

*Свідоцтво про державну реєстрацію: Свідоцтво Міністерства юстиції України КВ №17253-6023ПР 23.11.2010  
Рішення Національної ради України з питань телебачення і радіомовлення від 10.08.2023 №692. Реєстраційний номер – R30-01141.*

*Наукове фахове видання категорії «Б» з технічних (122, 133, 161, 183, 192, згідно наказів МОН України № 975 від 11.07.2019 р., №1643 від 28.12.2019 р., № 157 від 09.02.2021 р.), економічних наук (073, згідно наказу МОН України №1301 від 15.10.2019 р.) та архітектури (191, згідно наказу МОН України № 1188 від 24.09.2020 р.).*

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*Збірник затверджений до друку Науково-технічною Радою Харківського національного університету міського господарства імені О.М. Бекетова (протокол № 5 від 01 грудня 2023 року)*

ISSN: 2311-7257  
ISSN: 2708-6194 (online)

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## PROPERTIES INVESTIGATION OF POLYESTER RESIN COMPOSITE MATERIALS AND PRODUCTS

*The use of composite materials in construction is a promising direction due to their potential to reduce costs and improve the operational characteristics of building structures. The results of this study will allow to determine the optimal formulations and manufacturing technologies of polymer composite materials for use in construction. In this paper, a detailed analysis of the composite material based on polyester resin (polymer sand concrete) used for the manufacture of hatch covers for manholes in water supply and sewage systems is carried out. The main components of the considered composition are quartz sand, unsaturated polyester resin, hardening accelerator - cobalt naphthenate solution and hardener - benzoyl peroxide.*

*As part of the study, the improvement of the composite material's properties is also considered by adjusting the technological modes of formation. Special attention was paid to the analysis of the hardness of the samples after the research, since this parameter determines the resistance of the material to wear. The effect of different ratios of these components on the physical and mechanical properties of the final material was studied. It was experimentally determined how the consumption of polyester and hardener affects the compressive strength, bending strength, impact toughness and hardness of the composite material.*

*To obtain optimal characteristics, the STATISTICA 12 software package was used to specify the values of the factors that lead to maximum compressive and bending strength. The results of the research are presented in the conclusions in the form of quantitative indicators that indicate the optimal composition to achieve high physical and mechanical characteristics. The response surfaces of the variation factors' influence on the properties of interest are shown.*

**Keywords:** *composite material, polymer sand concrete, quartz sand, polyester resin, hardening accelerator - cobalt naphthenate solution and hardener - benzoyl peroxide.*

### Problem statement

The study of the composite materials' properties and products made of polyester resin includes a number of problems that require attention and study.

It is necessary to determine the mechanical characteristics of composites, such as compressive strength, bending strength, and impact strength.

The problem is how to optimize composition and manufacturing to achieve maximum mechanical properties. It is important to study the interaction of different components of the composition (quartz sand, polyester resin, cobalt naphthenate solution and benzoyl peroxide) and their influence on the final characteristics of the material.

The problem is to find the optimal ratio of components to achieve the highest quality and efficiency of the material in the manufacture of products. Study of the influence of various technological parameters on the formation and properties of composite products in order to optimize the production process.

The problem is to determine the resistance of polyester resin products to wear and improve their service life. These problems are the main challenges in the study of the properties of composite materials and

polyester resin products and require a systematic scientific approach to solve them.

The main goal of the research is the development and optimization of the composition of the composite material represented by polymer sand concrete based on polyester resin, which is used for the manufacture of manhole covers for manholes.

### Analysis of recent research and publications

Hatch covers must meet the requirements [1]. Authors of research [2] investigated the use of composites and utilized an efficient methodology of assessing the most impactful factors that influence the structural properties of the composites. The similar approach we'll use in the present study. In [3] there are presented the unified strength parameters of hatch covers which will serve as evaluation criteria for the research results obtained here. [4] deals with structural design of objects that are under investigation in the present study. This work also provides useful requirements with regards to features of hatch covers that must be met to ensure its safe exploitation. [5] offers interesting insights into finite element modeling of hatch covers behavior under stress. This gives clues about expected destruction pattern of the hatch. Research [6] deals with wear impact on a hatch

performance which is a useful tip on what test environment should be provided for testing results to be representable. Works [7 – 9] present data on hatch design consideration in view of its stress strained state. [10] provides more data on using industrial wastes in composites when manufacturing building constructions.

**Research goal**

The main tasks of this research are to perform an analysis of the existing theoretical and practical ideas about the production technology of polymer-sand concrete and the materials used for its production, to develop and optimize the compositions of polymer-sand concrete, to investigate the influence of concrete components on bending and compressive strength, impact strength and hardness polymer sand concrete, to develop a device for testing hatch covers for strength.

The planning of the study was carried out on the basis of a design using a two-factor experiment in three levels. The consumption of polyester resin and the consumption of hardener (benzoyl peroxide) were chosen as variable factors to determine the influence on compressive strength, bending strength, impact strength and hardness of polymer sand concrete. Variable factors in the experiment are given in relative units (-1, 0, +1).

**Main body**

The basis was the consumption of sand and, in relation to it, the consumption of polyester resin and hardener in %. The following consumption of components was chosen: polyester resin as a percentage of the mass of sand (27%, 33%, 39%); hardener as a percentage of resin weight (1.1%, 1.6%, 2.1%).

To determine the strength under compression, bending and hardness, samples of the beam with the size of 40x40x160 mm were made, and for the determination of the impact strength, the length was 55 mm and the square cross-section with a side of 10 mm.

A special stand was developed for hatch cover tests, which provided the test methodology given in the standard [1]. The tests were carried out in an accredited testing center in accordance with the requirements of DSTU EN ISO/IEC 17025:2019 General requirements for the competence of testing and calibration laboratories (EN ISO/IEC 17025:2017, IDT; ISO/IEC 17025:2017, IDT), (accreditation certificate No. 20174 dated July 19, 2022).

Experiments were carried out in accordance with the adopted experimental plan. The results of testing samples for bending and compressive strength, impact toughness and hardness are shown in Table 1.

Processing of experimental results was performed in the STATISTICA 12 software package.

To analyze the influence of the consumption of polyester resin and hardener, we will plot the surface of the effect of resin and hardener on the bending strength of the samples (Fig. 1).

Table 1. Results of testing samples for bending and compressive strength, impact toughness and hardness

No of samples series	Rb, MPa	Rc, MPa	W, kJ/m <sup>2</sup>	Hardness, N/mm <sup>2</sup>
1	2	3	4	5
1	8,8	29,3	57,2	31,0
2	8,4	27,8	51,5	29,3
3	3,0	4,7	51,2	18,6
4	3,2	6,2	57,9	19,5
5	4,5	26,5	65,3	20,4
6	8,3	7,3	48,1	27,8
7	7,9	18,7	51,2	21,5
8	8,3	26,5	45,4	26,3
9	8,5	26,4	65,1	25,0
10	7,5	24,6	63,7	23,7
11	8,6	25,0	68,8	22,6

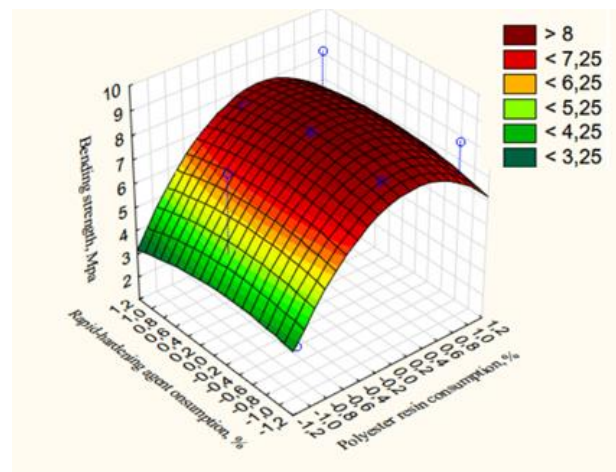


Fig. 1. The response function’s surface of the polyester resin and hardener consumption’s influence on the bending strength of polymer sand concrete samples

To display the most optimal content of resin and hardener in concrete, project the obtained surfaces on a horizontal plane (Fig. 2)

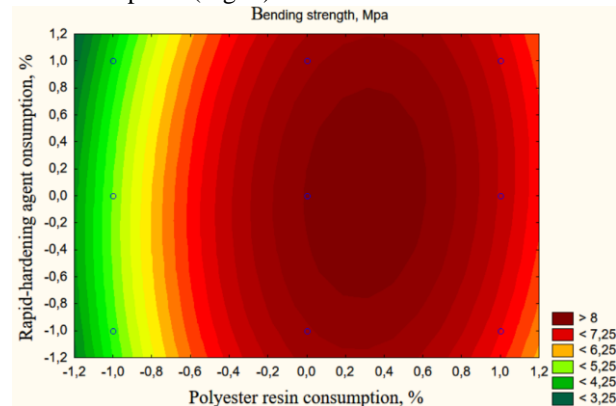


Fig. 2. Surface isolines of the response function of the influence of polyester resin and hardener consumption on the value of the bending strength of polymer sand concrete samples

As can be seen from Figures 1 and 2, the greatest strength was obtained with the maximum consumption of polyester resin and hardener.

To visually display the relationship between the content of polyester resin and the strength of the samples, it is advisable to determine the correlation coefficients (Table 2). The correlation coefficient can take on values from -1 to +1.

Table 2. Correlations of factors and variables

Factors	Bending strength, MPa
(1) Polyester resin consumption, % (L)	0,42
Polyester resin consumption, % (K)	-0,49
(2) Rapid-hardening agent consumption, % (L)	-0,01
Rapid-hardening agent consumption, % (K)	-0,20
1L by 2L	0,04
Bending strength, MPa	1,00

As can be seen from Table 2, the strength of the samples is most affected by the quantitative content of polyester resin.

Let's plot the surface of the effect of polyester resin and hardener on the strength of samples under compression (Fig. 3).

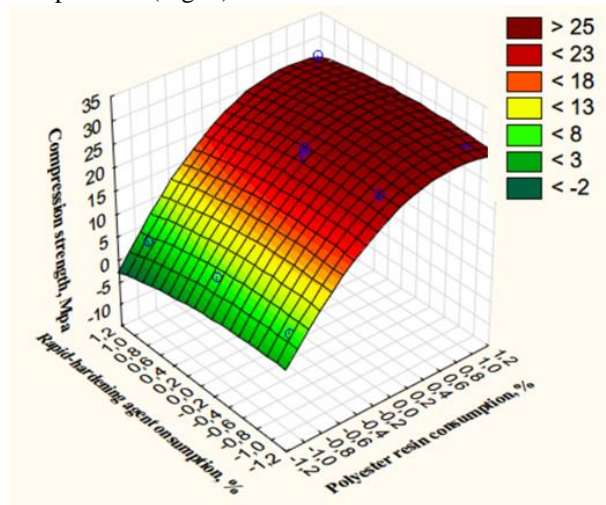


Fig. 3 The surface of the response function of the effect of polyester resin and hardener consumption on the compressive strength of polymer sand concrete samples

To explain the obtained results of the cost of polyester and hardener on the strength of the samples, we present the correlation coefficients.

The consumption of polyester resin has the highest correlation, which is expected. According to the data in Table 3, an increase in the amount of hardener has a negative effect on strength, as evidenced by a low negative correlation value.

The next study is characterized by the influence of polyester resin and hardener consumption on the value of impact viscosity, which is shown in Fig.4.

Table 3. Correlations of factors and variables

Factors	Compression strength, MPa
(1) Polyester resin consumption, % (L)	0,89
Polyester resin consumption, % (K)	-0,40
(2) Rapid-hardening agent consumption, % (L)	-0,11
Rapid-hardening agent consumption, % (K)	-0,17
1L by 2L	0,05
Compression strength, MPa	1,00

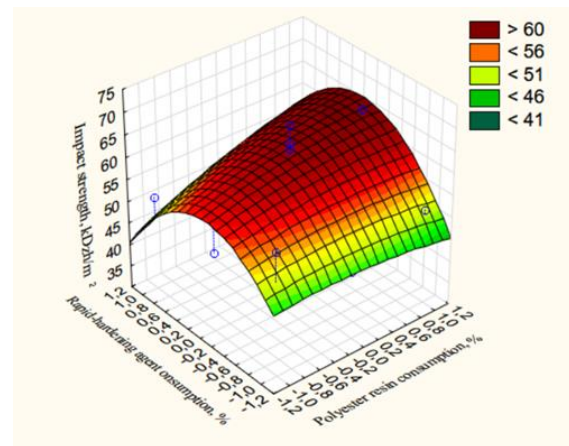


Fig. 4. The surface of the response function of the influence of the consumption of polyester resin and hardener on the value of impact viscosity

The highest impact toughness was obtained in 5 series of experiments with the highest consumption of polyester resin and the average consumption of hardener, which is confirmed by the graph shown in Fig.4.

Table 4. Correlations of factors and variables

Factors	Impact strength, kJ/m <sup>2</sup>
(1) Polyester resin consumption, % (L)	0,27
Polyester resin consumption, % (K)	-0,24
(2) Rapid-hardening agent consumption, % (L)	0,08
Rapid-hardening agent consumption, % (K)	-0,64
1L by 2L	0,25
Impact strength, MPa	1,00

Analysis of the data in Table 3 confirms that the consumption of the hardener has a positive effect on the value of impact viscosity, which is evidenced by the positive value of the correlation.

Special attention was paid to the analysis of the hardness of the samples of Figs. 5, as this parameter determines the wear resistance of the material.

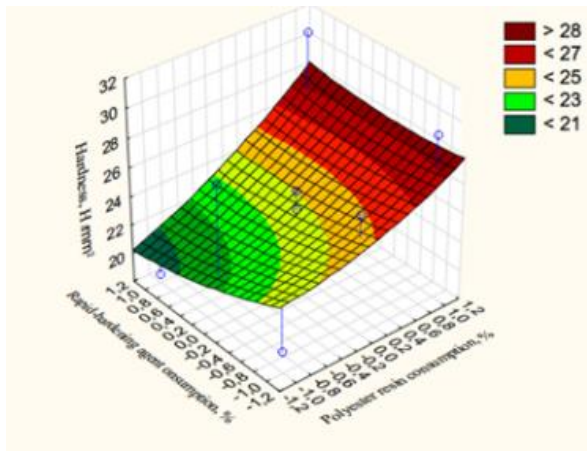


Fig.5 The surface of the response function of the influence of the consumption of polyester resin and hardener on the value of the hardness of polymer sand concrete.

The highest hardness of concrete was obtained in the first series of studies.

Table 5. Correlations of factors and variables

Factors	Hardness, N/mm <sup>2</sup>
(1) Polyester resin consumption, % (L)	0,47
Polyester resin consumption, % (K)	0,08
(2) Rapid-hardening agent consumption, % (L)	-0,13
Rapid-hardening agent consumption, % (K)	0,06
1L by 2L	0,10
Hardness, N/mm <sup>2</sup>	1,00

The consumption of polyester resin has an average effect on the hardness of concrete, as it has a value of 0.47 (table 4) and a positive effect of the curing agent.

The check of the selected optimized composition of the composite material was carried out on the manufactured hatch covers.

Testing of hatch covers for mechanical strength was carried out on a specially designed stand in accordance with DSTU B V.2.5-26:2005 and is shown in Figure 6.



Fig. 6. Testing hatch covers for mechanical strength

When the hatch cover was tested, fragile destruction was observed. The nature of the destruction of the hatch cover is shown in Figure 7.



Fig. 7. The nature of the destruction of the hatch cover

Hatch covers made on optimized compositions of polymer-sand concrete were tested. The test results are shown in Table 2

Table 6. Test results of polymer sand manhole covers

Type according to DSTU B V.2.5-26:2005	Actually obtained mechanical strength, kN	Normative requirements, kN
1	2	3
Type (designation according to EN 124) L(A15)	4,2	15

Test results of manhole covers comply with the requirements of DSTU B V.2.5-26:2005 for mechanical strength.

### Conclusions

Research has established the possibility of obtaining a composite material for the manufacture of manhole covers.

The mechanical strength of hatch covers was - 4.2 kN, which meets the requirements of DSTU B V.2.5-26:2005. Selected and optimized compositions of the composite material in terms of compressive strength of 30 MPa and bending of 8.7 MPa, impact strength - 65.3 kJ/m<sup>2</sup>, hardness - 31 N/mm<sup>2</sup>.

The study made it possible to obtain important data on the properties of composite materials and their applicability for the production of manhole covers. Optimizing the composition and production technology can improve the quality and service life of products.

Further research can be aimed at expanding the range of properties and applications in various fields of construction and infrastructure. The generalized data of the study indicate the prospects of using a composite material (polymer sand concrete) in the production of

hatch covers for inspection wells and determine the direction of further scientific research to achieve even higher results in this area.

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## ДОСЛІДЖЕННЯ ВЛАСТИВОСТЕЙ КОМПОЗИЦІЙНИХ МАТЕРІАЛІВ І ВИРОБІВ ВИГОТОВЛЕНИХ З ПОЛІЕФІРНОЇ СМОЛИ

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У даній роботі проведено детальний аналіз композиційного матеріалу на основі поліефірної смоли (полімерніщаного бетону), який використовується для виготовлення кришок люків оглядових колодязів у системах водопостачання та каналізації. Основними компонентами розглянутої композиції є кварцовий пісок, ненасичена поліефірна смола, прискорювач тверднення - розчин нафтенату кобальту та затверджувач - перекис бензоїлу.

Для отримання оптимальних характеристик було використано програмний комплекс STATISTICA 12 для уточнення значень факторів, що призводять до максимальної міцності при стиску та згині. Результати досліджень представлені у висновках у вигляді кількісних показників, які вказують на оптимальний склад композиції для досягнення високих фізико-механічних характеристик.

**Ключові слова:** композиційний матеріал, полімерніщаний бетон, пісок кварцовий, поліефірна смола, прискорювач тверднення - розчин нафтенату кобальту та затверджувач - перекис бензоїлу.