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Technological equipment package for preparing polystyrene concrete mixture

The study of the production process for polystyrene concrete mixture products is driven by the need to ensure high material quality while meeting modern construction standards. To achieve this goal, an analytical method was used for reviewing literature sources, along with a design-calculation approach in the development of a new type of equipment.
The main findings highlight the shortcomings of conventional concrete mixers, including extended mixing time, mixture non-uniformity, and material sticking to working surfaces. A novel design of a gravity-compelled cascade-type concrete mixer is proposed, featuring a horizontal ribbon-paddle shaft and a rotating drum. A key innovation is the ability to adjust the rotation modes depending on the mixture composition and the presence of sand. A compact equipment package was developed, comprising a mixer, fiber cutter, belt and screw feeders, all mounted on a single frame. The use of a belt feeder with synchronized component feeding and an automated fiber cutter ensures even distribution of reinforcing elements within the mixture. A methodology for determining the productivity of the unit has been developed, considering the mixer filling volume, the geometric parameters of working elements, and mixing process characteristics. Formulas were derived for selecting key parameters of the cutter and roller feed for the fiber bundle.The proposed equipment contributes to improved quality of polystyrene concrete, reduced energy consumption, and shorter production time. Future research will focus on optimizing operating modes of the equipment for different types of polystyrene concrete mixtures using fiber reinforcement.

Keywords: polystyrene concrete, mixing, fiber, reinforcement, concrete mixer, feeder, design, quality

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Introduction

The analysis of issues in the production of polystyrene concrete products requires consideration of several aspects related to raw material properties, the manufacturing process, and compliance with construction standards. The main challenges in polystyrene concrete production often arise from the difficulty in achieving optimal strength, thermal and sound insulation characteristics, as well as meeting environmental requirements.

Review of the research sources and publications

Polystyrene concrete consists of a cement-based mixture and expanded polystyrene, which is added to enhance thermal insulation properties. However, this combination can result in structural inhomogeneity, leading to unstable physical and mechanical properties. As noted in studies, the density and strength of polystyrene concrete can vary significantly depending on the quality of raw materials and the production technology [1].

Polystyrene concrete is prone to shrinkage, which may cause surface cracking in the final products. This issue becomes particularly critical when the material has high moisture content during curing. Some researchers have suggested that shrinkage can be reduced through the use of specialized additives [2].

Polystyrene concrete is characterized by high hydrophobicity, but in the presence of microcracks, water may penetrate the material's pores. This reduces its strength and durability, especially under fluctuating moisture conditions. Studies have shown that water resistance can be improved by adding specific admixtures, though this increases production costs [3].

Ensuring consistent quality of polystyrene concrete products is a complex task. In practice, it is crucial to control not only the quality of polystyrene and cement but also to maintain precise proportions of components, as well as temperature and humidity conditions during mixing and curing. Failure to adhere to technological standards may compromise the mechanical performance of the material [4].

The analysis of these issues suggests that while polystyrene concrete has significant potential in construction, its effective application depends on overcoming technological, environmental, and economic challenges.

International research on polystyrene concrete actively addresses its thermal insulation properties, strength, durability, and environmental impact. Scientists from various countries focus on improving production technology and applications of polystyrene concrete, particularly in the context of reducing energy consumption and enhancing environmental performance in construction.

Researchers from Europe and the USA are investigating ways to improve the thermal insulation properties of polystyrene concrete without significantly compromising its strength. For instance, studies by Türker and Ali [5] in Turkey have shown that optimizing the microstructure of polystyrene concrete—particularly by adjusting the size of polystyrene granules—can enhance thermal insulation without reducing the load-bearing capacity of the material.

Researchers in Germany and Japan are exploring technologies involving special admixtures that improve the hydrophobic properties of polystyrene concrete. In an article by Schulz and Lee [6], it was reported that using silicone-based admixtures and other water-repellent agents reduced water absorption by 20–30%, positively affecting the material's durability in high-humidity environments.

Research in Italy, particularly by Ricci and D'Angelo [7], demonstrated that adding polypropylene fibers to the polystyrene concrete mix enhances crack resistance and mechanical stability. Fiber reinforcement reduces the risk of microcrack formation and deformation, especially in low-temperature conditions.

International studies highlight strong interest in polystyrene concrete as a promising construction material. However, for its effective application, challenges related to environmental safety, hydrophobicity, strength, and quality control must be addressed. Therefore, the production of polystyrene concrete requires continuous improvement to ensure reliability and compliance with current environmental and technical standards.

Definition of unsolved aspects of the problem

Analyzing the various types of mixers used for the preparation of polystyrene concrete mixtures, it can be concluded that the most common are gravity and forced-action mixers (either single-shaft or twin-shaft). In gravity mixers, the mixing process occurs through the free-fall of the material. In forced-action mixers, mixing is achieved using mechanical elements that directly act on the components of the mixture. The simplest type of equipment for preparing the mixture is a gravity batch concrete mixer.

The company *"Energy Efficient Concretes"* recommends using the *Politherm-Machine MP1000* for feeding and preparing polystyrene concrete [8]. Foam, prepared in a dedicated unit called a foam generator, is added to the cement-sand mixture. After thorough mixing, the resulting cellular-structure mixture is ready for molding into various construction products. The hardening of foam concrete typically requires steam curing in chambers under atmospheric pressure.

The *MP1V3 unit* is designed for the preparation and pumping of high-quality monolithic polystyrene concrete that contains no sand, with a density ranging from 200 to 600 kg/m³ [9].

Problem statement

Drawing on decades of accumulated experience, it is necessary to develop equipment that integrates all the essential features for producing high-quality polystyrene concrete, with the capability to incorporate reinforcing elements.

Basic material and results

When analyzing existing mixer designs used for the preparation of polystyrene concrete mixtures, several aspects must be taken into account:

- the complexity of the mixer's structural design;
- the uncertainty in achieving mixture homogeneity;
- the adhesion of the prepared mixture to the mixer's internal surfaces;
- the long time required for the mixing process.

Due to these shortcomings, it is proposed to use a gravity-forced concrete mixer operating in cascade mode for the preparation of such mixtures [10, 11, 12]. Existing designs of such mixers are typically intended for low-mobility and stiff concrete mixtures.

The gravity-forced concrete mixer features a cylindrical body with a horizontal shaft inside, onto which blades are mounted helically. Both the mixer body and the blade shaft rotate in opposite directions. Depending on the composition of the mixture, if it contains sand, the mixer body rotates; if the mixture is sand-free, the body remains static while only the ribbon-blade shaft rotates. The improved mixer design meets the requirements for producing polystyrene concrete mixtures reinforced with fiber elements.

The mixer is part of a compact equipment set, as shown in Figure 1 [13].

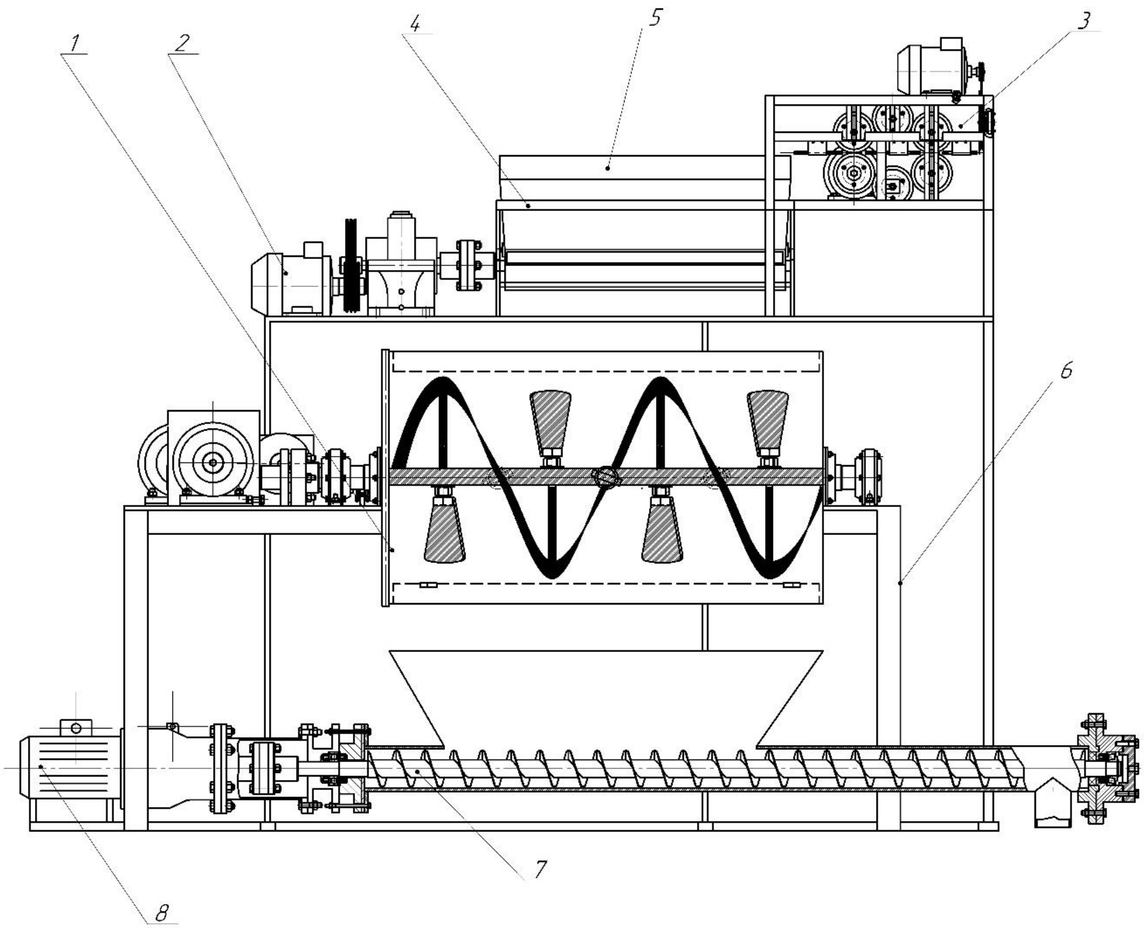

Figure 1 – Equipment set for the preparation of polystyrene concrete mixture:
1 – gravity-forced mixer; 2 – belt feeder drive; 3 – fiber cutter; 4 – belt feeder; 5 – component storage hopper; 6 – frame; 7 – screw feeder; 8 – screw feeder drive

The equipment set includes a base machine – a forced-action mixer, a fiber cutter, a belt feeder for component delivery, and a screw feeder for transporting the prepared mixture. The entire system is mounted on a single frame and operates in a synchronized manner (depending on the mixer's output capacity), allowing for reduced time in feeding components.

The operating process of the equipment set is as follows: pre-measured mixture components are stored in hopper 5 and delivered to the mixer's loading port (1) using belt feeder 4. Simultaneously, fiber strands are cut by fiber cutter 3 and evenly distributed onto the feeder belt 4 [14]. The ready polystyrene concrete mix is discharged from mixer 1 into the intake hopper of screw feeder 8, from where it is conveyed to the forming station for product fabrication.

To ensure synchronized operation of the equipment set, it is necessary to feed the material components evenly and to cut the fibrous elements. All these stages are interrelated and depend on the performance of the main equipment — the concrete mixer.

To determine the main performance indicators of the machine, a calculation method is proposed that takes into account the machine's structural parameters and the specifics of the working process:

$$П_{tech.mix} = V_{total} \cdot К_z \cdot Z_c, \text{ m}^3/\text{h};$$

where:

V_{total} – total volume of the mix in the mixer body, m^3;

$К_z = 0,5$; – volume filling coefficient of the mixer;

$Z_c = 3600/t_c$ – number of cycles per hour;

$(t_c = t_1 + t_2 + t_3)$ – duration of one cycle (including loading t_1, mixing t_2, and unloading t_3), s.

Загальний обсяг суміші визначається як, m^3:

$$V_{total} = V_{\text{body}} - V_{\text{shaft}} - V_{\text{blade } leg} - V_{\text{blade}} - V_{\text{screw}} - V_{\text{support}},$$

where:

$V_{\text{body}} = \frac{1}{2} \cdot \pi \cdot R^2_{body.in} \cdot L_{body}$; – volume of the mixer body, m^3;

$V_{\text{shaft}} = \frac{1}{2} \cdot \pi \cdot r^2_{\text{shaft}} \cdot L_{\text{shaft}}$; – shaft volume, m^3;

$V_{\text{blade } leg} = \frac{1}{2} \cdot \pi \cdot r^2_{leg.in} \cdot z_{leg} \cdot C_{leg}$; – volume of blade legs, m^3;

$V_{\text{blade}} = \frac{1}{2} \cdot Z_{\text{blade}} \cdot b_{\text{blade}} \cdot h_{\text{blade}} \cdot C_{\text{blade}}$; – blade volume, m^3;

$V_{\text{screw}} = \frac{1}{2} \cdot \pi \cdot (L_{\text{screw}}) \cdot (R^2_{\text{screw}} \cdot r^2_{\text{screw}}) \cdot C_{\text{screw}}$; – screw volume, m^3;

$V_{\text{support}} = \frac{1}{2} \cdot \pi \cdot R_{\text{support}}^2 \cdot C_{\text{support}} \cdot Z_{\text{support}};$ – volume of shaft supports, m^3;

$R_{body.in}$. – inner radius of the mixer body, m;

L_{body}– body length, m;

r_{shaft} – shaft radius, m;

L_{shaft} – shaft length, m;

$r_{leg.in}$ – inner radius of blade leg, m;

z_{leg}, C_{leg} – number of blade legs and thickness, m;

$Z_{\text{blade}}, b_{\text{blade}}, h_{\text{blade}}, C_{\text{blade}}$ – blade width, height, number of blades and thickness, m;

$L_{\text{screw}} = \sqrt{S^2 + (\pi \cdot D_{ш})^2};$ – developed length of screw, m;

$R_{\text{screw}}, r_{\text{screw}}$. – outer and inner screw radius, m;

$C_{\text{support}}, Z_{\text{support}}$ – number and thickness of screw supports, m.

The cutting machine's productivity can be determined by two approaches [14]:

1. Based on the concrete mixer's productivity:

$$П_{tech.cut.1} = П_{tech.mix} \cdot К_{max.fiber},$$

where:

$К_{max.fiber} = \frac{\pi \cdot d_{fiber}{}^2 \cdot f}{4 \cdot h \cdot l_f};$ – maximum volumetric reinforcement coefficient;

d_{fiber} – fiber diameter, m;

f – friction coefficient;

$h = 0{,}8 \cdot H$ – where H is the mixer height, m;

l_f – length of the cut fibers, m.

2. Based on knife head design parameters:

$$П_{tech.cut.2} = \frac{47{,}1 \cdot n_{\text{н.г.}} \cdot D_{\text{bundle}}^2 \cdot l_f}{4 \cdot Z_{kh}},$$

where:

n_{kh} – knife head rotation speed, rpm;

D_{bundle} – diameter of synthetic fiber bundle, m;

Z_{kh} – number of knives on the head.

From this, the required number of knives can be derived:

$$Z_{kh} = \frac{П_{tech.mix} \cdot К_{max.fiber}}{188{,}4 \cdot n_{kh} \cdot D_{\text{bundle}}^2 \cdot l_f}.$$

3. Productivity based on feed rollers:

$$П_{tech.cut.3} = 60 \cdot n_{roller} \cdot \pi \cdot D_{roller} \cdot d_f \cdot l_f,$$

thus:

$$n_{roller} = \frac{П_{tech.mix} \cdot К_{max.fiber}}{60 \cdot \pi \cdot D_{roller} \cdot d_f \cdot l_f},$$

where:

D_{roller} – roller diameter, m;

d_f diameter of synthetic thread, m.

Therefore, depending on the mixer performance and fiber geometry, the necessary rotation speed of the knife head and feed rollers can be determined.

Based on these dependencies, a study was conducted on the effect of fiber length on the strength of the test samples. The results are shown in Figure 2.

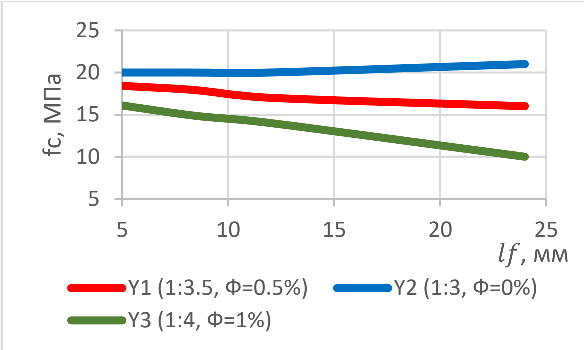

Figure 2 – Strength of test samples depending on the length of fiber elements:
Y1 – Cement-to-sand ratio 1:3.5, fiber content F = 0.5%;
Y2 – Ratio 1:3, no fibers (F = 0%);
Y3 – Ratio 1:4, fiber content F = 1%.

The study showed that the addition of reinforcing fibers improves the microstructure of the mixture, reduces porosity, and enhances the strength of finished products. The optimal fiber length is 6–12 mm.

Conclusions

The proposed set of compact equipment enables the preparation of polystyrene concrete mix with the addition of reinforcing fibers, which enhances the strength of the final product. The equipment included in the set operates asynchronously and allows for adjustable output based on the characteristics of the mixture and the requirements for the fibrous elements.

The addition of fibrous reinforcement to the polystyrene concrete mix significantly improves its mechanical properties and microstructure. Optimal selection of the fiber type, length, and quantity allows for achieving the desired material characteristics for specific construction applications.

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Комплект обладнання для приготування полістиролбетонної суміші

Дослідження процесу виробництва виробів із полістиролбетонної суміші обумовлене необхідністю забезпечення високої якості матеріалу за умов дотримання сучасних будівельних стандартів. Для досягнення поставленої мети було застосовано аналітичний метод аналізу літературних джерел, а також конструктивно-розрахунковий підхід при розробці нового типу обладнання. Основні результати дослідження вказують на недоліки традиційних бетонозмішувачів, що проявляються у тривалому часі приготування суміші, її неоднорідності та налипанні матеріалу на робочі поверхні. Запропоновано конструкцію бетонозмішувача гравітаційно-примусової дії каскадного режиму роботи з горизонтальним стрічково-лопатевим валом і обертовим корпусом. Особливістю є можливість змінювати режими обертання залежно від складу суміші та наявності піску. Створено малогабаритний комплект обладнання, що включає змішувач, різчик фібри, стрічковий і шнековий живильники, змонтовані на єдиній рамі. Використання стрічкового живильника із синхронною подачею компонентів і автоматизованого різчика фібри дозволяє рівномірно розподіляти армуючі елементи в суміші. Розроблена методика визначення продуктивності установки враховує об'єм заповнення змішувача, геометричні параметри робочих органів та особливості процесу перемішування. Визначені залежності для підбору основних параметрів різчика і роликової подачі джгута. Запропоноване обладнання сприяє підвищенню якості полістиролбетону, зменшенню енергоспоживання і часу виробництва. Перспективою подальших досліджень є оптимізація режимів роботи обладнання для різних типів полістиролбетонних сумішей із використанням фібрового армування.

Ключові слова: полістиролбетон, змішування, фібра, армування, бетонозмішувач, живильник, конструкція, якість.

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