Збірник наукових праць. Галузеве машинобудування, будівництво
Academic journal. Industrial Machine Building, Civil Engineering
http://journals.nupp.edu.ua/znp
https://doi.org/10.26906/znp.2022.58.3077

UDC 691.327.5:669.14

Justification of new equipment development for preparing concrete solutions

Rudyk Rostyslav[1]*, Kuzub Yurij[2]

[1] National University «Yuri Kondratyuk Poltava Polytechnic» https://orcid.org/0000-0001-8386-977X
[2]LLC «KUZUB» https://orcid.org/0009-0006-8463-3914
*Corresponding author E-mail: rostyslavrudyk@nupp.edu.ua

Production of various types of reinforced concrete structures and concrete products of appropriate quality in Ukraine currently requires special attention, as there is an urgent need for rapid restoration and repair of buildings and structures after military operations. The preparation of concrete mixtures and mortars, as a rule, takes place at mechanized enterprises equipped with modern high-performance equipment, as well as directly on the construction site. The role of concrete mixing equipment in modern conditions is considered in the article. The need to develop a new design of small-sized mobile equipment for preparing concrete solutions was determined, and the existing mixing equipment was classified. On the basis of the conducted classification, the design features of the highly efficient equipment to be developed are determined

Keywords: Concrete mixtures, concrete mixer, solution, preparation

Обґрунтування розроблення нового обладнання для приготування бетонних розчинів

Рудик Р.Ю.[1]*, Кузуб Ю.О.[2]

[1]Національний університет «Полтавська політехніка імені Юрія Кондратюка»
[2]ФОП «КУЗУБ»
*Адреса для листування E-mail: rostyslavrudyk@nupp.edu.ua

У статті розглянуто значення бетонозмішувального обладнання в сучасному будівництві та необхідність розробки нових конструкцій малогабаритного мобільного обладнання для приготування бетонних розчинів. Проведено класифікацію існуючого змішувального обладнання та визначено конструктивні особливості високоефективного обладнання для розробки. Виробництво в Україні різноманітних видів залізобетонних конструкцій та бетонних виробів належної якості потребує на сьогодні особливої уваги, а також гострої потреби у швидкому відновленні та ремонті будівель і споруд після військових дій. Розглядаються джерела та публікації, пов'язані з розробкою та вдосконаленням різноманітних складів для приготування бетонних сумішей та будівельних розчинів. Розглянуто різні типи змішувачів, які використовуються для приготування бетонних і розчинових сумішей, у тому числі гравітаційні, примусового, пересувні бетонні заводи. Він також охоплює транспортування сумішей за допомогою вантажівок, насосів та іншого обладнання. Стаття завершується припущенням про необхідність малогабаритних мобільних бетонозмішувачів для покращення будівельних робіт в обмеженому просторі та зменшення транспортних витрат. Розглядається розробка нової конструкції малогабаритного мобільного обладнання для приготування бетонних розчинів, яке має переваги перед традиційними бетонозмішувачами. Стверджується, що підвищення мобільності змішувача дозволяє оптимізувати його розміщення по відношенню до виконуваної роботи, завантаження і вивантаження суміші без використання додаткового обладнання. Застосування комплексного обладнання для автоматизації процесів управління мобільним бетонозмішувачем сприятиме підвищенню продуктивності праці та зниженню енерговитрат, підвищенню ефективності змішування та оптимізації реологічних властивостей суміші, що готується. На основі проведеної класифікації визначено конструктивні особливості високоефективного обладнання, що буде розроблятися

Ключові слова: бетонна суміш, бетонозмішувач, будівельний розчин, приготування

Introduction.

In modern industry, one of the main roles belongs to the construction industry, which develops every year and increasingly affects the use of the entire economic system efficiency in the world. This industry is very important for the economy of any modern country. Capital construction, like no other similar branch of the economy, provides many jobs and uses the products of various branches of the national economy.

Production of various types of reinforced concrete structures and concrete products of appropriate quality in Ukraine currently requires special attention, therefore there is an urgent need for rapid restoration and repair of buildings and structures after military.

At present, the production of concrete mixtures and mortars, as a rule, takes place at mechanized enterprises equipped with modern high-performance equipment, as well as directly on the construction site.

In global construction engineering, equipment for preparing concrete of various types and designs is used, depending on the conditions in which they will be used. But mixers that work in construction site conditions are not given enough attention [7]. Therefore, the use of time for the preparation of finished products and the energy consumption are significantly greater compared to the production of similar products at the enterprise. Because of the small working space of the construction site, it is usually necessary to involve additional equipment.

Therefore, it is important to develop new designs of small-sized mobile equipment for the preparation of concrete solutions.

Review of the research sources and publications.

Ukrainian scientists were also engaged in the development and improvement of various structures for the preparation of concrete mixtures and construction solutions. Scientific schools of Nazarenko I.I. [1, 6], Onyshchenko O.G. [2], Emeljanova I.A. [3-5] are the most famous among them.

Problem statement

The development of a new design of small-sized mobile equipment for preparing concrete solutions based on research carried out by us, taking into account the experience of domestic and foreign researchers and designers.

Basic material and results

Concrete mixtures and mortars require mixing for their high-quality preparation. Mixing is a process in which several components are in a certain ratio to each other, forming a homogeneous mixture [8]. Mixers, which, in turn, are diverse in principle and differ in terms of mobility, mode of operation, and method of mixing, have become widespread in the construction industry.

According to the mode of operation, mixers are divided into cyclic and continuous action.

In machines with a cyclic action, loading, mixing and dispensing of the finished mixture are carried out sequentially, so the preparation of the mixture per cycle takes a certain time.

In continuous machines, the time for loading and unloading is not included in the time of preparing the mixture, so they have increased productivity. But due to the large number of components, it is not always possible to ensure a high-quality mixture, and the use of weighing dosing devices is often economically impractical.

Mixers by mobility are usually divided into mobile and stationary.

Mobile mixers have a cyclic action, so they are mostly used on objects with a small amount of work, as they are light and mobile and do not require additional effort for their operation.

Stationary mixers are most common in large enterprises and are designed for a longer service life.

Depending on the mixing method, there are gravity mixers, that is, with free mixing, or with forced mixing.

Gravity mixers are used to prepare mobile mixtures and have the ability to mix a mixture with a large aggregate. They are simple in design, have low energy consumption, and are easy to maintain and operate. These are the advantages of this mixer. The mixer is characterized by prolonged mixing, which is one of the main disadvantages. Mixing time reaches 180 s, but if you take into account loading, mixing and unloading, the cycle can last up to 240 s. The disadvantage of such mixers is also the low efficiency of mixing hard and fine-grained mixtures. Therefore, it is advisable to prepare only plastic concrete in such mixers.

Gravity mixers of cyclic action (Fig. 1) are classified according to the method of their unloading: overturning (in them, the drums rotate at an angle of 15° to the vertical during loading and mixing, and during unloading at an angle of 45°), non-overturning reversible with a horizontal drum axis (for mixing mixing paddles move in one direction, and for unloading - in the other), non-overturning with an unloading tray (during loading, mixing and unloading, the drum rotates in one direction, and before unloading, a tray is introduced into the drum and the mixture lifted by the paddles falls on this tray and is discharged from the mixer).

Mixers with forced mixing prepare the mixture using the forced movement of the blades in the mass of material. Also, in the conical body of the bowl, a fast-rotating rotor can be installed for better mixing and preparation of mixtures of any consistency.

In turn, forced mixers can be of different designs and are of several types: blade, tray, rotary, planetary-rotor and turbulent.

Blade mixers (Fig. 2, a) differ in that they have a fixed drum in which a drum with separate flat blades or with a continuous screw rotates. The problem of such mixers is a change in the direction of rotation of the shaft, which can be the cause of low mixing efficiency and accumulation of the mixture near the walls of the case.

Tray mixers (Fig. 2, c) contain vanes that form an intermittent spiral line on the shaft. To achieve high-quality mixing of the mixture, it is necessary to achieve the correct ratio between the angular speed of the shaft, the arrangement of the blades and the length of the tray.

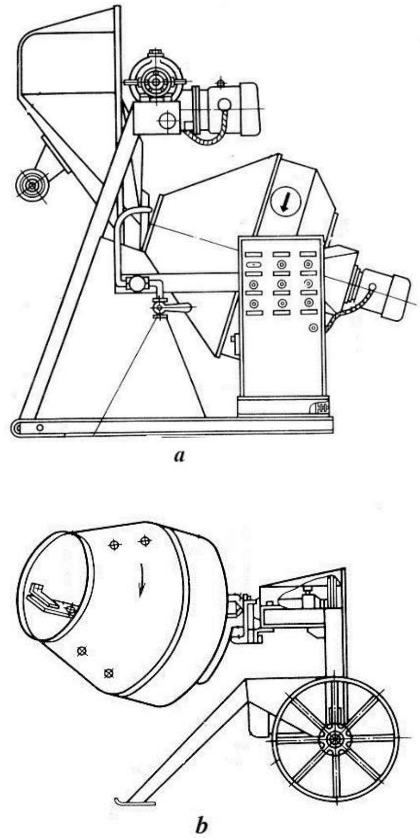

Figure 1 – Gravity mixers of cyclic action:
a – type SB-16B, *b* – type SB-101

Rotary mixers (Fig. 2, b) consist of two stationary concentric cylinders that form a working zone between them, in which blades of different radii, mounted on a common rotor, rotate in a circle.

Planetary-rotary (Fig. 2, d) mixers differ from rotary mixers in that they have two opposite movements of the blades. The rotor rotates in the rings of the working zone of the shaft with blades, and the blades simultaneously rotate on their shafts, forming additional vortex flows of the mixture.

In turbulent mixers (Fig. 2, e), the rotor rotates rapidly in the conical stand of the bowl, which creates vortex flows of the mixture. Such mixers have a number of advantages: mixture quality and increased homogeneity, simple construction and quick preparation. They are often used to prepare plastic cement and lime solutions, emulsion and mastic mixtures.

Mobile concrete batching plants are used to service small facilities located in several locations. They are installed on trailers and have the form of separate blocks that are transported by motor vehicles at low speed (up to 30 km/h) in assembled form. After the equipment is delivered to the facility, the preparation of the mixture can be started through 0.5-2 hours (depending on availability of raw materials). Assembly and disassembly are carried out with the help of conventional lifting equipment.

The main mechanisms of the equipment are activated by means of electric motors and a pneumatic drive. Automated control of the equipment makes it possible to reduce the maintenance staff to one person.

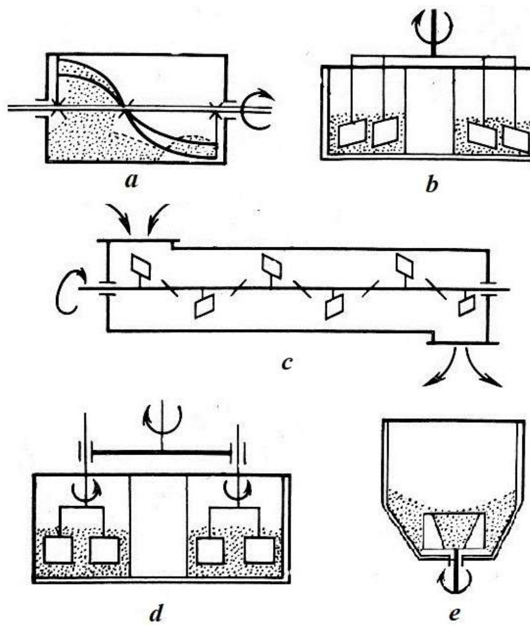

Figure 2 – Schemes of mixers:
a – blade, *b* – rotary, *c* – tray
d – planetary-rotary, *e* – turbulent

Depending on the degree of automation, concrete and mortar mixers come with manual and semi-automatic (with the use of a preset program) control or with the use of microprocessors. If necessary, the operator can manually control the process of making the mixture.

For automated control of the mixer, modern electronic systems with microprocessor, microcontroller control with the possibility of using cloud computing are used.

Existing types of mixers are presented in Figure 3.

The most important characteristic of the mixer is the mixing efficiency. The criterion for mixing efficiency may be standard deviation. For such a study, components are first prepared. For example, granite crushed stone is prepared (a fraction of 5-10 mm is screened out on a sieve) and sand. Mixing occurs without adding a binder, after which the finished mixture is divided into several (for example, five) servings. Dispersion on a sieve of 5 mm of each of these servings gives a mass of nourishing and super-satiating material. The standard deviation of portion masses, for example, supersaturated material, can be used as a criterion for mixing efficiency.

$$\sigma = \sqrt{\frac{\left(M_1 - M_{cep}\right)^2 + \left(M_2 - M_{cep}\right)^2 + \ldots + \left(M_n - M_{cep}\right)^2}{n}}, \quad (1)$$

If it is necessary to determine the efficiency of mixing components with a binder, detachment of components can be applied.

In the case where screening or detachment cannot be applied (for example, due to the homogeneity of the components in size), the standard deviation of the strength of samples formed from the test mixture and solidified under the same conditions can be estimated to assess the mixing efficiency.

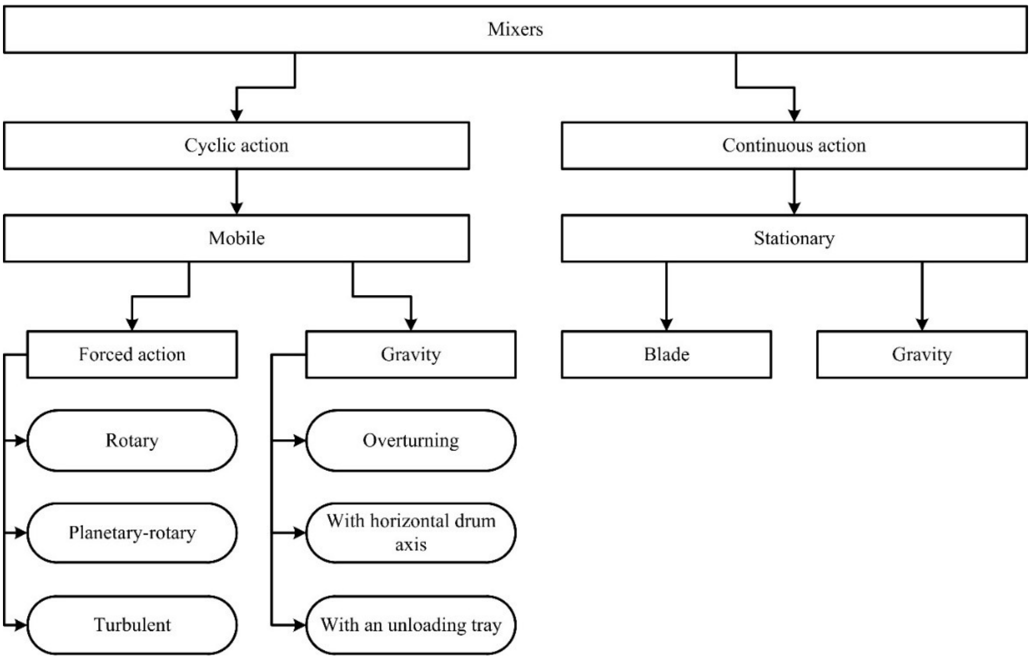

Figure 3 – Types of mixers that are used to preparing concrete mixes and solutions

The standard deviation has the same dimension as the dimension of the quantity under study. Sometimes it's convenient. However, it is often more convenient to apply the coefficient of variation as a criterion for mixing efficiency. For example, for silicate bricks (a type of concrete products) for grade M100 is regulated by the standard [12] average compressive strength of a sample of five bricks 10.0 MPa. At the same time, the strength of the least durable brick is not lower than 7.5 MPa. In this case, the coefficient of variation of the strength of the brick is about 20%. Consequently, when estimating mixing for this process, one cannot obviously assume a coefficient of variation in the uniformity of mixing less than 20%.

Known and more exotic options for assessing the quality of mixing. For example, mixing powders of equal density and particle size distribution can be evaluated using visualization (if one of the powders is prepainted). The mixing result (mixed two-component powder) can be placed on a slide and scanned on a scanner with subsequent analysis of gradients using graphics programs on a computer.

However, mixing quality is not the only factor when choosing a faucet or mixing technology. In any case, the more important factor will be the profitability of production. But the mobility of equipment, the speed of its deployment in a new location, environmental, social and other selection criteria may also be important. For such a multi-criteria choice of equipment, tool or technology, the method of expert assessments, multicriteria analysis and radar diagrams are often used [13]. An example of the application of such diagrams for two conditionally taken mixers is shown in Fig. 4. Preference in the choice will be given to the mixer, which is characterized by a larger area of the diagram.

In difficult cases, the method of paired comparisons and the method of hierarchy analysis can also be applied for selection [14].

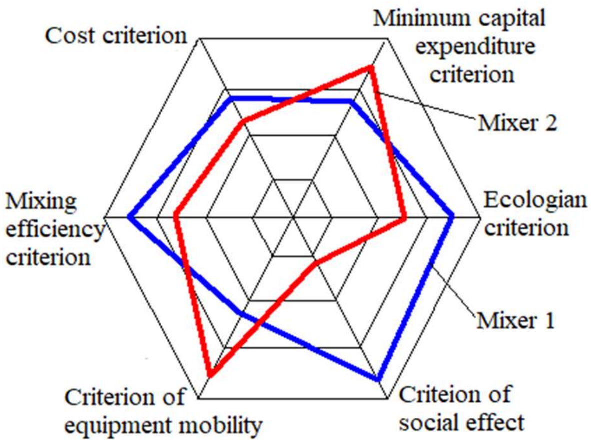

Figure 4 – Example of using radar charts to select equipment

The creation of new mixing principles is effective in the case of process simulation.

Many models use a physical analogue of the flow structure. On this principle, models of ideal mixing, ideal displacement, recirculation model, piston model with partial diffusion, cell model are developed. The cell model based on Markov chains has recently found increasing application for modeling mixing in technological processes. In figure 5 – an illustration of such a model. A schematic representation of some abstract mixer contains four cells (from "1" to "4"). Their numbers are the coordinates of the cell location. The contents of the mixer move, as a result, the material that was in cell "1" after some time ends up in cell "2"; The contents of all other cells will move accordingly to the next (adjacent) cell. Such a movement by one cell is called a transition. In this case, there are certain reasons why the binding material (for example, cement) can get from cell "1" to cell "2" with probability 10%;

The same probability of moving the binder from cell "4" to cell "3". In the example (in Fig. 5), initially the binder (let's call it the key component) is only in cell "1". The reasons for such a hit of components from one cell to another (as well as the probability of this) may be different; Softening, thanks to this, mixing occurs [15].

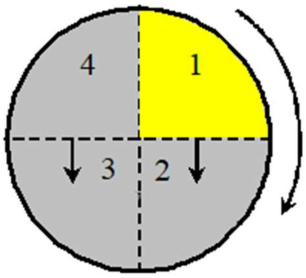

Figure 5 – Illustration of a cell model based on Markov chains

The initial state of the system is determined by the matrix:

$$E_0 = \begin{pmatrix} 1 & 0 & 0 & 0 \end{pmatrix}. \quad (2)$$

It can be seen that the key component (all 100% of it) is in cell "1". In other cells, the content of the key component is zero. Transition matrix (the matrix in which the state change is encoded):

$$P_i = \begin{pmatrix} 0.9 & 0.1 & 0 & 0 \\ 0.1 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0.1 \\ 0 & 0 & 0.1 & 0.9 \end{pmatrix}. \quad (3)$$

Matrix multiplication E_0 on P_i gives a matrix $E_0 = (0.9\ \ 0.1\ \ 0\ \ 0)$. Next, we take into account that there is a shift due to the rotation of the drum or shaft of the mixer (in our case – rotation by a quarter turn – by one cell):

$$\begin{pmatrix} 0.9 & 0.1 & 0 & 0 \end{pmatrix} \longrightarrow E_1 = \begin{pmatrix} 0.1 & 0 & 0 & 0.9 \end{pmatrix} \quad (4)$$

Matrix E_1 is the matrix of the state after the first transition. Repeating this iteration, we obtain state matrices after subsequent transitions:

$E_2 = (0\ \ 0\ \ 0.91\ \ 0.18)$,

$E_1 = (0.091\ \ 0.91\ \ 0.18\ \ 0.018)$,

$E_{10} = (0.165\ \ 0.31\ \ 0.736\ \ 0.392)$

It can be seen that cement (a key component) is distributed among the cells – mixing occurs. After a certain number of transitions, the standard deviation of the concentration of cement in the cells will reach a value that we can consider necessary. Consequently, this modeling approach can help in process optimization and in the development of new faucet designs.

The current level of development of computers and digital analysis systems, in particular those based on the methods of discrete elements (MDE) allow to simulate mixing processes as a process of interaction of a large number of individual (discrete) particles [16].

Consequently, modern tools for modeling the mixing process, determining criteria for assessing the intensity (quality) of mixing and assessing the significance of these criteria can make the process of creating new equipment the most efficient.

After conducting an analysis and identifying the advantages and disadvantages of existing units for the preparation of concrete mixtures and mortars, it is possible to determine the main directions for the further development of a new design of a small-sized mobile concrete mixer.

Transportation of concrete mixture from the enterprise to the construction site is a complex technological process that depends on many factors. That is why it is necessary to organize the process so that the concrete mixture has an acceptable temperature and homogeneity, the specified mobility, and the transportation time does not exceed the permissible.

Based on this, the use of small-sized equipment for the production of concrete mixtures directly on the construction site, as well as the provision of mobility, makes it possible to better perform construction work in conditions of limited space and reduce transportation costs.

Most mixers are not automated, so loading and unloading is done manually or by changing the angle of the tray. Agitation is not controlled, which can lead to poor mixing efficiency in different cycles.

Thanks to the optimal use of engine power, the creation of better working process conditions and lower consumption of construction materials, the economic efficiency of the developed equipment can be increased.

Conclusions

As a result of the conducted research, a new design of small-sized mobile equipment for preparing concrete solutions was proposed, which has a number of advantages compared to traditional concrete mixers.

Increasing the mobility of the concrete and mortar mixer will make it possible to optimize its placement in relation to the work being performed, loading and unloading of the mixture without the use of additional equipment.

The use of complex equipment to automate the processes of managing a mobile solution mixer will contribute to increasing work productivity and reducing energy consumption, increasing mixing efficiency and optimizing the rheological properties of the mixture being prepared.

References

1. Баладінський В.Л., Назаренко І.І., Онищенко О.Г. (2002). *Будівельна техніка*. Київ-Полтава: КНУБА-ПНТУ.

2. Онищенко О.Г., Помазан В.М. (1999). *Будівельна техніка*. Київ: Урожай

3. Ємельянова І.А., Гордієнко А.Т., Субота Д.Ю. (2018). Особливості виконання бетонних робіт в умовах будівельного майданчика. *Будівництво*, 3 (93), 205-214 https://doi.org/10.29295/2311-7257-2018-93-3-205-214

4. Емельянова И.А., Анищенко А.И., Сорокотяга А.С. (2013). Перспективы использования бетоносмесителя гравитационно-принудительного действия в условиях строительной площадки. *Галузеве машинобудування, будівництво*, 1(36), 9-15

5. Ємельянова І.А., Блажко В.В. (2015). *Сучасне обладнання для приготування будівельних сумішей в умовах будівельного майданчика*. Матеріали IV Міжнародної науково-технічної конференції. Актуальні задачі сучасних технологій. Тернопіль*,* 93-94

6. Назаренко І.І., Клименко М.О., Чичур А.І., Сахно С.В. (2011). Перспективні конструкції автобетонозмішувачів. *Теорія і практика будівництва*, 7, 2-9

7. Вірченко В.В. (2011). Приготування будівельних сумішей за допомогою ефективних змішувачів. *Вісник Кременчуцького національного університету ім. М. Остроградського,* 1/2011 (66), 71-74

8. Chiara F. Ferraris (2001) Concrete Mixing Methods and Concrete Mixers: State of the Art. *Journal of Research of the National Institute of Standards and Technology*, 2 (106), 391-399

9. Yang J., Zeng H., Zhu T., An Q. (2017). Study on the dynamic performance of concrete mixer’s mixing drum. *Mechanical Sciences* 1 (8), 165-178 https://doi.org/10.5194/ms-8-165-2017

10. Kamble R., Baredar P., Kumar A., Gupta B. (2021). New Approach for Evaluating Different Concrete Mixer Based on Concrete Slurry Property. *Lecture Notes in Mechanical Engineering. Springer, Singapore* https://doi.org/10.1007/978-981-15-9678-0_55

11. Ferraris Ch. (2001) Concrete Mixing Methods and Concrete Mixers: State of the Art. *Journal of Research of the National Institute of Standards and Technology*, 2 (106), 391-399. https://doi.org/10.6028/jres.106.016

12. ДСТУ Б В.2.7-80:2008 (2009). *Цегла та камені силікатні. Технічні умови.* Київ

13. Wan Y., Cheng K., Liu Z., Ye H. (2013). An investigation on machinability assessment of difficult-to-cut materials based on radar charts. *Journal of Engineering Manufacture*. 227(12), 1916-1920 https://doi.org/10.1177/0954405413497008

14. Крот О.П. (2018). Метод аналізу ієрархій для вибору раціонального обладнання термічного знешкодження відходів. *Вчені записки Таврійського національного університету імені В.І. Вернадського. Серія: Технічні науки»*, 29 (68) № 2, 216–219

15. Крот О.П., Ровенський О.І. (2017). Ланцюги Маркова при моделюванні змішування компонентів у барабанній печі при спалюванні муніципальних відходів. *Збірник наукових праць Українського державного університету залізничного транспорту*, 170, 48-59 https://doi.org/10.18664/1994-7852.170.2017.111276

16. Mahmood A A, Elektorowicz M. (2015). A Review of Discrete Element Method Research on Particulate Systems. *IOP Conference Series: Materials Science and Engineering* https://doi.org/1757-899X/136/1/012034

1. Baladinslyi V.L., Nazarenko I.I., Onyshchenko O.G. (2002). Building machinery. Kyiv-Poltava: KNUCA-PNTU

2. Onyshchenko O.G., Pomazan V.M. (1999). *Building machinery*. Kyiv: Harvest

3. Emeljanova I.A., Gordienko A.T., Subota D.Yu. (2018). Features the performance of concrete works at the construction site. *Civil Engineering,* 3 (93), 205-214 https://doi.org/10.29295/2311-7257-2018-93-3-205-214

4. Emeljanova I.A., Anishchenko A.I., Sorokotyga O.S. (2013). Determination of basic indicators of technology package equipment consisting of concrete mixers gravitational enforcement action and trough belt feeders. *Industrial Machine Building, Civil Engineering*, 1(36), 9-15

5. Emljanova I.A., Blazhko V. V. (2015). *Modern equipment for making smsey building in a construction site*. Materials of the IV International Scientific and Technical Conference. Current problems of modern technologies. Ternopil, 93-94

6. Nazarenko I.I., Klymenko M.O., Chichur A.I., Sakhno S.V. (2011). Promising constructions of truck-mounted concrete mixers. *Theory and practice of construction*, 7, 2-9

7. Virchenko V.V. (2011). Mixing and construction mortar solutions with the effective mixers. *Bulletin of Kremenchuk Mykhailo Ostrohradskyi National University*, 1/2011 (66), 71-74

8. Chiara F. Ferraris (2001) Concrete Mixing Methods and Concrete Mixers: State of the Art. *Journal of Research of the National Institute of Standards and Technology*, 2 (106), 391-399

9. Yang J., Zeng H., Zhu T., An Q. (2017). Study on the dynamic performance of concrete mixer’s mixing drum. *Mechanical Sciences* 1 (8), 165-178 https://doi.org/10.5194/ms-8-165-2017

10. Kamble R., Baredar P., Kumar A., Gupta B. (2021). New Approach for Evaluating Different Concrete Mixer Based on Concrete Slurry Property. *Lecture Notes in Mechanical Engineering. Springer, Singapore* https://doi.org/10.1007/978-981-15-9678-0_55

11. Ferraris Ch. (2001) Concrete Mixing Methods and Concrete Mixers: State of the Art. *Journal of Research of the National Institute of Standards and Technology*, 2 (106), 391-399. https://doi.org/10.6028/jres.106.016

12. DSTU B B.2.7-80:2008 (2009). *Silicate bricks and stones. Specifications*. Kyiv

13. Wan Y., Cheng K., Liu Z., Ye H. (2013). An investigation on machinability assessment of difficult-to-cut materials based on radar charts. *Journal of Engineering Manufacture*. 227(12), 1916-1920 https://doi.org/10.1177/0954405413497008

14. Krot O.P. (2018). Hierarchy analysis method for choosing rational equipment for thermal waste disposal. *Scientific Notes of the Tavra National University named after V.I. Vernadskyi. Series: Technical Sciences*, 29 (68) No. 2, 216–219

15. Krot O.P., Rivenskyi O.I. (2017). Markov chains in modeling the mixing of components in a drum furnace during the incineration of municipal waste. *Collection of scientific works of the Ukrainian State University of Railway Transport*, 170, 48-59 https://doi.org/10.18664/1994-7852.170.2017.111276

16. Mahmood A A, Elektorowicz M. (2015). A Review of Discrete Element Method Research on Particulate Systems. *IOP Conference Series: Materials Science and Engineering* https://doi.org/1757-899X/136/1/012034