter | Pipe type | Cost |
|---|---|---|---|---|
| Criterion weight | 0,4 | 0,3 | 0,2 | 0,1 |
| Active 3D Laser Scanning | 0,526315789 | 0,140540541 | 0,2 | 0,180327869 |
| Laser Profiling Tool | 0,263157895 | 0,421621622 | 0,3 | 0,234192037 |
| Coolvision | 0,131578947 | 0,259459459 | 0,2 | 0,234192037 |
| Laser Profiler – CUES | 0,078947368 | 0,178378378 | 0,3 | 0,351288056 |
| TOTAL | 1 | 1 | 1 | 1 |

Table 9 – Data normalization for laser scanning methods

| Device | Accuracy | Pipe diameter | Pipe type | Cost |
|---|---|---|---|---|
| Criterion weight | 0,4 | 0,3 | 0,2 | 0,1 |
| Sonar Sweep Attachment | 0,294117647 | 0,28125 | 0,125 | 0,105580694 |
| Sonar Sewer Profiling | 0,205882353 | 0,28125 | 0,125 | 0,086726998 |
| Envirosight | 0,147058824 | 0,09375 | 0,0625 | 0,12066365 |
| A-SIS | 0,117647059 | 0,09375 | 0,1875 | 0,113122172 |
| PipeEye | 0,088235294 | 0,078125 | 0,125 | 0,148567119 |
| Sonar Profiler System | 0,073529412 | 0,09375 | 0,1875 | 0,199095023 |
| RVS2 | 0,073529412 | 0,078125 | 0,1875 | 0,226244344 |
| TOTAL | 1 | 1 | 1 | 1 |

As mentioned earlier, each of the methods separately does not allow an objective assessment of the internal condition of pipelines due to various factors. The optimal solution can be considered the application of several methods at the same time in order to compensate the disadvantages of one of them. Based on this logic, five combinations of solutions including several monitoring methods were built (Figure 5).

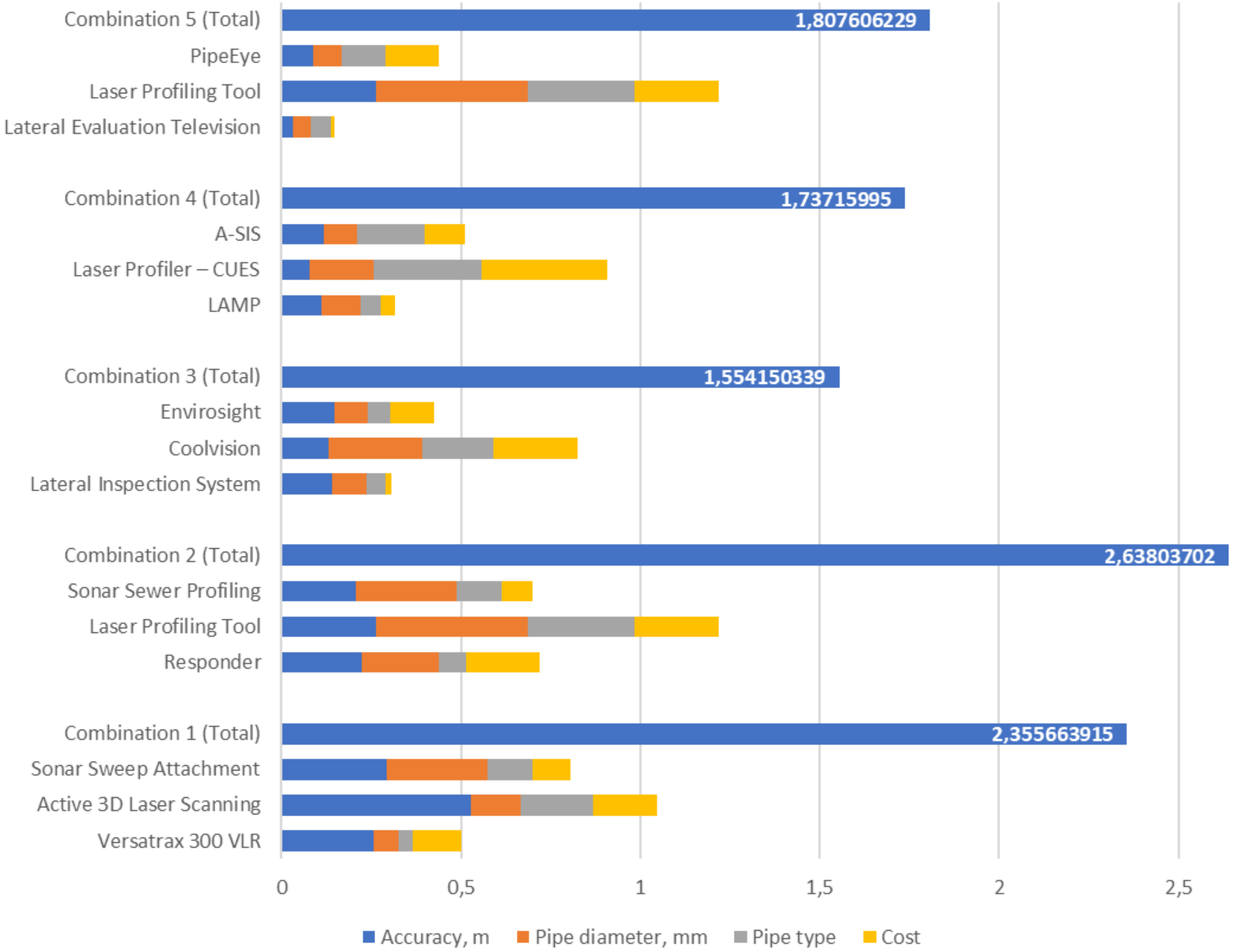


Figure 5 – Analysis of the technical and economic performance of the proposed combinations

As can be seen, the combination of solutions No. 2 has the highest score for each criterion - 2.638. The methods of this combination allow monitoring of large diameter pipes with relatively high measurement accuracy.

Combination No. 1 scored slightly lower than combination No. 2 – 2.355. The methods of this combination allow monitoring of medium and small diameter pipes with a relatively high degree of accuracy.

In general, the two combinations described above can be recommended as basic methods of sewer monitoring. Compared to the other suggested combinations, they have the best price/performance ratio.

In the case of gravity and wastewater lines, combination No. 1 is recommended because it is best suited for pipes of medium and small diameter (100 mm to 1300 mm). For main sewer lines the most suitable solution is combination No.2 (for pipes with a diameter of 900 mm to 3900 mm).

## 4. Conclusions

In this article, a multi-criteria analysis of methods for monitoring the internal condition of sewers was performed. As a result, the following conclusions can be made:

1. Many factors influence the choice of equipment: technical characteristics of the equipment itself; diameter of the pipeline; material of which the pipeline is made; availability of convenient access to the inspected area.

2. In some conditions, one method of monitoring is not enough to determine an accurate picture of the internal condition of the pipeline, so it is recommended to use a symbiosis of several devices, combined into a single system suitable for a particular case.

3. In general, the use of one or another symbiosis of solutions depends primarily on the amount of available funds on the balance of the city. Not always the most expensive methods can guarantee the quality of the final results. Often in the choice of one or another equipment it is necessary to find the optimal balance between price and quality.

4. After the analysis, two most optimal combinations of solutions for sewer monitoring were proposed.

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*Article*

# Features of using modified bitumen in road construction

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**Abstract**. The road industry is one of the important components of the economy. Quantitative and qualitative changes in the road industry require new technological approaches to road construction. The higher the transport-operational level of roads, the less the negative consequences of motorization are manifested. The condition of highways and their compliance with the international standards largely depends on the observance of construction technologies of road pavement, and the road pavement itself should have layers of strong, frost and temperature resistant monolithic materials which provide a long period of exploitation. The paper presents the peculiarities of the application of different types of modifiers for bitumen. It discusses their advantages and disadvantages, the importance of selecting the composition of the bituminous and mineral mixture. The use of crumb rubber as a modifier allows to realize the concept of a closed resource-saving technology of construction of roads. This approach will allow, on a technologically sound basis and taking into account the real needs of road construction materials, to restore the road network.
**Keywords:** road, construction, bitumen, modify, method.

## 1. Introduction

The productive work of road transport, the effective use of personal cars requires a developed network of landscaped roads. Therefore, the road industry faces the task of ensuring the competitiveness of the domestic transport and communication complex in the world market. In this regard, the quality of roads must meet international requirements. The main transport and operational indicators of the road: the strength of pavement and subgrade, smoothness and roughness of the road surface, tire traction with the road surface, wear resistance of the road surface, the serviceability of the pavement.

One of the promising ways to improve the quality of road to development, implementation in the practice of road construction of bitumen improved quality, based on new materials that can provide greater strength, durability of road surfaces, compared with the potential capabilities of petroleum bitumen. The application of high-quality binding materials, providing the prolongation of service life of road asphalt concrete pavement reduces the expenses for its repair and maintenance. In this regard, bitumen, as a gross product produced on a large scale, serves as the basis. The required level of quality, which determines the performance characteristics of asphalt concretes, is achieved by the introduction of various modifying components.

Bitumen perfectly resists the influence of various chemical reagents, is waterproof and gas-proof, resistant to different types of radiation and prolonged thermal influence [1–3]. It is these valuable qualities of bitumen combined with low cost and mass production have made them indispensable in many industries. Most of the existing methods of bitumen analysis are based on the difference in solubility of their components in a number of organic solvents. The methods of structure-group analysis, although with significant assumptions, give an idea of the averaged structure of bitumen substance molecules or its components. The first of such methods was the n-d-M method developed by Tadema for oils [4]. Subsequently, it was developed by Van Krevelen in a densimetric graphical method for structural analysis of coals and later found its development in a number of researchers [5]. There are also many other methods of analysis, which serve to study the composition of bitumen. For example, reverse and pyrolytic chromatography [6], mass spectroscopy.

When modifying bitumen [7-8], the following modifiers are distinguished: adhesion, diluting, plasticizing, structuring-plasticizing, adhesion-structuring, structuring, stabilizing, emulsifiers (Figure 1).

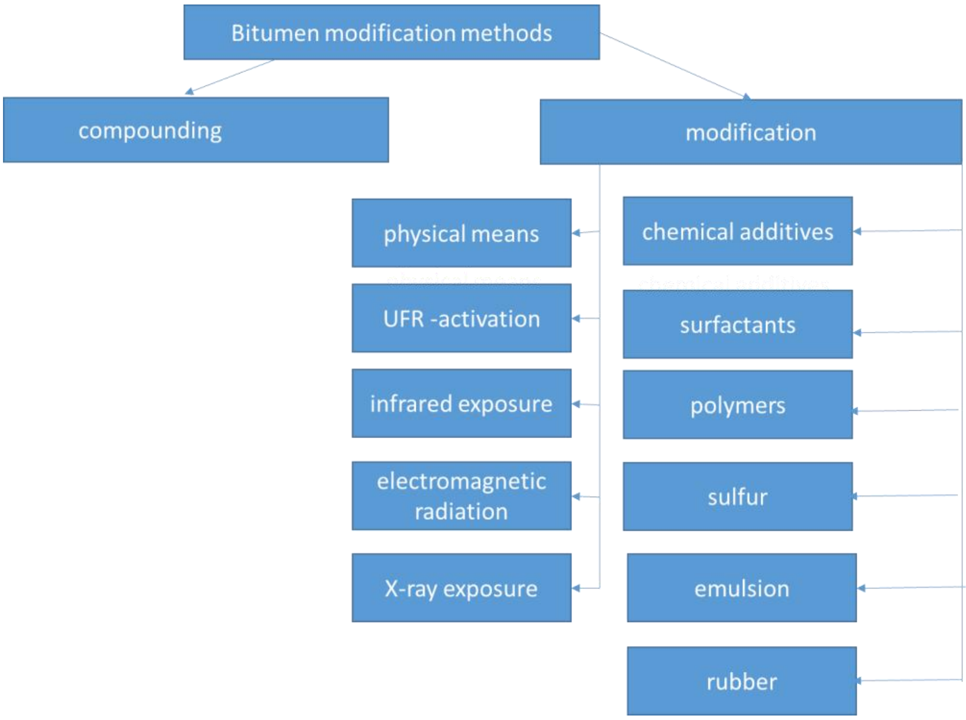


Figure 1 – Bitumen modification methods

Additives of adhesive nature are most widely used in the production of asphalt concrete [3-9]. The introduction of such additives can improve the wetting conditions of the bitumen surface of mineral materials, forming an absorption layer, facing the polar groups to the surface of the mineral material and the hydrocarbon part in the bitumen volume. This reduces the temperature and time to obtain a homogeneous mixture, and also significantly reduces the intensity of aging processes of bitumen. Also by using the surfactant at the interface of the mineral material-bitumen can form a monomolecular chemisorption layer that promotes the formation of a strong bond between them.

In the study of influence of sulfur additives on the performance properties of bitumen Eigenson and Fryazinov [10] observed the increase of expandability of bitumen produced by cracking of residues of high-paraffin oils, when treated with 1-10% sulfur. Improvement of properties of road bitumen can be achieved by the introduction of sulfur at temperatures from 110 to 170°. In order to improve durability of road bitumen Kikichi Eiichi offers additives of calcium sulfonate-sulfur compounds.

Generalizations of foreign experience in sulfur application for road construction were made by [11] and allowed to distinguish three directions of sulfur application:

- the introduction of sulfur into bitumen in relatively small quantities (up to 20%) to produce sulfur-bitumen binder in asphalt concrete production;
- introducing sulfur into bitumen in relatively large quantities (over 20%) shows itself as a kind of active filler in the binder;
- plasticization of sulfur with organic plasticizers with complete replacement of bitumen.

Sulfur acts similarly on high-molecular-weight hydrocarbons of oil fraction selenium. When oil is heated with selenium, selenohydrogen is released. At the same time with increasing temperature oil gradually transforms into a solid asphalt-like mass. It has been noted that more than 1% of selenium is chemically bound to the oil. Chlorine passing through bitumen layer causes dehydrogenation and polymerization reaction. Some of the chlorine binds with the compounds in the bitumen to form chlorinated organic compounds, and some is released as hydrogen chloride. Some researchers point out the higher activity of the most aromatized asphaltene part of bitumen in relation to chlorine.

Repeatedly emphasized in works [2] that the main disadvantage of asphalt concrete mixtures is a large consumption of bitumen and suggested to reduce the bitumen content in asphalt concrete mixtures by 40-50%. This led to obtaining asphalt concrete with porosity more than 10%. Also derived the factors that ensure the reduction of bitumen consumption:

- rational selection of the grain composition of the mineral part in order to provide a certain density of the mineral skeleton and framework monolith;
- mandatory content of mineral powder to increase the cohesion of bitumen, improve the adhesion of bitumen to the surface of mineral grains and partial filling of intergranular pores;
- reduction of the total specific surface of the mineral part by increasing the content of crushed stone, which reduces the consumption of bitumen to envelope the grains, to provide water resistance due to thicker films of bitumen on the mineral grains;
- maximum compaction of the substrate.

## 2. Methods and materials

Pavement is a multilayered structure that is designed to redistribute the pressure on the ground from the action of traffic loads and to ensure an increase in the service life and transport performance of highways. Pavement includes the following layers: pavement, subgrade and subgrade. Figure 2 shows the structural layers of road pavements [12].

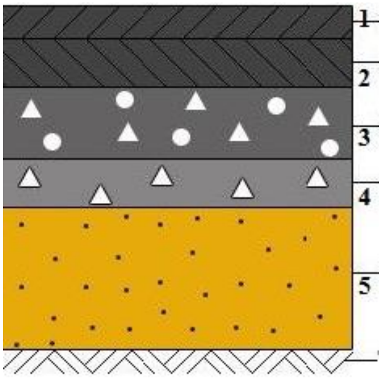


Figure 2 – Constructive layers of roadways [13]: 1 – top layer of asphalt; 2 – base or bottom layer of asphalt; 3 – rolling concrete; 4 – crushed stone; 5 – sand

For the use of innovative resource-saving road-building materials, the following measures are proposed:

– reuse man-made industrial materials;
– introduce new complex binders for road asphalt concrete;
– to monitor their effectiveness;
– introduce the needs accounting;
– create production bases for the development of innovative materials for road construction;
– use on pilot sites.

The problem of worn-out automobile tires and out-of-use rubber products is of great environmental and economic importance. The greatest potential for improving the properties of bituminous binders, has the crumb from general purpose rubber, including tire rubber. In this case, the problem with raw materials is completely removed. Compared with the use of expensive modifiers based on synthetic rubbers and elastomers, crumb rubber is a much cheaper product, which also makes the new technology one of the most economical ways to improve the properties of road bitumen [14].

Rubber is much more resistant to the oxidizing effects of air oxygen than rubber. It is highly resistant to water and salt solutions. In addition, an important feature of rubber crumb, especially tire crumb, is the presence in its composition of special chemicals-antioxidants and antioxidants [14]. Their presence can provide increased resistance of the binder to oxidative degradation in operating conditions. Slow down the aging processes at operating temperatures and under operating conditions. Will slow down the aging processes at operating temperatures and under conditions of warming to a high technological temperature. In the rubber separation module, rubber pieces 100-150 mm in size enter the pelletizer (Figure 2), where they are crushed to 10-15 mm, separation of metal and partially textile cord. Free metal is removed by magnetic separators, and the textile cord by textile removal system. The crumb rubber cleaned from the metal cord goes to the storage hopper.The processing technology is based on mechanical shredding of tires into small pieces with subsequent mechanical separation of metal and textile cords and obtaining rubber "granulate" with a size from 0.5 mm to 5.0 mm by shear shredding. The technological scheme of the fine grinding unit is shown in the Figure 3.

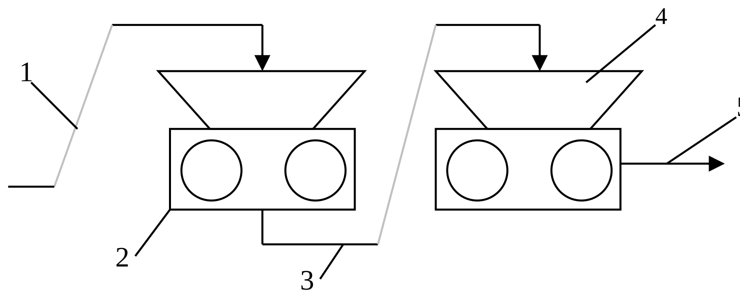


Figure 3 – Technological scheme of the rubber shredding module: 1, 3, 5 – belt conveyors; 2 – double-rotor knife crusher 1; 4 – double-rotor knife crusher 2

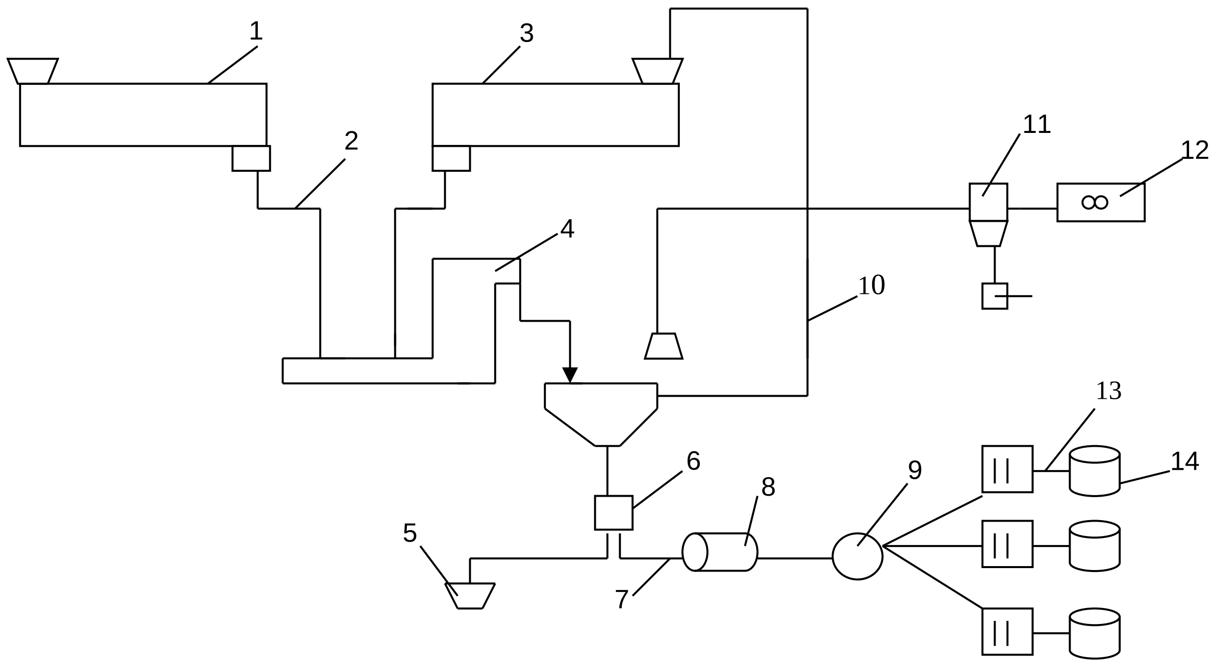


Figure 4 – Technological scheme of the fine grinding unit: 1 – grinder of coarse grinding; 2, 7, 10, 13 – conveyors; 3 – fine grinding grinder; 4 – cooler conveyor; 5, 6 – magnetic separator, 8 – fine grinder; 9 – vibrating screen; 11 – cyclone; 12 – fan; 14 – fulfilment racks

The study [15] proposed the use of waste packaging "Tetra Pak", the use of which provides durability and increase the brightness of the color of asphalt concrete pavement. The properties of the secondary polymer, which includes aluminum foil particles, provide protection of the polymer component from premature aging associated with photochemical degradation. Tetra Pak" packaging consists of the following elements shown in Figure 5.

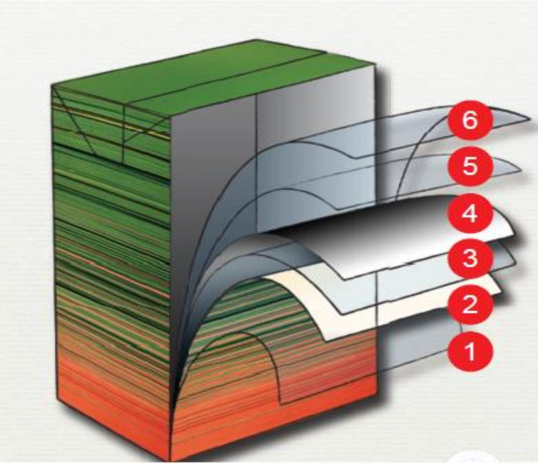


Figure 5 – Tetra Pak packaging elements [16]: 1 – outer layer of polyethylene; 2 – cardboard backing; 3 – polyethylene layer; 4 – aluminum foil; 5 – one bonding layer of polyethylene; 6 – special polyethylene layer

The technological process for the preparation of the mixture for the road bed includes the following basic operations:

– preparation of mineral materials (supply and pre-dosing, drying and heating to the desired temperature, fractional dosing);
– feeding of cold mineral powder and stabilizing additive, their dosing before introduction to the mixer;
– bitumen preparation (heating and fed, if necessary, from the bitumen storage to the asphalt melting plant, evaporating the moisture contained in it and heating to a working temperature, if necessary, the introduction of surfactants and other improving additives, dosing before fed into the mixer's mixer);
– "Dry" mixing of hot mineral materials with cold mineral powder and modifying additive
– mixing of mineral materials with bitumen and unloading of the prepared asphalt-concrete mixture into the storage bin or dump trucks.

The addition of polymers in terms of the possibility of increasing the operational properties of the pavement, namely, expanding the operating temperature range of the bituminous binder. This polymer increases the resistance of roads to both rutting in summer and cracking in winter. This property is especially valuable in climatic conditions, where due to significant seasonal temperature fluctuations conventional bitumen without additives often cannot ensure the durability of the pavement.

According to the classification, the experimental site to be built, is located in the built-up part of Nur-Sultan, confined to the right bank above the floodplain valley of the river Ishim.

The street is an important planning axis of the city in the direction north - south, providing transport links right bank of the city with the main highways' districts, overlooking the bridges over the river Ishim to the new administrative center of the capital on the left bank.

In the geological area involved: middle to Upper Quaternary deposits of clayey deluvial proglovial formations uncovered by all wells to a depth of 0.8 - 4.5 m; weathering crust formation on siltstones uncovered by separate wells to a depth of 0.8 to 4.5 m; from the surface the sediment overlaps the soil-vegetation layer.

Ground waters at the area to be constructed are uncovered by the wells №3.5-13 at the depth of 0.9 to 2.2 m, are confined to the sandy interlayers of clay formations. Established level of groundwater in all wells from 0.75 to 2.0 m.

Within the existing carriageway right-of-way, there is a temporary 0.2- 0.36-thick pavement, represented by artificially compacted timber soil.

Soils, within the spread of the active zone of the working layer (to a depth of 1.5 m), throughout the road to be built are porous.

Under the normative location of ground waters do not affect and moistening of soils of the working layer in the pre-frost period:

- in loams light, sandy, dusty 184+150 = 334 cm;
- in sandy loam 225+100=325cm;
- in clays, heavy loams 184+200=384 cm [39].

Ground waters are moderately saline, salinity 3191 mg/dm³. According to salt composition, they are sulfate-chloride and sodium-depth, have carbonic acid aggression to concrete of W 4 grade, medium to reinforcement of reinforced concrete structure at periodic wetting.

The pavement is designed with asphalt-concrete surface on cement-concrete base. The thickness of layers is calculated taking into account the category of the street, perspective intensity of traffic, the service life of the construction of hydrological and construction properties of the underlying soils, the availability of local road-building materials. Rubber crumb was used as a bitumen modifier.

Experimental study of bituminous composition presented in Table 1.

Table 1 – The bituminous composition

| Incoming Components | Quantity, kg | Composition |
|---|---|---|
| Bitumen 90/130 | 350 | Bitumen 90/130 |
| H2SO4 | 15 | H2SO4 |
| Surfactant oxyethylated alkylphenol | 5 | Surfactant oxyethylated alkylphenol |
| Mineral powder fraction 0.07mm | 25 | Mineral powder fraction 0.07mm |
| Rubber crumb (tire) fraction 0.5 mm | 25 | Rubber crumb (tire) fraction 0.5 mm |

Technology of preparation of the composition includes the following procedures: oil bitumen is raised to a temperature of 180 ° C, then a solution of sulfo-oxidizer, which can be sulfuric acid H2SO4, is introduced in portions discretely or using a dispenser calibrated to the flow per unit time for 20 minutes and stirred, after stopping the acid, then the surfactant - oxyethylated alkylphenol R-C6H4O-(CH2CH2)n-CH2CH2OH is introduced into the mixture and blended for 10 minutes at 180 °C. Then mineral powder and rubber granules are introduced in portions and blended for 45 minutes until complete distribution and homogeneity.

Organic binders used in road construction must have a set of properties that ensure high quality and standard service life of pavements and foundations built on the basis of these binders [17]:

- strong adhesion to the surface of mineral materials - water resistance and frost resistance of asphalt concrete;
- plasticity at low temperatures - cracking resistance of pavement in winter time;
- strength and heat resistance at high temperatures - shear stability of pavement in hot summer days;
- resistance to aging (preservation of properties in time) during technological processing (evaporation, heating, mixing with mineral materials) and during operation.

Comparative performance of modified bitumen is shown in the Table 2.

Table 2 – Comparison of the characteristics of bitumen binder samples

| Property values | Values of indicators of binder samples | |
|---|---|---|
| | Bitumen 90/130 | Bitumen 90/130 with rubber crumb |
| Needle penetration depth | | |
| 25°C | 100 | 100 |
| 0°C | 28 | 28 |
| Plasticity interval, °C | 69 | 81 |
| Stretch ability at 0°C, cm | 3.5 | 6 |

## 3. Results and Discussion

By creating in the mixture of bitumen and crumb rubber the conditions for specific step polymerization in the mode of "live" chains, the rubber particles, which absorbed a part of the maltene fraction of bitumen, are combined both between themselves and with high-molecular bitumen components in a heterogeneous, reinforcing, polymeric spatial structure by chemical bonds. Due to this structure, the binder becomes elastic enough for operational purposes. The stability of the entire dispersed heterogeneous system and the high and long-term adhesion of the binder are ensured by polar molecular groups introduced in large quantities into the chemical structure of the material during its preparation [14]. On the one hand, these groups increase the polarity of asphaltenes, which stabilizes the heterogeneous structure of the binder; on the other hand, they sharply increase the density of intermolecular (associative) bonds, which in this case are responsible for the adhesion of the material. Adhesion properties are inherent to the material itself of the composite rubber-bitumen binder. The rubber is also resistant to the oxidizing effects of air oxygen. It is highly resistant to water and salt solutions. In addition, an important feature of the rubber crumb, especially tire, is the presence in its composition of special chemicals - antioxidants and antistatic agents. Their presence can provide increased resistance of the binder to oxidative degradation in service conditions. It will slow down the aging processes at operating temperatures and under conditions of heating to high technological temperature.

Chemical substances involved in the polymerization process can create conditions under which it is possible to almost completely localize mobile unpaired conductivity electrons in colloidal bitumen particles and achieve their stabilization.

Coagulation and precipitation of crystals of the asphaltene fraction and carbonaceous graphite-like formations during aging in this case is kinetically and spherically difficult and practically does not occur. As well as gelation, which often happens during bitumen modification with rubbers and elastomers of SBS type, when the equilibrium and stability of colloidal state is broken because of the competition of polar molecules of asphaltenes and polymer in relation to the liquid dispersion phase. Rubber does not decompose and dissolve, but binds to the bitumen components by strong, but quite mobile chemical bonds.

## 4. Conclusions

In the interaction of bitumen and additives with high positive potential and a large number of adsorption centers in the form of cations an intensive transfer of bitumen from the bulk state to the state of diffusion-solvation shells occurs. During this structuring relatively strong physical and chemisorption bonds are formed, which firmly hold bitumen films on the surface of the additive particles.

When combining bitumen with additives, a microstructure is formed, which reflects the quantitative ratio, location and interaction of the binder and the most active component of bitumen. As shown by the study of methods of preparation of bitumens with polymer modifiers provide, as a rule, increased process temperature and intensive mixing of components. Bitumens soften when heated, and thermoplastic polymers, regardless of whether they are crystalline or amorphous, go into a viscous state. The use of modifiers solves the problem of using recycled construction materials and industrial waste.

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*Article*

# Performance of maturity method for estimation of concrete strength based on cubic specimens

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**Abstract**. To assess the condition of the structures of buildings and structures, a comprehensive analysis of the factors affecting their performance characteristics - concrete strength, protective layer, and rebar diameter, thermal conductivity and moisture content of concrete, adhesion of protective and facing coatings, frost resistance and water resistance of concrete - is required. However, with all the variety of monitored parameters the control of concrete strength has a special place because when assessing the condition of the structure the determining factor is the compliance of the actual strength of concrete to the design requirements. This paper presents studies on the determination of concrete strength based on modern technology, wireless sensor as well as instrumentation IPS. These methods are particularly effective in the case of non-linear relationships between different system parameters, as in the behavior of concrete parameters. They can also provide rapid measurements by continuously monitoring the internal condition of the reinforced concrete structure. The found graduation dependences and determination coefficients equal to 0.9234 and 0.9702 justify the convergence of the results of the two methods of strength gain control.
**Keywords:** strength gain, sensor, concrete, construction, destructive method, non-destructive method.

## 1. Introduction

Construction is a rapidly growing sector of the economy, undergoing constant changes aimed at improving the quality, operating conditions and reducing the final cost of products. Development of new materials, equipment, and technologies of their production allows to get products with high characteristics of strength, durability, and wear resistance, which gives a reflection not only on the reliability and safety of operation of construction objects but also affects the cost, making construction investments the most attractive from an economic point of view. One of the effective ways to reduce costs is to optimize the construction process. For example, by optimizing formwork removal cycles, it is possible to save time, reduce overhead costs and labor costs [1-2]. Timely detection of the moment of maturity of a reinforced concrete structure and the decision to load it allows for additional profits by reducing the construction time [3]. The method of determining the moment of maturity, which is based on non-destructive methods of controlling the strength of concrete, plays a huge role. Of the many methods for determining the qualitative indicators of nondestructive testing methods are shocking pulse, ultrasonic, temperature-strength [4–7].

The advantages of the shock pulse method are mobility and ease of application. The ultrasonic method works on the principle of sound transmission, experimentally obtained by the dependence of the indicators of the devices on the strength of the material [8]. These devices are used not only to determine the strength but also to determine the timing of setting and hardening, as well as the quality of the reinforcing elements. For instance, this method is well disclosed in [1], which describes the most common methods for compressive strength prediction. The authors confirm this with experimental data obtained after testing concrete specimens using non-destructive testing methods. Similar work was performed in [9] where the results show the difference between predicted and actual strength and the average deviation of the test results was 0.18%. Other authors in their paper [10-11], apply non-destructive testing methods to find the strength of samples taken from the existing concrete structure and then the same samples are crushed on a press in the laboratory. In any case, all non-direct methods of strength control are indirect and, therefore, may have measurement errors. Today, one of the promising methods of nondestructive testing, which is still little used in our construction market, is the temperature-strength method. This method allows you to determine the quality of the material depending on the temperature changes in the process of hydration of the concrete mixture. Sensor sensors register the quality indicators with the smallest error, and also allow controlling the hydration process of concrete from the beginning of hardening up to 28 days and even during the entire life cycle of the concrete structure, if necessary [12-13]. In this regard, the relevance of this article lies in the use of the above-mentioned sensors of domestic production, and a series of field and laboratory tests with widely used concrete on construction sites in the city gives an understanding of its temperature-strength behavior.

## 2. Methods and materials

The study included several stages:

1. Preparation of large samples (LS) of standard composition, size more than 50x50x50, with the installation of temperature sensors (Figure 1a). Carrying out operational control of the strength of large samples (road slab) by ultrasound. Determination of the temperature strength by the method [14].

2. Preparation of small samples (SS) of the same composition, cubic shape of size 15x15x15 with the installation of temperature sensors (Figure 1b).

Measurements of SS and LS: continuous temperature measurement; daily strength measurement by non-destructive method (ultrasonic method); control measurement of the compressive strength of selected cylinders on 3, 7, 14, 21, and 28 days (3 samples each).

3. Determination of the functional dependencies of SS and LS to adjust the dependency.


a) LS b) SS

Figure 1 – Sample preparation

The strength tests of the samples by the non-destructive testing method are performed by the shock-pulse device IPS MG-4 [15]. This method (Figure 2) belongs to the express method, however, it is an indirect estimation of strength characteristics of structures, it requires the establishment of calibration dependence with the destructive method [16], performed on the test press. For a general visualization of the trend of concrete strength gain of a production batch of a particular factory composition, Figure 3 shows the concrete strength gain plots for all 17 samples. The trend of strength gain, in general, is proportional, the width of the range bounded by the edge curves is relatively the same, indicating a close relationship between the individual measurement values and the minimal assumption of random variables.


Figure 2 – Operational control of the strength of large samples (road slab) by ultrasound method

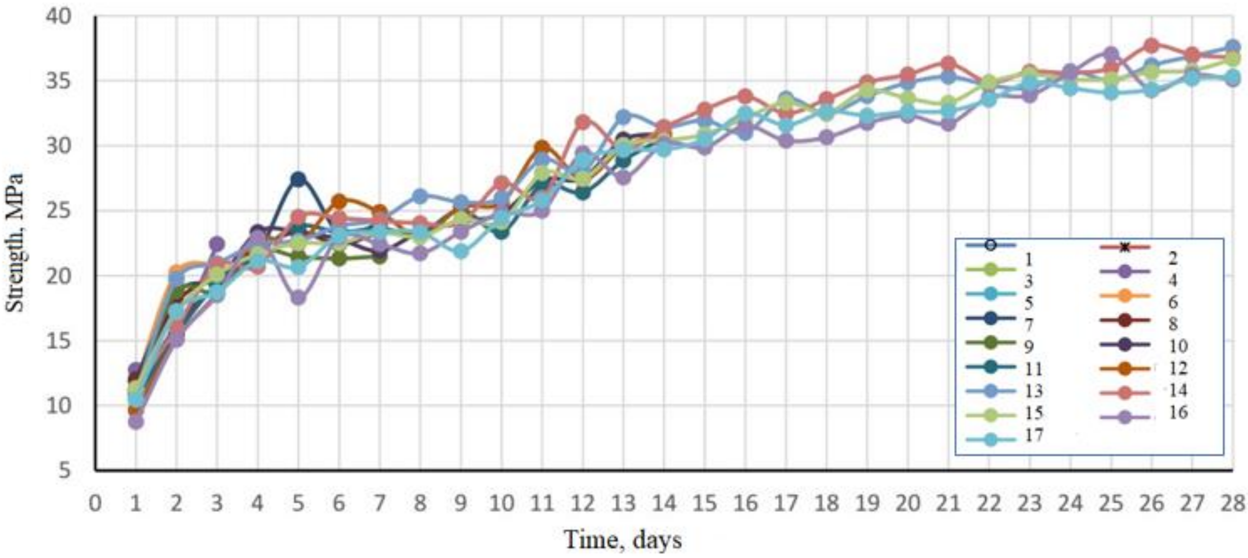


Figure 3 – Graphs of strength for 17 specimens

A self-developed measuring device (Figure 4) consisting of the following components was used to measure the temperature mode of concrete hardening:

– 4 temperature sensors type DS18B20;

– 2 lithium-ion batteries, rated 3.7V and 3000mAh capacity;

– atmega328p microcontroller (this microprocessor possessing 8-bit AVR microcontroller with 32KB programmable Flash memory is relatively cheap compared to other energy-efficient microcontrollers, as well as has a compact TQFP32 package).

– 8GB memory card for storing records for 28 days;

– time module of DS3231 type, so that the device periodically wakes up and polls the sensors connected to it.

This device is capable of performing the following functions: to measure the temperature with an accuracy of not more than + / -1º C; has guaranteed performance of 1 month, in operating mode, the microcontroller on an electronic board interrogates the temperature sensor connected through a cable inside the concrete with a given frequency and records the data on the SD card.

Registration of data on temperature changes, processing, and analysis of research results were carried out according to the methodology regulated by [14]. Before the measurements, the temperature sensors were calibrated to a maximum error of ±1°C. Temperature measurements were taken at intervals of every 30 minutes.


a) Sensor


b) Data collection device

Figure 4 – Concrete strength control sensor

According to [14] the concrete maturity function is used to calculate the temperature-time factor:

$$M(t) = \sum(T_a - T_0)\Delta t \quad (1)$$

M(t) – the temperature-time factor at age t, degree-days, or degree-hours;
$\Delta t$ – time interval, days or hours;
$T_a$ – average concrete temperature during the time interval, $\Delta t$, °C;
$T_0$ – datum temperature, °C.

The process of drilling core samples of reinforced concrete road slabs to control the cylindrical compressive strength is shown in Figure 5.

Figure 5 – Process of drilling core samples

## 4. Results and Discussion

The result of the ASTM formula based on Eq. (1), is a strength graph of the cylindrical concrete specimens compression results, i.e. Figure 6 shows graphs of strength gain vs. time of concrete curing (age of concrete).

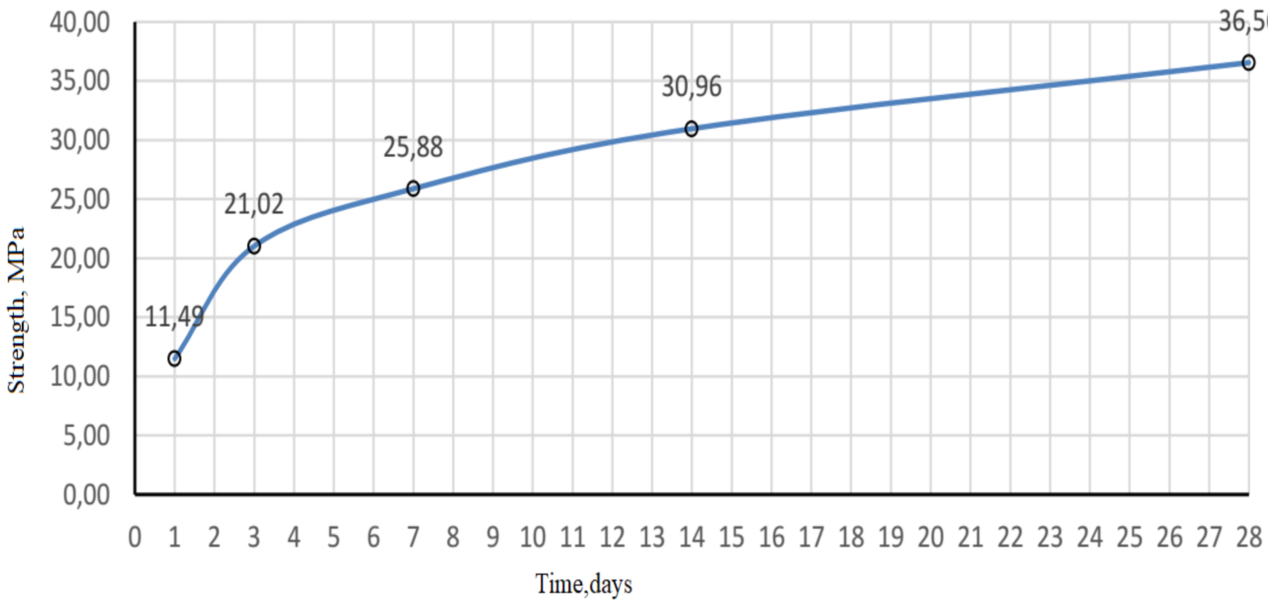


Figure 6 – Concrete strength gain graph

In general, the tendency of strength gain is classical, relatively uniform strength gain over time is observed, the change of partial strength values is smooth, without sharp jumps.

According to the definition in [15], the found graduation dependence in Figure 7 is the relationship between the indirect strength characteristic and the compressive strength of the concrete specimen. As can be seen in the graph, the formula of analytical dependence is expressed as a linear function and its coefficient of determination with finding the trend line. The coefficient of determination equal to 0.9234 close to 1 says about reliability of the found graduation dependence.

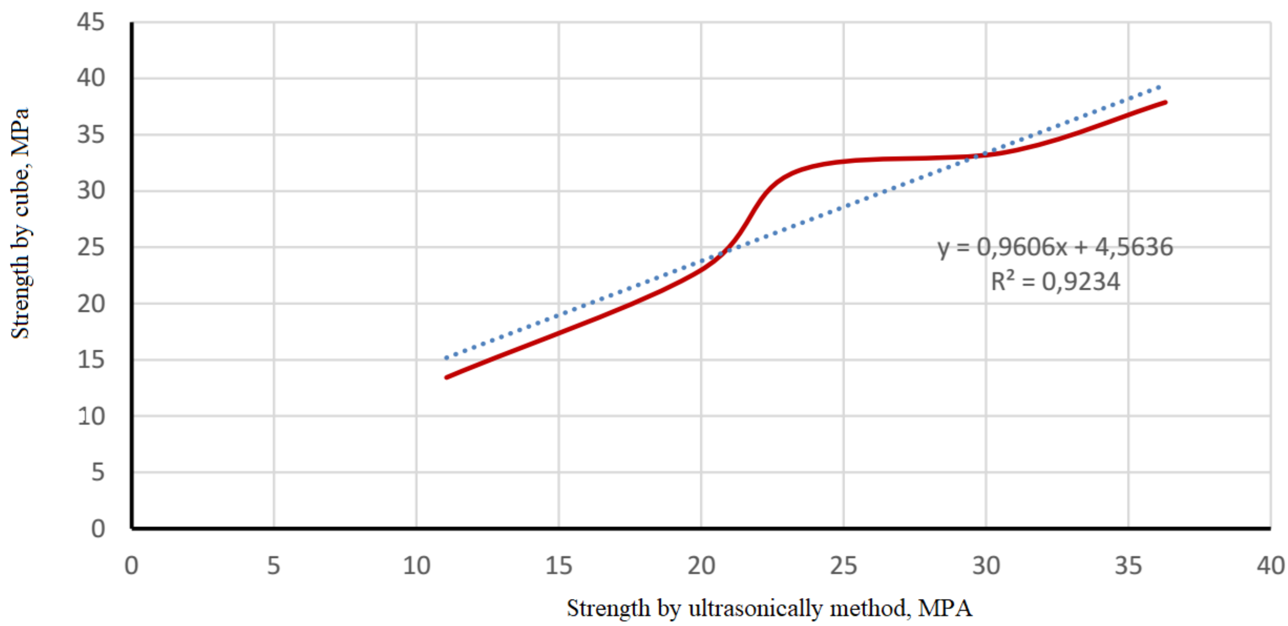


Figure 7 – Graduation relation

Then a graduation relationship between the temperature-strength control methods was found in a similar way of calculation. The plotted graph in Figure 8 is comparable to the standard graph of concrete strength gain, which is based on the normative-safe time of strength gain, where ideally at 30°C the optimal normative strength gain in 11 days should exceed the design strength and reach up to 97% of the projected strength. In this case, the logarithmic function describes the resulting trend line better than anything else, and the coefficient of determination is close to 1.

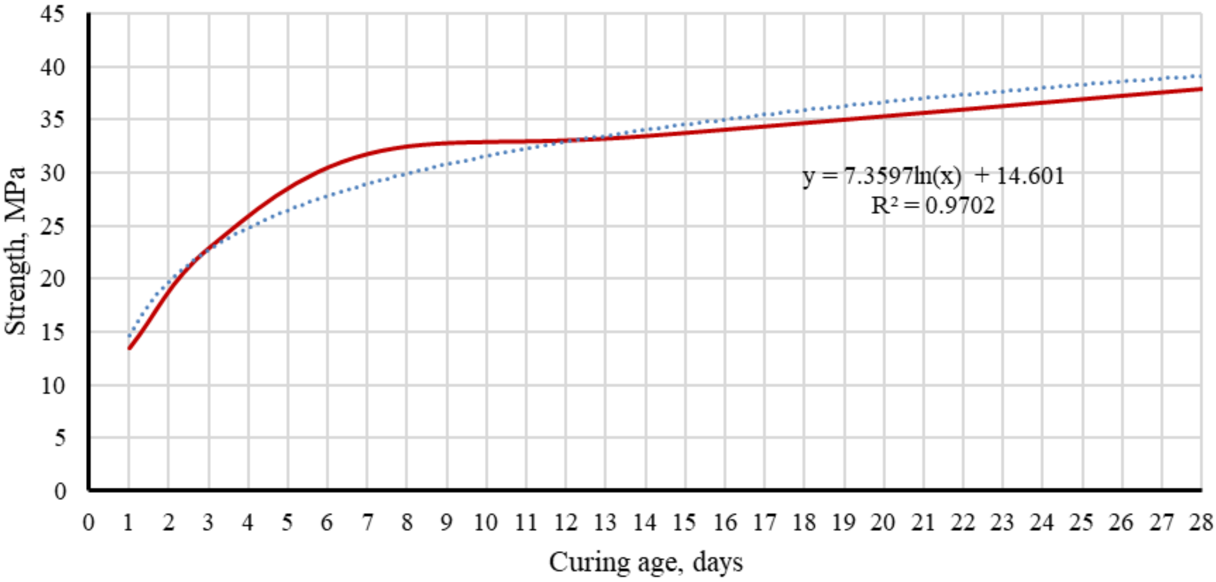


Figure 8 – Strength gain chart by maturity method

Thus, the results obtained in the course of the study substantiate the relevance of the use of temperature-strength control of concrete strength gain.

## 5. Conclusions

The strength of concrete is an important parameter by which to ensure the durability of a building or structure. The results showed sufficient convergence of the results, which confirms their reliability. These methods of determining the strength of concrete are used on construction sites around the world. The study showed that the temperature factor is fundamental in the formation of the required properties of the concrete structure. Also, a special feature was using of cubic specimens for research.

Whereas according to the standard, cylindrical samples of at least 15 pieces are used. Thus, the study can be identified certain techniques and objectives, the methods used in them (methods of temperature-strength control of concrete), which, and led to the effectiveness of the results.

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# House stock forecasting based on population growth. A case of Nur-Sultan City, Kazakhstan

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**Abstract.** Since the beginning of 2020, the "Nurly Zher" housing and communal development program for 2020-2025 came into force in Kazakhstan. Within the framework of this program there are tasks of capital repair and renovation of the housing stock. The passportization of the housing stock was adopted as one of the measures to solve this problem. At the same time there are some discrepancies in the statistical data between the Committee of Statistics of the Ministry of National Economy of the RK and Local Executive Authorities with a simultaneous increase in the volume of housing construction. This article examines the volume of residential buildings commissioned in Nur-Sultan depending on changes in the population of the city. It is assumed that as the number of people in the city will increase the volume of housing stock. To understand the volume of housing in Nur-Sultan in the period of the program "Nurly Zher" in the article gives a forecast increase in commissioned housing by 62% by 2025, compared with the value at the end of 2020. Based on the data obtained it is concluded that for a more effective solution to the problem of capital repair and renovation of housing stock an alternative approach or tool is needed.
**Keywords:** model for forecasting, housing stock, renovation of dilapidated housing, complete overhaul, housing programs.

## 1. Introduction

Over the past few years, various government documents of the Republic of Kazakhstan (RK) addressed the issue of housing. In particular, in the message of the Head of State to the people of Kazakhstan on October 5, 2018 it was mentioned the need to build rental housing for socially vulnerable populations [1]. On September 2, 2019, the Nationwide Action Plan on the implementation of the Address of the Head of State to the People of Kazakhstan [2] included the issue of allocation of budgetary credits for the modernization and repair of the housing stock of Kazakhstan. These and other documents can be attributed to the prerequisites for the development of the housing and communal development program "Nurly zher" for 2020-2025. This program was approved by the decree On Approval of the State Program of Housing and Communal Development "Nurly Zher" for 2020-2025 (hereinafter - the Program), which came into force on 1 January 2020 [3]. The program is a logical continuation of the previous State program of housing "Nurly Zher", adopted on June 22, 2018 [4]. The program is aimed at combining measures of state support in matters of housing construction, provision of housing for citizens, modernization and development. The document states that "the unified housing and housing and communal policy will provide a comprehensive approach to the development of a comfortable living environment of settlements, taking into account the trends of urbanization, population growth" of the housing and communal system.

It is especially worth highlighting one of the tasks of the Program "Capital repair and renovation of the housing stock", for the implementation of which the following indicators are supposed to be measured for the period of the Program:

− Number of repaired apartment buildings - measured in units.

− Coverage of the assessment of the technical condition of the housing stock - measured as a percentage.

As measures to solve this problem, the Program adopted:

− Passportization of the housing stock;

− Overhaul of the repaired apartment buildings;

− Promotion of energy saving in the sphere of housing and communal services;

− Renovation of the housing stock.

Passportization is understood here as the so-called inventory of the repaired apartment buildings, which will collect data and form a register of the number of houses with their technical characteristics and equipment. On the basis of this data emergency housing will be identified, subject to demolition or major repairs.

As regards the renovation of the housing stock it is envisaged to comprehensively reconstruct the "old" neighbourhoods of the cities through the demolition of emergency (dilapidated) housing. The objects subject to renovation will be determined on the basis of the wear and tear of the building structures and their compliance with the operational requirements for each individual building.

However, the same document in the SWOT analysis (or SWOT matrix, where S - strengths, W - weaknesses, O - opportunities, T - threats) in the factors "Weaknesses" highlighted item "Discrepancy data on the number of housings between the Committee of Statistics of the Ministry of National Economy of Kazakhstan and the Local Executive Bodies", while the factors "Strengths" has a point "Continuous growth in housing construction and public financing" [3].

Considering the trend of the development of Nur-Sultan, it is impossible not to pay attention to the growth of the population. In the period from 1998 to 2020, the population grew from 326.9 thousand people to 1.18 million people (data are taken at the end of the period), that is, the number of people living in the capital, increased by more than 3.5 times over the past 23 years (Figure 1) [5].

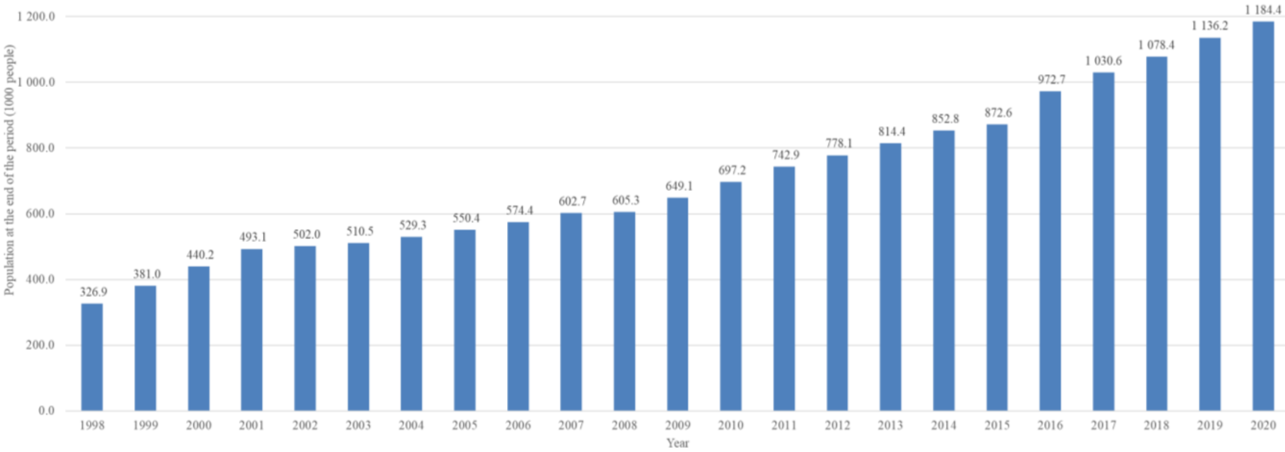


Figure 1 – Population of Nur-Sultan at the end of the period, thousand people

In addition, a similar situation is noticeable in social security during the same period [5]:

− the number of hospital organizations increased from 15 to 37 units (almost 2.5 times);

− the number of schools increased from 48 to 133 units (more than 2.5 times);

− the number of higher educational institutions increased from 7 to 15 units (more than 2,5 times).

One of the target indicators of the Program is to increase the annual volume of housing commissioned and the provision of housing – 26 m$^2$ per resident. In 2020, a total of 15.3 million m$^2$

of housing was commissioned across Kazakhstan, of which 3 million m$^2$ was built only in the city of Nur-Sultan. At the same time, the total area of the housing stock in 2020 was 24300700 m$^2$. If we consider the period from 1998 to 2020, there is also a positive trend of growth in the volume of housing (Figure 2) [5]. It is noteworthy that this volume increased by 22.5 times.

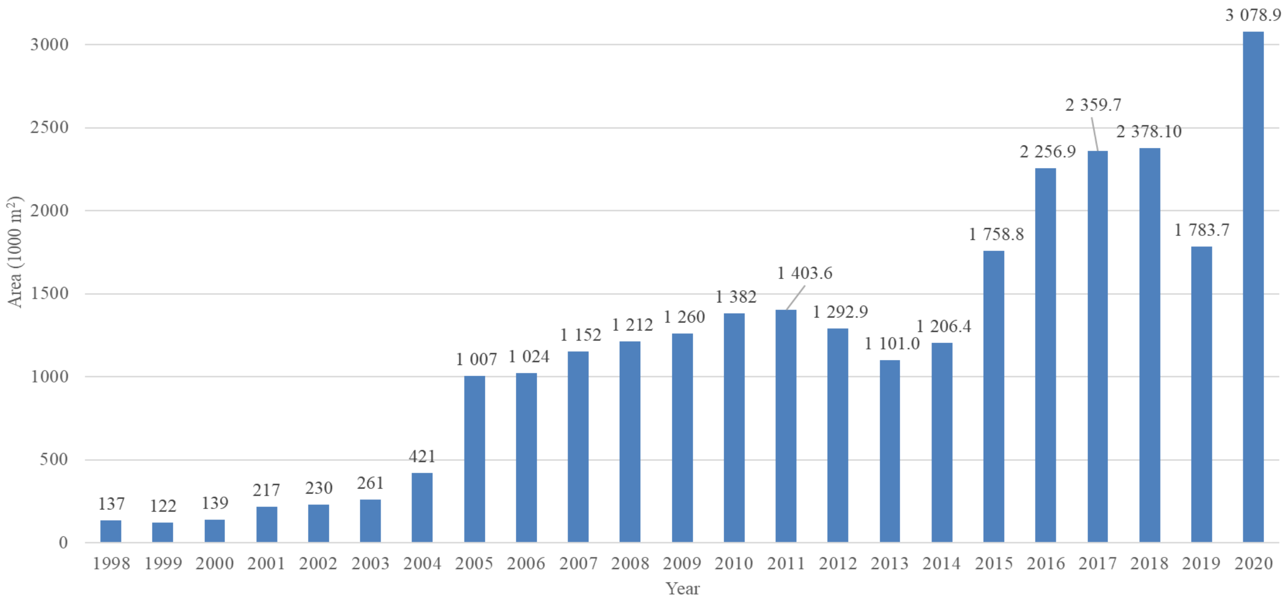


Figure 2 – Commissioning of residential buildings in Nur-Sultan, thousand m$^2$

Provision of the population with housing in Nur-Sultan during the period from 1998 to 2020 increased by 1.7 times from 17.5 m$^2$ to 30.5 m$^2$ [5], which means that in 2020 provision of the population with housing in the capital exceeded the target national value by 4.5 m$^2$. From all the above it is possible to trace the regularity of growth of the population with the growth of commissioned residential buildings and growth of provision of the population with housing.

In order to implement the Program and fulfil one of its objectives "Capital repairs and renovation of the housing stock" it is necessary to understand the current size of the housing stock and in addition it is necessary to have an idea of its further development during the program implementation period (2020-2025).

The purpose of this article is to analyze and forecast statistical data on the volume of the Nur-Sultan real estate fund on the basis of data from the Bureau of National Statistics of the Agency for Strategic Planning and Reforms of Kazakhstan [5–7].

## 2. Methods

As part of the analysis of the housing stock of the city of Nur-Sultan compared 2 indicators, namely the total area of annually commissioned residential buildings and the population of the city at the end of the period. Graphs of changes in these two indicators for the period from 1998 to 2020 were constructed. In this graph on the x-axis indicated years, and the y-axis values of the number in thousand people and area in thousand square meters (Figure 3).

In order to predict changes in the indicators we need, we used the method of approximation, in which the so-called trend line is constructed. There are various parameters for constructing a trend line: exponential, linear, logarithmic, polynomial and power. All of them are based on forming equations with a certain value of approximation reliability – $R^2$. This number is the coefficient of determination of the equation of the trend line and shows how close the values of the trend line are to the actual data. The closer this value is to 1, the more reliable the trend line is.

After determining the equation of the trend line, y is calculated by substituting instead of x the following values after the period in question.

In this paper, we first determined the trend line for the graph of the population against the graph of the area of residential buildings put into service. In determining a more accurate trend line, polynomial trend lines of degree 2, 3, 4, 5 and 6 were analyzed to obtain more reliable data. It was the polynomial trend line that had the $R^2$ value closest to 1.

After the obtained values of the number for each degree were compared with the current value on November 1, 2021 from the database of the Bureau of National Statistics of the Agency for Strategic Planning and Reforms of the Republic of Kazakhstan. Thus, the closest to reality trend line was selected and the forecast of population change until 2025 was formed.

Next, we plotted the change in the area of residential buildings commissioned in relation to the change in the population, where along the x-axis we took the values of the population and along the y-axis - the values of the area.

Then, by analogy with the population projection, a trend line was determined for the area of commissioned residential buildings, and then the projected values up to 2025 were calculated, where the projected population values were substituted for the x values in the resulting trend line equation.

## 3. Results and Discussion

The graph below (Figure 3) shows the changes in the two indicators in question from 1998 to 2020. As can be seen, the annual increase in the area of residential buildings commissioned is accompanied by a positive increase in the population. From this we can assume that the total area of housing commissioned depends on the population.

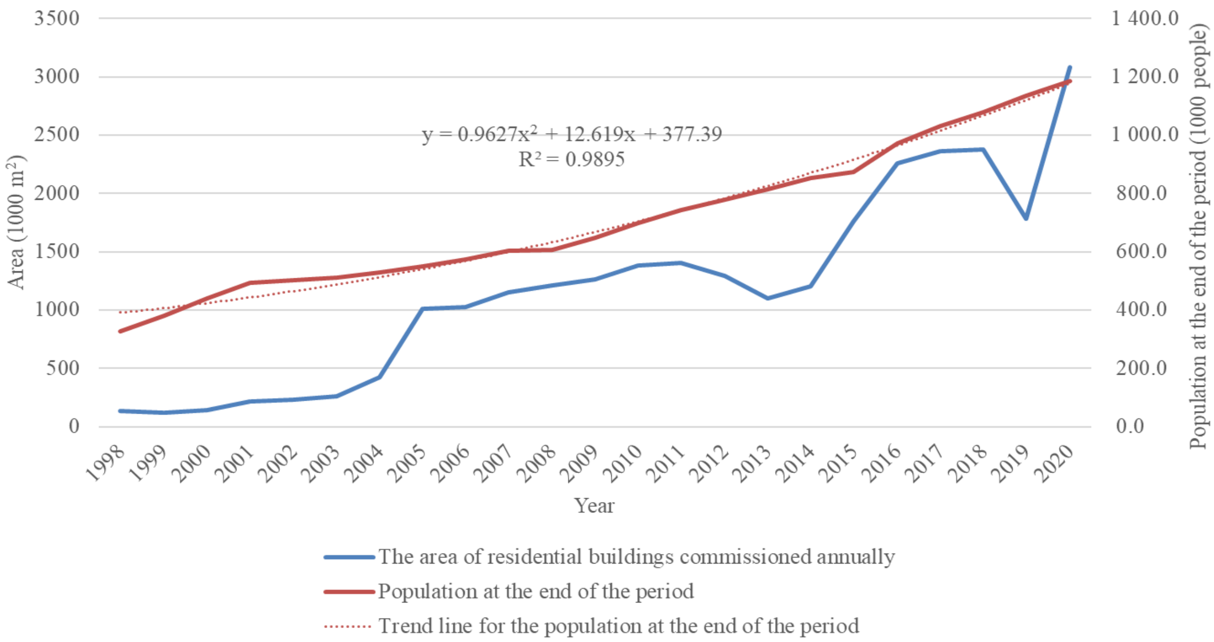


Figure 3 – Relationship between the total area of commissioned residential buildings and population in Nur-Sultan 1998-2020

Figure 3 also shows the forecast of population growth over the next 5 years using a trend line.

In this case, a polynomial trend line of degree 2 was chosen for the population indicator and equation 1 was defined for it:

$$y = 0.9627x^2 + 12.619x + 377.39 \tag{1}$$

where $R^2$ = 0.9895, at which the prediction results were as close to reality as possible, taking into account the data at the time of writing.

Further, to calculate the projected values of the indicator for the next 5 years, the values of periods are substituted into the obtained equation, where 1998 is period 1, 2021 is period 24 (x = 24), 2022 is period 25 (x = 25), etc. The obtained results of the population forecast are shown in Table 1.

Table 1 – Population Forecast Nur-Sultan 2021-2025

| Indicators | The Year | | | | |
|---|---|---|---|---|---|
| | 2021 | 2022 | 2023 | 2024 | 2025 |
| Population, thousand people | 1234.8 | 1294.6 | 1356.3 | 1419.9 | 1485.5 |

Now consider the dependence of the total area of housing commissioned on the population indicator. Figure 4 shows the resulting graph.

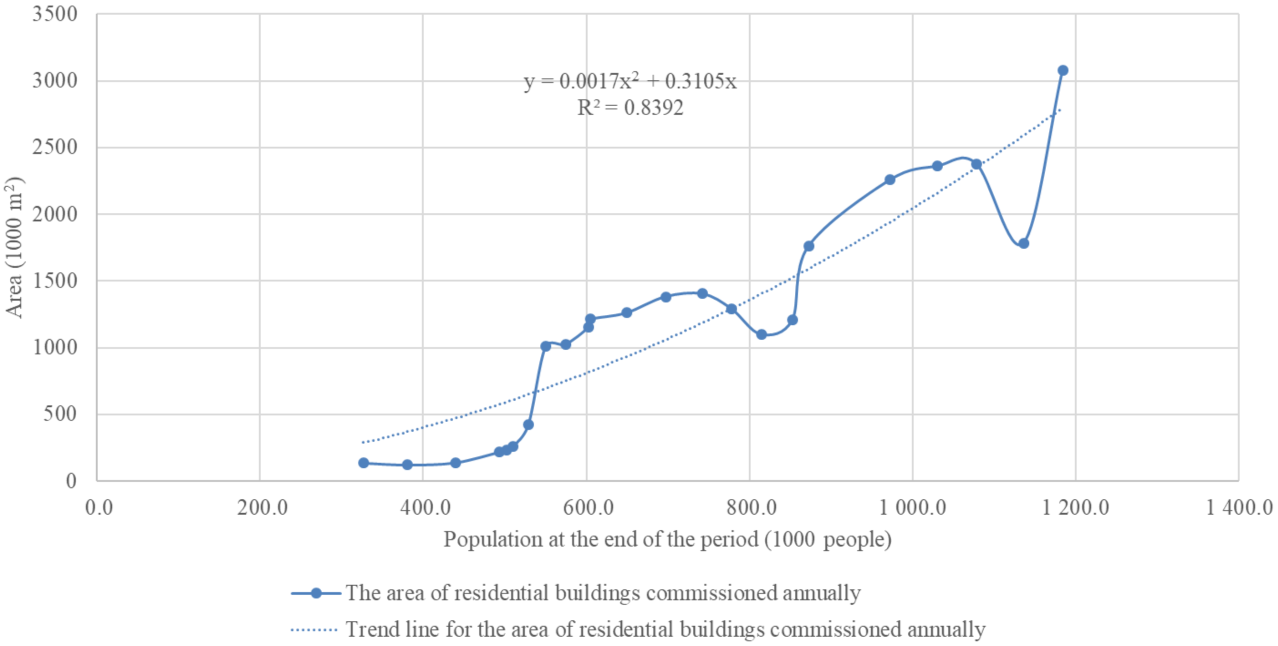


Figure 4 – The total area of commissioned residential buildings depending on changes in the population

The resulting trend line for the total area of commissioned residential buildings is described by equation 2:

$$y = 0.0017x^2 + 0.3105x \quad (2)$$

where $R^2 = 0.8392$, at which the results of the forecast were as close to reality, taking into account the data at the time of writing.

Using the resulting equation, we calculated the projected values of the total area of housing to be commissioned, see Table 2.

Table 2 – Forecast of the total commissioned residential buildings area in Nur-Sultan for 2021-2025

| Indicators | The Year | | | | |
|---|---|---|---|---|---|
| | 2021 | 2022 | 2023 | 2024 | 2025 |
| Commissioning of residential buildings, thous. $m^2$ | 2975.3 | 3250.9 | 3548.2 | 3868.3 | 4212.5 |

As can be seen from the forecast increase in the area of annually commissioned residential buildings will continue with the growth of the population in Nur-Sultan (Table 1 and Table 2). Already by 2025, with a population of almost 1.5 million people, the volume of commissioned residential buildings will reach 4.2 million $m^2$ per year. This is 37% higher than in 2020. At the same time, the total volume of housing stock by 2025 is expected to increase by 17.8 million $m^2$.

## 4. Conclusions

Returning to the task " Capital repair and renovation of the housing stock" of the Program, the forecast clearly shows that every year the volume of housing fund of Nur-Sultan will grow. Taking into consideration that in 2020 there were 24300.7 thousand m$^2$ of the total floor area of the housing stock in the city and in the next 5 years the projected increase is 17855.3 thousand m$^2$, that is the housing stock will increase by 73%. Such increase in the volume of housing stock will have a significant impact on the solution of this problem.

Taking into account all of the above there is a need to form a more effective approach to the issue of capital repair and renovation of housing stock

The results of this analysis will be used in the work to create a tool that will be used to facilitate decision-making on the demolition or reconstruction of dilapidated housing in Nur-Sultan.

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# Effect of modifiers and mineral additives from industrial waste on the quality of aerated concrete products

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**Abstract.** The given article is devoted to research of influence of polymer modifiers and mineral additives on quality of composite aerated concrete products. When selecting the composition of composite aerated concrete local raw materials and components were used: portland cement, sand, aluminum powder, polyvinyl acetate, fly ash, post-alcoholic bard and whey of milk. Preliminary polyvinyl acetate was combined with binder mixing water at a temperature above 55ºC to obtain a readily soluble polymer emulsion. Dispersion was carried out with a rotary-pulsation apparatus at a pressure of 0.5-1.0 MPa and a rotor speed of ~1200 rpm. In the same apparatus the complex modifier was produced. The offered technology of production of a complex modifier seems to be the most effective for composite aerated concrete. It made it possible to reduce water absorption and capillary suction of composite aerated concrete by an average of 25% and 45%, respectively. Moreover, different combinations of fly ash, polymer and modifier made it possible to achieve optimal values of thermal conductivity, compressive strength and frost resistance of composite aerated concrete.
**Keywords:** composite aerated concrete, polymers, modifiers, emulsion, strength, frost resistance.

## 1. Introduction

The use of polymeric additives in cement materials can improve the whole complex of their properties: durability, tensile strength, bonding with other materials. There are two technological methods of using polymeric additives - their introduction into the composition of construction mixtures and impregnation of products [1].

For successful design of polymer-mineral compositions it is necessary to know the basic material science regulations and the dependences of physical and mechanical properties of materials on the composition, which are reflected in the theory of composite construction materials (CCM). CCMs are artificial materials of complex structures, composed of two or more monomaterials with sharply different properties, as a result of which they acquire a set of new properties that are not inherent to the original materials. From the engineering point of view, it is most important to study the overall structure of composites on two levels: the microstructure inherent in binders and the macrostructure characteristic of the composite as a whole [2].

The most effective, from the positions of more complete involvement of both cement and polymer, is the introduction of small additives of polymer into compositions at P/C=0.15-0.20 ratio. This is due to the fact that for polymer-cement systems with P/C = 0.2, the most desirable structure of the inorganic binder strengthened in the defective points of the polymer binder. At higher doses of polymer hydration of cement has a limited nature, a significant part of it performs the role of microfillers, and the strength of the structure is determined mainly by the polymer component [3].

Polymers are quite widely used in products based on cement binders, in particular known additives of latexes, organosilicon compounds, fluates, polyvinyl acetate (PVA) and other polymer cement compositions [4]. In the technical literature, the application of polymer binder in the production of composite cellular concrete is a relatively new and insufficiently well-studied area.

This study is aimed at solving the problem of effective combination of the polymeric component of PVA with mineral binder in the manufacture of composite aerated concrete. A number of issues of interaction of water-soluble polymer and cement binder were taken into account. The work proceeded from the position that the basic materials for the preparation of composite aerated concrete should be mostly of Kazakhstan origin.

## 2. Materials and methods

The following raw materials were used in the study:

1) Natural quartz-feldspar sands from quarries in Karaganda were used as a silica component, which meets the requirements of [5]. According to chemical analysis, the sand contains alkaline oxides ($Na_2O$, $K_2O$) and significant amounts of $Al_2O_3$, indicating the presence of feldspar minerals. At the same time, the quantitative content of $K_2O$ is slightly higher than $Na_2O$, indicating the predominance of potassium feldspar in it. The small losses during calcination indicate the insignificant presence of calcium carbonates in the sand, which is confirmed by the very minor release of carbon dioxide when the sand is exposed to hydrochloric acid. In the thermographic study of sand on the differential thermal curve, in addition to the effect of modification transformation of quartz (at 575 ºC), a small effect associated with the release of adsorption water (at 115 ºC) is noted. Weakly expressed endothermic effect at about 800 ºC is apparently caused by dehydration of micaceous minerals and dissociation of carbonates. On the basis of data of the analysis the specified sand on structure - polymineral, and on a classification of L. Fadeev, belongs to quartz-feldspar. The sands were milled in a ball mill to a specific surface of 2500-3000 $cm^2/g$ by the device PSH-2. The content in the sand of gravel with a grain size of 5-10 mm is 5-15 %. Grain composition of the total residue on the sieve with a mesh No. 0.63 - from 30 to 45% inclusive. The content of grains with grain size less than 0.16 mm - not more than 15 %. The grain size modulus is class 2 medium and sand group 2.0 to 2.5 inclusively. The content of dust and clay particles - not more than 3 %. The content of clay in clumps - not more than 0,25 %. Bulk density when wet - 1230 $kg/m^3$. Bulk density in dry state - 1355 $kg/m^3$.

2) Portland cement of Karaganda cement plant grade 400 with the following characteristics was used as a binder [6]: bulk density - 1095 $kg/m^3$; specific surface - 3150 $cm^2/g$; residue on sieve No. 008 - 8.8 %; normal density of cement dough - 27.1 %; ultimate strength at the age of 28 days - 5.4 MPa. Setting time of cement were in the intervals: the beginning - from 3 hours 45 min to 3 hours 57 min, the end - from 4 h 20 min to 6 h 50 min.

3) Aluminum powder with the following characteristics: aluminum content - more than 86 %, hiding power in water - not less than 7000 $cm^2/g$, particle size - 35-75 microns, gas emission rate for 4 minutes - 40-60 %, residue on the sieve No. 008 - 2.9 %.

4) Water-soluble polymer polyvinyl acetate (PVA) with the following characteristics, meeting the requirements of [7]: Mass fraction of dry residue - not less than 30 %; dynamic viscosity of the dispersion - 2.0-15.0 mPa-s; pH level - 3.3...6.0; frost resistance - not frost-proof; deposition when diluted - not more than 1 %; adhesive capacity - not less than 300 kgf/cm; plasticizer is present.

5) Fly ash from wastes of burnt coals in TPPs of Ekibastuz coal basin with the following characteristics, corresponding to [8]: mineralogical composition of ash - feldspar 5-10 %, glass phase 60-65 %, amorphized clay particles 10-15 %, corundum 5-10 %; calcite, hydrogarnet, mullite - 3 %. Content of $SiO_2 + Al_2O_3 + Fe_2O_3$ - about 70 %, $SO_3$ content - 3.2-3.5 %. The ash passed the tests on uniformity of volume change. Specific surface of the tested ashes was within 2800-3000 $cm^2/g$. Chemical analysis of fly ash showed the following: humidity - 15,09 %; loss of weight on ignition - 5,82 %; content of silicon oxide ($SiO_2$) - 58,69 %; content of calcium oxide (CaO) - 3,48 %; content of magnesium oxide (MgO) - 2,42 %; content of sulphur trioxide ($SO_3$) - 1,82 %.

6) Post-alcoholic bard (PAB) and whey of milk.

To prepare PVA for the production of composite aerated concrete it is necessary to make the polymer into a readily soluble emulsion by combining it with the mixing water of the cement binder. The emulsion is required for saponification of the aluminum powder surface, which improves the contact area with the cement binder and maximize the chemical reaction. During the preparation of the emulsion, the water temperature must be at least 55 °C. This will ensure effective mixing of all components. It is also very important to consider the amount of all components in the preparation of the emulsion. The quality of the prepared emulsion can be influenced by the method of dispersion (emulsification), the temperature mode of combining in connection with which the temperature mode from 55 °C was defined. Such temperature allows together with surface-active substances (surfactants) of PVA polymer to effectively remove the paraffin layer from the surface of aluminum powder.

Rotary-pulsation apparatus (RPA) was used as a dispersant. Peculiarities of operation of RPA-type apparatuses are described in the works of A.L. Tomashpolsky and others. The main factors that cause the emulsification process in the dispersant of RPA type are pressure (0,5-1,0 MPa) and the centrifugal effect (rotor speed ~1200 rpm). These factors cause the occurrence of high-frequency vibrations in the RPA, accompanied by cavitation and other hydrodynamic processes. This method, as practice has shown, allows obtaining high-quality emulsion. Accepted composition of polymer emulsion and scheme of its preparation are shown in Table 1 and in Figure 1.

Table 1 – Polymer emulsion composition

| Components | Content, % |
|---|---|
| Water-soluble PVA polymer | 40 |
| Water | 20 |
| Aluminum powder | 40 |

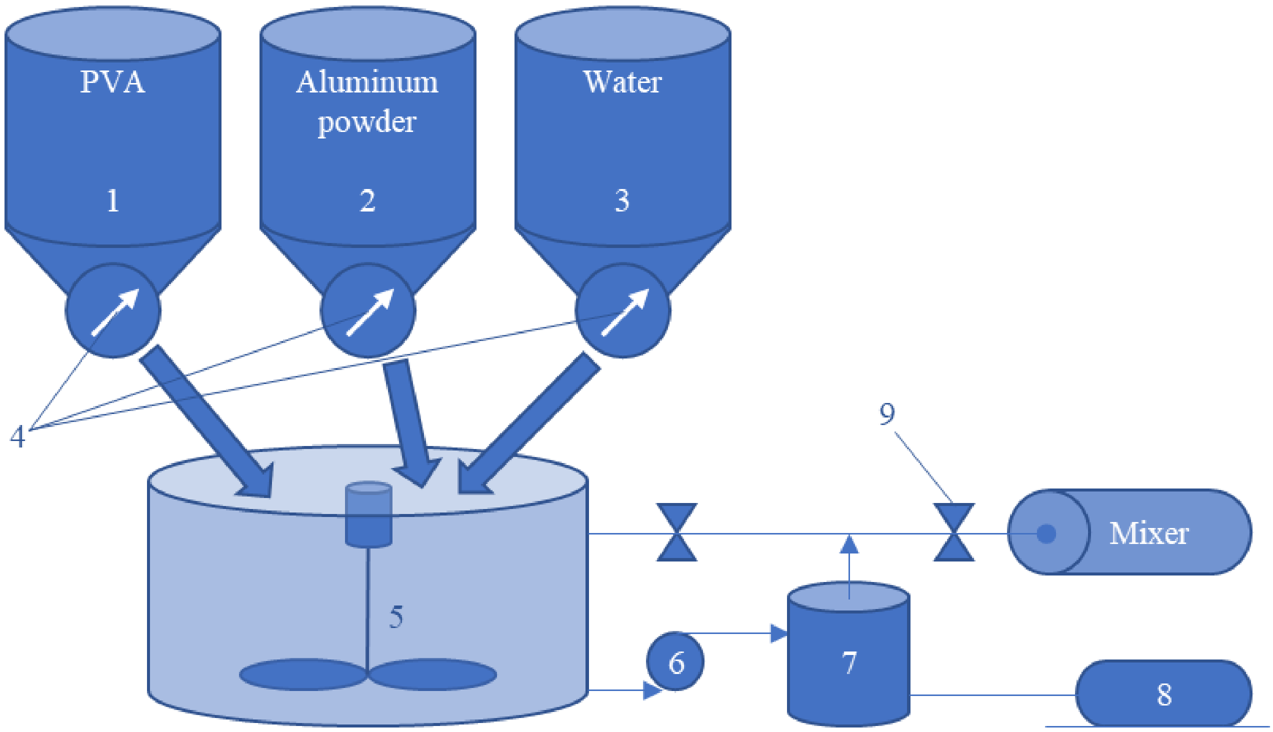


Figure 1 – Scheme of emulsion preparation: 1, 3 – thermally heated PVA and water hoppers; 4 – dispensers; 5 – heatable mixer; 6 – pump; 7 – RPA; 8 – electric motor; 9 – valve.

The effective emulsion was prepared according to the recommendations given in the works of V.G. Batrakov, G.I. Gorchakov, F.M. Ivanov and M.I. Higirovich.

In this case, the polymeric component of the emulsion, in addition to the role of the second binder, acts as a “saponifier” – wetting agent of aluminum powder grains, neutralizing the hydrophobic properties of the paraffin layer on the gas-forming grains. It is known that a fatty layer is created during the production of aluminum powder and protects it from oxidation and dusting and thus provides a synergistic effect. The experience of combining a polymer emulsion with aluminum powder is highlighted in [9] (Figure 2).

Thus, by obtaining an effective polymer emulsion with saponified and ready-to-use aluminum powder, a number of advantages are defined:

- Convenience in the production of aerated concrete products: the dusting of aluminum powder affects the health of the manufacturer's plant personnel.
- The amount of gas emitted from the chemical reaction with cement binder increases.
- The polymer component allows the aluminum powder to be evenly distributed throughout the structure of the aerated concrete mortar.

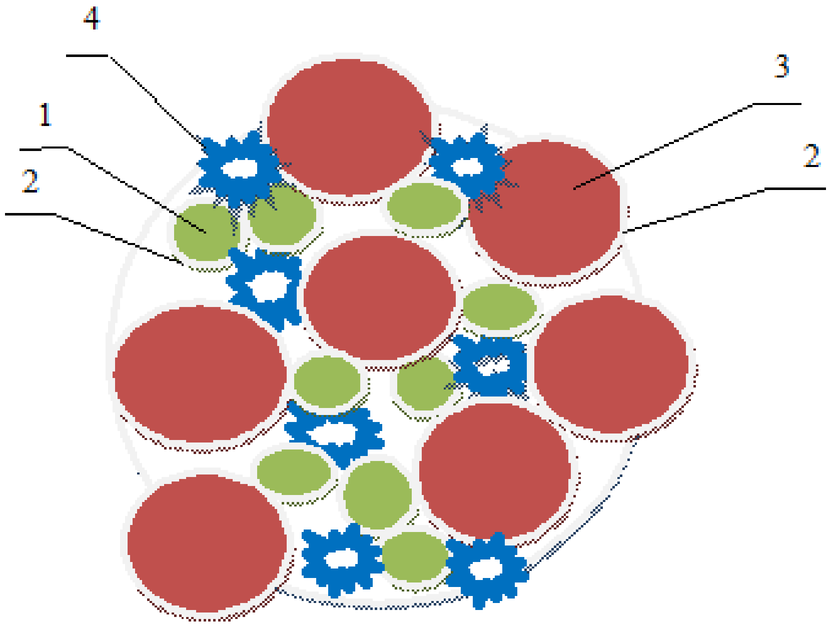


Figure 2 – Component distribution scheme of composite aerated concrete using an effective emulsion of polymer and gas-forming agent: 1 – cement binder particles; 2 – polymer binder; 3 – sand; 4 – aluminum powder.

One of the disadvantages of aerated concrete products are unsatisfactory indicators of residual moisture, water absorption and capillary leakage, as well as low frost resistance. Solving these problems will fundamentally revise the performance properties of the material. In this connection, this study considers the possibilities of the complex application of hydrophilic-hydrophobic additives, which improve the physical-mechanical and chemical properties of composite aerated concrete. Reduced water absorption of composite aerated concrete cannot be ensured by increasing the dosage of polymer emulsion. However, if we consider the possibility of using complex modifiers from industrial wastes, it is quite possible to significantly increase the quality indicators within a manageable framework.

Secondary raw materials and industrial wastes were considered as components for the complex modifier. The main plasticizing component used in the study is post-alcoholic bard (PAB), hydrophobic component is whey of milk, tracer is fly ash of dry selection. The complex application of the above-mentioned components makes it possible to significantly increase the qualitative indicators of the composite aerated concrete. Figure 3 considers the method of preparation of a complex modifier, the main feature of which is the synergistic effect. When combining all components in RPA, a dispersed emulsion is obtained, which enhances the existing characteristics of all components. When combining fly ash with plasticizing components its water absorption is reduced, which positively affects the strength of the composite aerated concrete. And the use of the whey of milk in combination with the fly ash stabilizes its hydrogen index, bringing it closer to the neutral environment.

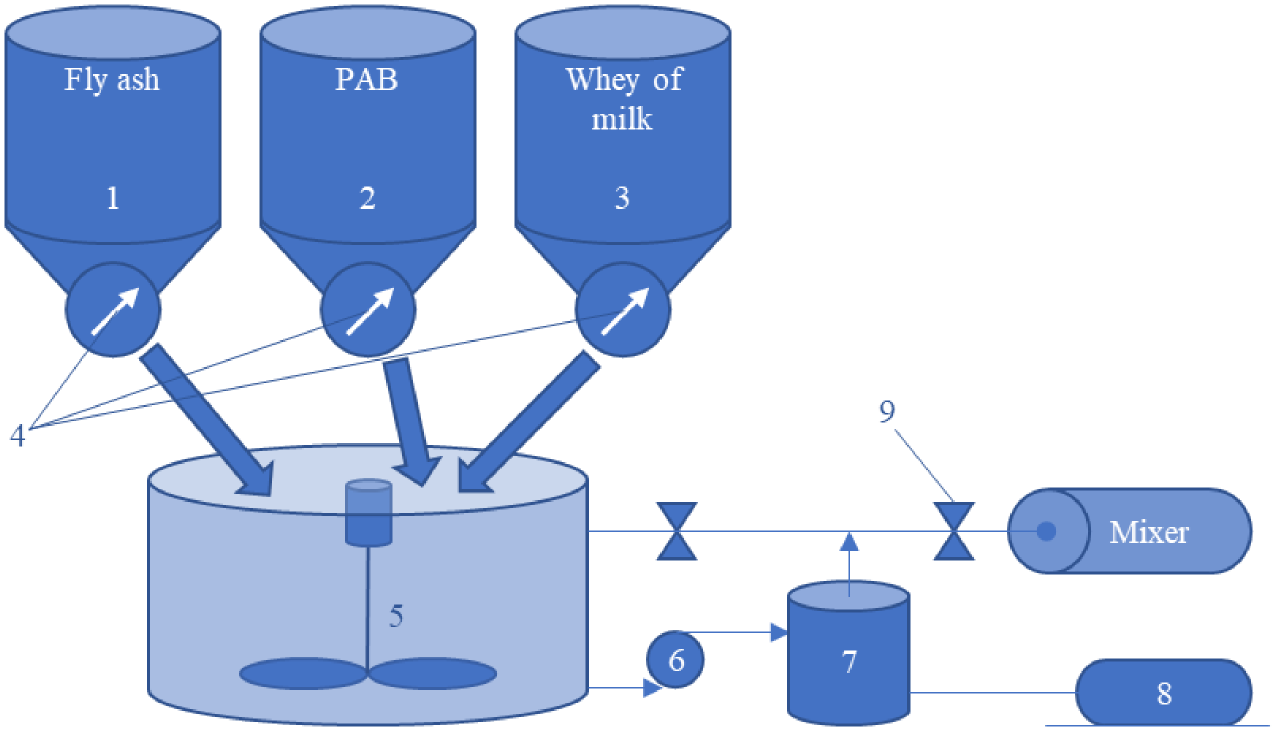


Figure 3 – Scheme of preparation of complex modifier: 4 – dispensers; 5 – mixer; 6 – pump; 7 – RPA; 8 – electric motor; 9 – valve.

The accepted composition of the dispersed emulsion of complex modifier is shown in Table 2 below.

Table 2 – Disperse emulsion composition

| Components | Content, % |
|---|---|
| PAB | 35 |
| Fly ash of dry selection | 30 |
| Whey of milk | 35 |

Thus, the proposed production technology of complex modifier seems to be the most effective for composite aerated concrete. The porosity of aerated concrete determines its sorptive moisture capacity and deformability, as well as largely determines the durability of aerated concrete during operation. The operating properties of cellular concrete largely depend on the structural characteristics of the material (integral and differential porosity) and the pore space geometry features. To indirectly assess the durability of cellular concrete, as well as other masonry materials, are used various indicators of their physical structure, such as density, water absorption and degree of pore filling with water, the rate of capillary suction. A characteristic that reflects the ability of moisture to migrate in the pore space of cellular concrete is capillary absorption. The capillary absorption of water by modified aerated concrete and aerated concrete without additives was determined by the well-known method, and the results are presented below.

**3. Results and Discussion**

The test results of aerated concrete for water absorption and capillary leakage are shown in Figure 4 below.

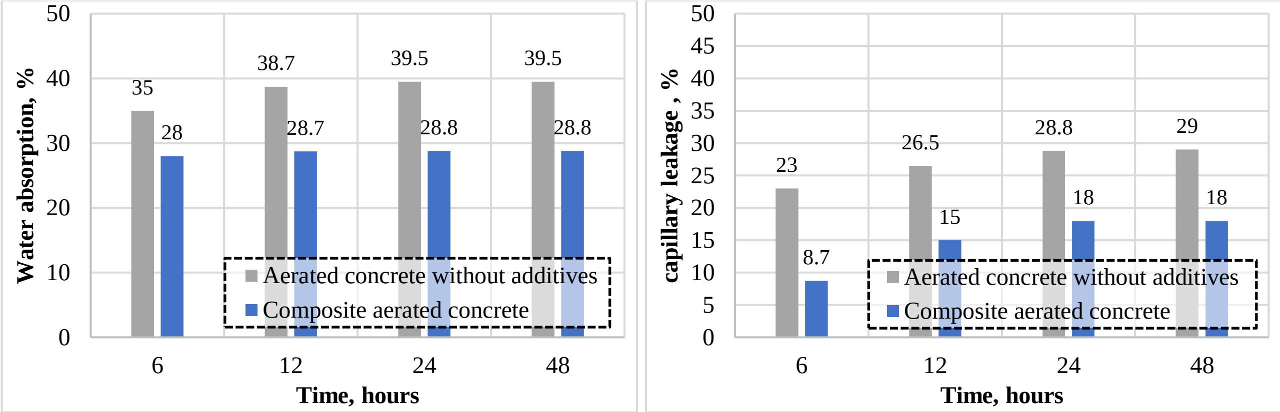


Figure 4 – Kinetics of water absorption and capillary leakage in gas concrete with an average density of 600 kg/m$^3$

The experimental results show that the composite aerated concrete has improved characteristics of water absorption and capillary leakage: water absorption and capillary leakage of composite aerated concrete are on average 25% and 45% lower, respectively. This is explained not only by the hydrophobic properties of the polymer component and complex modifiers in the aerated concrete, but also by the formation of relatively closed pores in it for the most part and the smaller diameter of capillary pores. Information about the positive effect of relatively closed pores on the hydrophysical properties of cellular concrete are given in the works of A.R. Akhmetov [10]. The work showed that the capillary absorption of water under vacuum was less in aerated concrete, the differential porosity of which was in the range from 1.5 to 300 microns. Thus, the study of water absorption and capillary suction confirmed the results obtained by A.R. Akhmetov about the low permeability of cement stone with pores smaller than 300 microns. Hydrophobization further reduces water absorption and capillary absorption of water by aerated concrete. The carried out comparative analysis allows to draw a conclusion about the best hydrophysical properties of modified aerated concrete, which during the operation of buildings constructed of these materials provide high thermal comfort indoors.

It is known that during the operation of buildings, especially in winter, in an environment with high humidity, when the insulation is located on the outer side of the wall there is a gradual accumulation of moisture, which does not have time to air out. As a result, the thermal conductivity of the insulation increases and the heat transfer resistance of the wall envelope decreases. Therefore, when operating buildings in an environment with high humidity in the winter, insulation in terms of technology is more effective to place it indoors.

Studies showed that the composite aerated concrete on ash has a reduced thermal conductivity. The results of the research are presented in Table 3.

Table 3 – Thermal conductivity of aerated concrete with different aggregates

| Type of aerated concrete | Grade of concrete by average density | Thermal conductivity coefficient, W/m-K | | |
|---|---|---|---|---|
| | | on sand | composite on ash | on ash |
| Structural and thermal insulation | 600 | 0.14 | 0.12 | 0.12 |
| | 700 | 0.17 | 0.15 | 0.15 |
| | 800 | 0.22 | 0.17 | 0.18 |
| | 900 | 0.24 | 0.20 | 0.21 |

The introduction of ash into aerated concrete leads to a decrease in its strength, which negatively affects the quality of structural and thermal insulation and structural aerated concrete products. Studies on the effect of complex modifiers on the construction and technical properties of composite aerated concrete have been conducted. Complex modifier contains fly ash of dry selection as a finely dispersed filler. We made in the standard forms and drilled composite aerated concrete specimens with complex modifiers and without additives. The obtained results of the compression test are shown in Figure 5 (left). Also tests on frost resistance of similar samples results of researches are shown in Figure 5 (right).

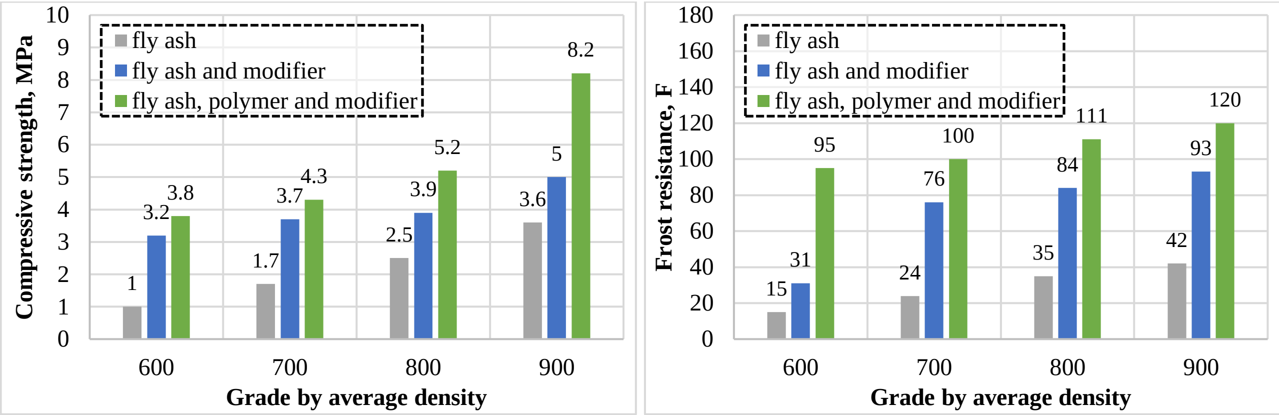


Figure 5 – Influence of polymer and complex modifier on strength and frost resistance of composite aerated concrete

The results show that the strength and frost resistance of composite aerated concrete with additives significantly increases. The best results were obtained for composite aerated concrete with a complex modifier and a polymer component. The studies showed that the specimens of aerated concrete with complex modifier even with low strength, when interacting with water, do not collapse, which indicates the effectiveness of the application of this modifier. The post-alcohol bard, which is a part of the complex modifier, contains casein, which during interaction with the filler and fine aggregate of composite aerated concrete polymerizes, forming additional contact layers that increase the resistance of the material to water.

## 4. Conclusions

The following conclusions can be made based on the results of the studies:

1. Thus, from the conducted studies it is clear that the use of complex modifiers of hydrophilic-hydrophobic type, a polymeric component to obtain a durable and effective material is effective when using fly ash.

2. Complex modifier from industrial wastes improves building-technical properties providing reduction of water-cement ratio and thus increasing product strength, creating a high-quality pore structure, which allows to save cement binder and solve the problem of utilization of fly ash wastes.

3. Studies have shown that the use of all elements and new developments in the production of composite aerated concrete with the selection of optimal quantities and modes will allow to obtain high-quality materials.

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