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INFORMATION TECHNOLOGIES IN THE MANAGEMENT OF TECHNOLOGICAL PROCESSES FOR THE PRODUCTION OF BUILDING PRODUCTS

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The object of the study is the production of construction products with fillers from recycled wind turbine blades.

The study solves the problem related to the possibility of using fillers from recycled wind turbine blades in the technological process of manufacturing construction products.

According to the results of the study, concrete mixtures with the most optimal formulations that meet the requirements of state standards were classified, this was achieved due to effective indicators reflecting the characteristics of concrete mixtures.

The developed algorithm of the technological process of production of building products was used in the development of the program code, this became possible due to the consideration of assumptions and limitations of the technological equipment used in production.

The program for managing the technological process of manufacturing construction products is developed in C++, which does not require additional resources for auxiliary operations, has the ability to metaprogram and has the necessary performance. The adequacy of the model is ensured by the maximum approximation to real production.

The effectiveness of research results in real production is explained by high-quality mixtures, dosage of ingredients, optimal parameters of technological equipment, process control based on data obtained by modeling, which reduces the number of defects and increases equipment productivity.

The conditions for using the results of the study are the legislation of the country related to environmental requirements, as well as compliance with the technological process.

For the resulting construction products, the bending strength increased by 20 % compared to traditional ones, the number of defects does not exceed 15 %, and equipment productivity increased by 12 %

Keywords: information technology, automation of process control, wind turbine blades, production of construction products

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1. Introduction

According to the 2019 composite materials market research conducted by Carbon Composites e.V., global demand for fiberglass (silicon dioxide) increased from 51 kilotons in 2010 to 141.5 kilotons in 2019 [1].

Renewable energy sources account for 29 % of global electricity production, and the number of wind turbines in the world is growing exponentially.

The service life of the turbine blades is 15–20 years, after which a complete replacement is required.

According to forecasts, by 2050, the amount of waste from blades in the United States will reach 2.2 million tons, the total volume will approach 43 million tons, it is expected that the use of spent blades (made of coal and fiberglass) will increase from 1 million tons in 2020 to 2 million tons in 2030, while 25 % of waste will be in Europe [2–4].

Companies and scientists have been working on various approaches for many years to develop technologies for using wind turbine blade material, including in the construction industry, although many potential solutions are in their infancy or remain small-scale.

Existing approaches to the reuse of recycled turbine blade material for building materials are quite ambiguous, moreover, there are no sufficiently advanced technologies for scaling technological processes.

There is a need to develop technologies for using recycled wind turbine blades as additives in building materials using information technology to ensure production efficiency.

Thus, the direction of this research is relevant and provides not only high scientific value, but also solves the environmental problems of mankind.

2. Literature review and problem statement

The source [5]; states that the widespread use of glass fiber and carbon fiber reinforced composites is hampered by the lack of recycling technologies and the need to develop effective technologies for processing these composites.

The work [6] describes studies on the use of crushed carbon fiber in concrete mixtures, while increasing the bending strength of samples up to 5 %. The disadvantages of the study are the possibility of practical application of the results.

In [7], more than 200 works related to the use of plastic in concrete mixtures were reviewed. The study is purely descriptive in nature without practical implementation.

In [8], the mechanical properties of wind turbine blades sharpened in "needles" were studied, the developed concrete mixture with a 10 % additive withstands longitudinal and bending stresses with an increase in the impact strength of the samples. However, research needs to be continued, since only prototypes have been developed and there is no systematic classification of prototypes.

In [9], crushed waste from wind turbines in geopolymer composites was studied, the strength of the resulting material increases due to a decrease in porosity. The disadvantages of the study are the availability of only prototypes, and further research is required.

In [10], methods of recycling wind turbine blades in Ireland are described, in the production of clinker, environmental benefits are achieved through the replacement of materials. Research is ongoing, as the environmental standards of European countries are strict, and cost estimates are needed.

Mechanical processing and combustion of turbine blades are described in [11], while CO_2 emissions into the atmosphere amount to 13.68 g. Research continues to find the most effective scenarios.

In [12], the grinding process of a wind turbine blade is described, a material called (RCWTB) is formed by fibers as a result of grinding a composite reinforced with glass fiber (GFRP), particles of cork wood and polyurethane. The addition of 6 % RCWTB does not impair the mechanical properties of concrete. It is necessary to continue research to obtain optimal compositions of concrete mixtures.

The paper [13] describes carbon fiber reinforced concrete (CFRC), a study that is still under development.

The paper [14] describes a project for recycling wind turbine blades for reuse, including cement production. Currently, the research lies on a theoretical plane, without any scientific conclusions.

The analysis of the considered works suggests that it is advisable to conduct a study of the problems associated with the classification of concrete mixtures with additives from recycled wind turbine blades for subsequent use in the technological process of manufacturing construction products based on information technology, since none of the works address these issues.

3. The aim and objectives of the study

The aim of the study is to increase the efficiency of the technological process management of the production of building products with fillers made of fiberglass through the introduction of information technologies.

To achieve the aim, the following objectives were accomplished:

– to classify concrete mixtures using information technology;

– to develop an algorithm for controlling the technological process of manufacturing construction products;

– to develop a program for managing the technological process of production of building products;

– to perform an evaluation of the effectiveness of the developed software.

4. Materials and methods

The object of the study is the production of construction products.

The main hypothesis of the study is that concrete mixtures made from fillers from recycled wind turbine blades meet the requirements of State standards in terms of characteristics and construction products can be made from them.

The assumptions made in the work include that all materials used in the development of concrete mixes comply with standards, the equipment used for production is standardized and has the corresponding quality certificates.

Simplifications adopted in the work: GOST– state standard.

The following methods and materials were used in the study:

– K-means statistical analysis methods, Takamura;

– methods of object-oriented programming;

– methods of system analysis;

– object-oriented C++ language;

– graph theory;

– methods of simulation and mathematical modeling;

– fragments of blades of wind turbines of the Yereymentau wind farm, Akmola region, Fig. 1;

– cement, Fig. 1, GOST 31108-2020, Semey;

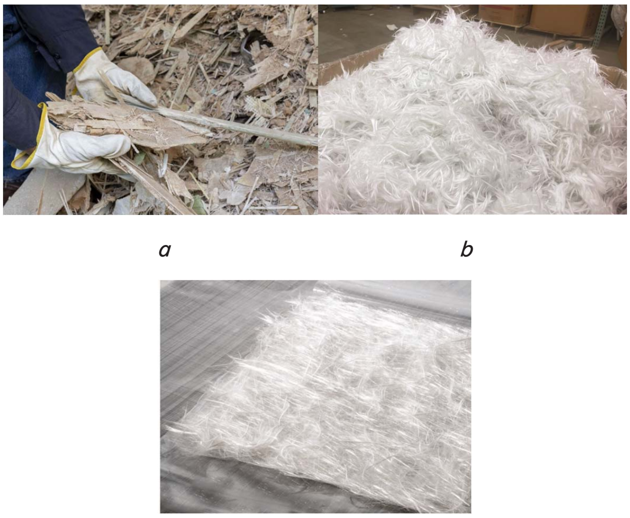
– river sand, GOST 8736-2014 "Sand for construction works", Fig. 3;

– metallurgical slag of various fractions GOST 3476-2019, Casting LLP, Pavlodar, Fig. 4;

– crushed stone, Maykain quarry, GOST 8267-93 "Crushed stone and gravel from dense rocks", Fig. 5.

All laboratory and field experiments within the framework of the study were performed on the equipment of Toraighyrov University and "EcostroiNII-PV" LLP (Fig. 6).

The results of the study were obtained on the basis of laboratory experiments, on certified equipment, the adequacy of the models was verified by the methods of Fisher and Student.



a *b* *c*

Fig. 1. The main signature: *a* – blade fragment; *b*, *c* – crushed blade material

Fig. 2. GOST 31108-2020, Semey cement

Fig. 3. River sand, GOST 8736-2014 "Sand for construction works"

a *b*

Fig. 4. The main signature: *a* – metallurgical slag of Casting LLP fraction 0÷5; *b* – fraction 0.1

Fig. 5. Crushed stone, Maykain quarry

a *b* *c* *d* *e* *f* *g* *h* *i*

Fig. 6. The main signature: *a* – vibrating table; *b* – scales; *c* – laboratory mill; *d* – press; *e* – crucible; *f* – bake; *g* – water absorption chamber; *h* – freezer; *i* – bending press

In addition, users have access to the HP ProBook 450 G10 laptop (15.6 FHD/Core i7 1355U/16 GB DDR4-3200/1 TB SSD/GeForce RTX 2050 4 GB/noOD/DOS).

5. Results of the study of using information technology in the technological process of production of building products

5. 1. Classification of concrete mixtures with glass fiber additives using information technology

For each composition of concrete mixtures, prototypes were made for testing (Fig. 7) according to [15–18].

a *b*

Fig. 7. The main signature: *a* – prototypes 1; *b* – prototypes 2

The form containing data on tests for strength, moisture absorption, frost resistance, concrete mixtures is given in Table 1.

The content of fiberglass additives in the concrete mix varied from 10–30 % of the total weight of cement in the test sample.

A software tool was used in the study [19]. The data in Table 1 are used as criteria for concrete mixtures.

The classification results are shown in Fig. 8, each class has its own color.

Table 1

The form of representation of concrete mixture composition

No. recipe	Criteria for metrics			
	Compressive strength, MPA	Tensile strength, MPA	Water absorption W_m, %	Frost resistance number of cycles
40	11	27	5.1	$F_1$41

The use of information technology makes it possible to exclude the influence of the human factor.

5. 2. Development of an algorithm for controlling the technological process of production of building products with glass fiber additives

Fig. 9 shows an algorithm for controlling the technological process of manufacturing construction products with glass fiber additives, based on [20].

Block 1 provides the setting of the initial values of the model:

– ST[0]= 0 (free);
– ST[1]= 32767 (any number);
– ST[2]= 32767 (any number);
– ST[3]= 480 (modulation interval).

Blocks 2–7 provide the Tt system time setting, block 8 analyzes the Vs value, 4 branches work on their own events. Event 3, the end of the simulation interval by block 16.

The algorithm calculates the system time of the occurrence of a new event, the array of events S[T] is reset to zero for events with numbers from 0 to NS=2.

A feature of the algorithm is the possibility of using a range of ingredients of the concrete mixture.

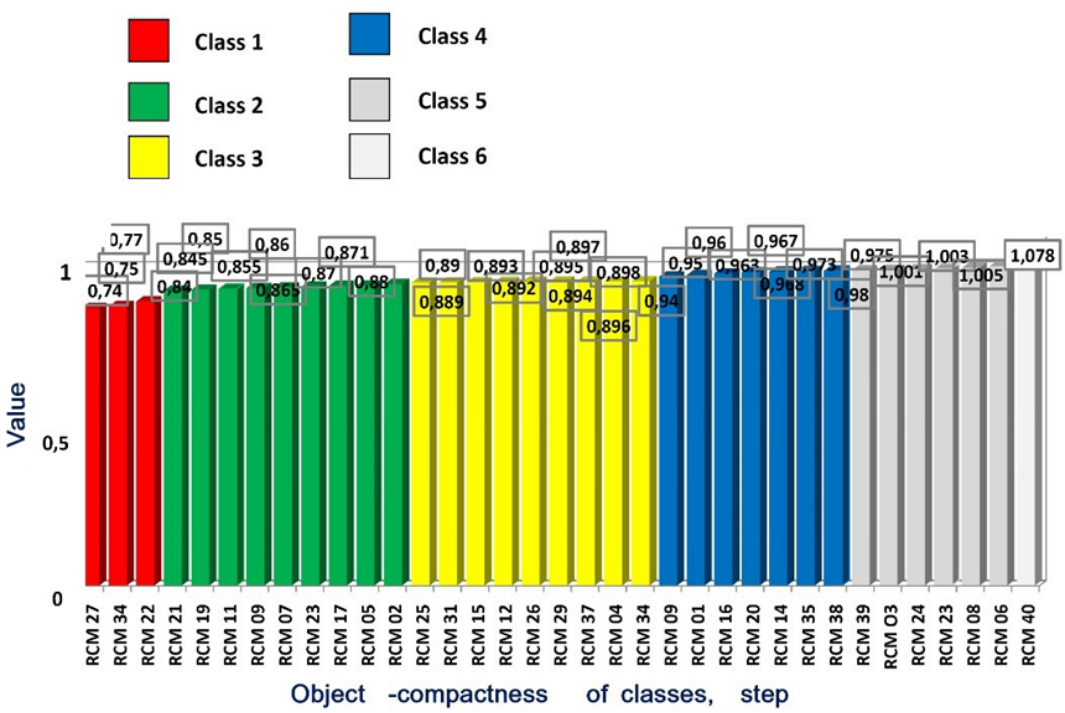


Fig. 8. Results of classification of concrete mixtures

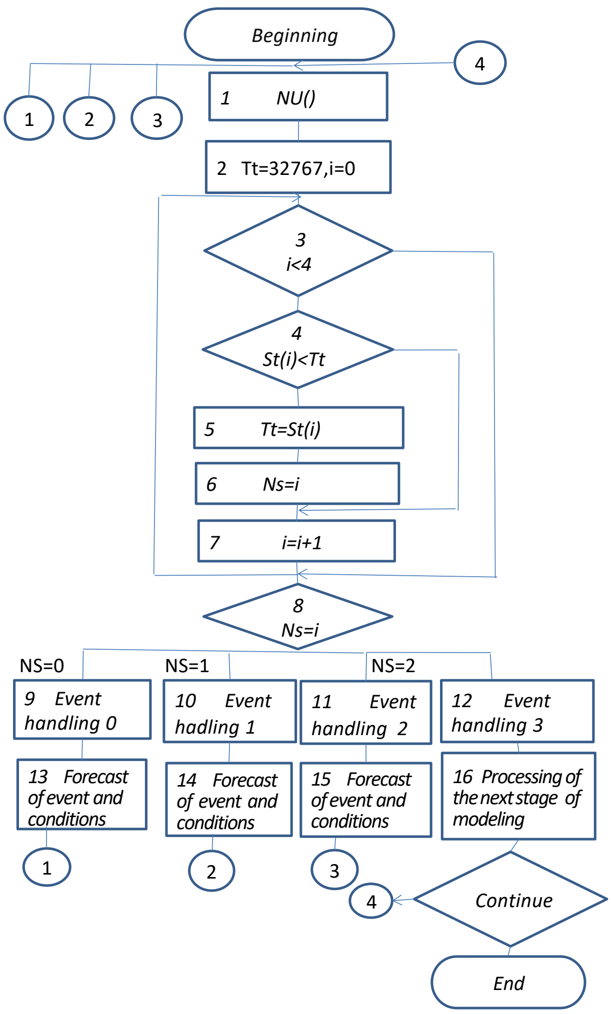


Fig. 9. Block diagram of the technological process control program for the production of building products with glass fiber additives

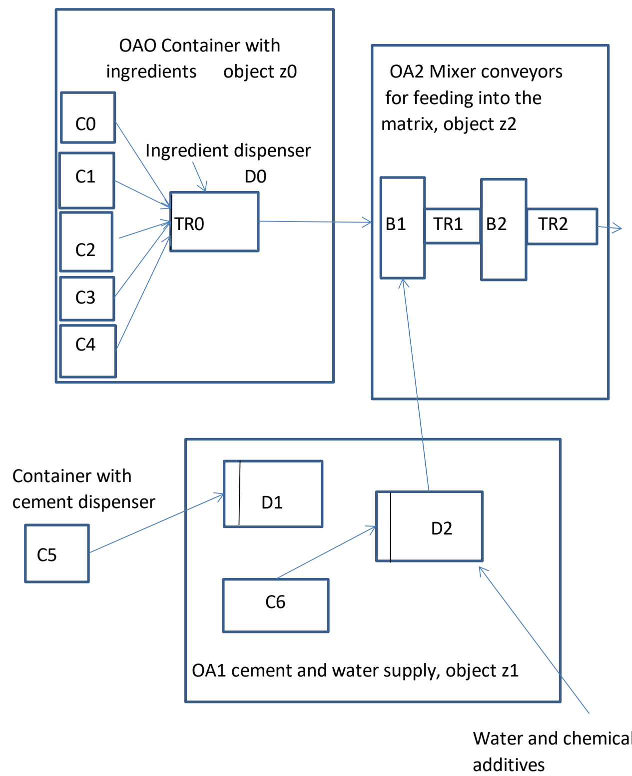


Fig. 10. Functional diagram of technological equipment

5. 3. Development of a process control program for the production of building products with glass fiber additives

The program code is written in C++.

The program presents three classes of objects: OA0, OA1, OA2, objects of classes: z0, z1, z2, Fig. 10.

At the beginning of the program, the plug-in (header) files with the h extension are specified, Fig. 11.

Listing of the process control program for the production of building products with glass fiber additives is given in Fig. 12.

```
//------------------------------------------------------------------------
#include <stdio.h>   (standard library input output directives)
#include <conio.h>(console input output directives)
# include <math.h> (directive of mathematical library)
#include <stdlib.h> (directive of standard  library)
#include <time.h> (guidelines for working with time and data)
#include <windows.h> (guidelines for working with Windows OS)
# define NNp 9 (The directive defines the NNP identifier with a
sequence of 9 characters)
# define Nk 10 The directive defines the NK identifier with a
sequence of 9 characters)
//------------------------------------------------------------------------
```

Fig. 11. Listing of the program with header files

The description of the OA0 class is presented in the program listing in Fig. 13.

Similarly, classes OA1, OA2 of the program are organized.

```
float Norm(float, float);
float ST[4];// list of events:
// ST[0]-  the end of the mixture formation by the z0 device  and
transfer to mixing
// ST[1]-  the end is mixing the mixture and pouring water z1
// and transfer of the wet mixture to the molding matrix and  vibro
press
//  ST[2] – the end of shaking and forming, the release  of finished
products z2
//  ST[3]- simulation interval in min *60=480 - one shift
floatTt;//system time
```

Fig. 12. Listing of the process control program for the production of construction products with glass fiber additives

```
class OA0// service class. apparatus forming a dry mixture (without cement)
{private:
public:
floatMassa[NNp]; // the actual mass of the components of the mixture, case. value(+- dispenser error)
intne;// the current number of the container to which the OA is connected, ne =0.1,...4
floatproisv;  // performance of the dry mix dispenser
intsost;// 0- it is free and can form a dry mixture
        // 1 – the formation of dry components without cement has been completed,
        //  The  transfer time of the components has been ordered, it is possible to transfer  the dry mixture to z1
        // 2 simple transfer is impossible - cement, water are supplied to the container, mixing is underway
        // 3- simple, because no, some ingredient has run out
floatsummamass;
// the total mass of the dry mixture in z0
floatoch;
// dispenser error %
OA0(); // designer
intFobr();
voiddisplay();
 };
```

Fig. 13. Listing of the OA0 class description program

5. 4. Evaluation of the effectiveness of the developed software

Fig. 14 shows the results of the program, using the example of paving slabs.

In this technological process, 6 tiles are formed simultaneously in a matrix, each weighing 5 kg. In total, 5,396 tiles were produced over a period of 480 minutes. The average productivity of technological equipment is 67.5 kg/min.

The mean square deviation of the system is 0.2 kg/min.

The presented program may vary the different compositions of the concrete mixture, their percentage content. Various scenarios for the production of construction products are possible, Fig. 14.

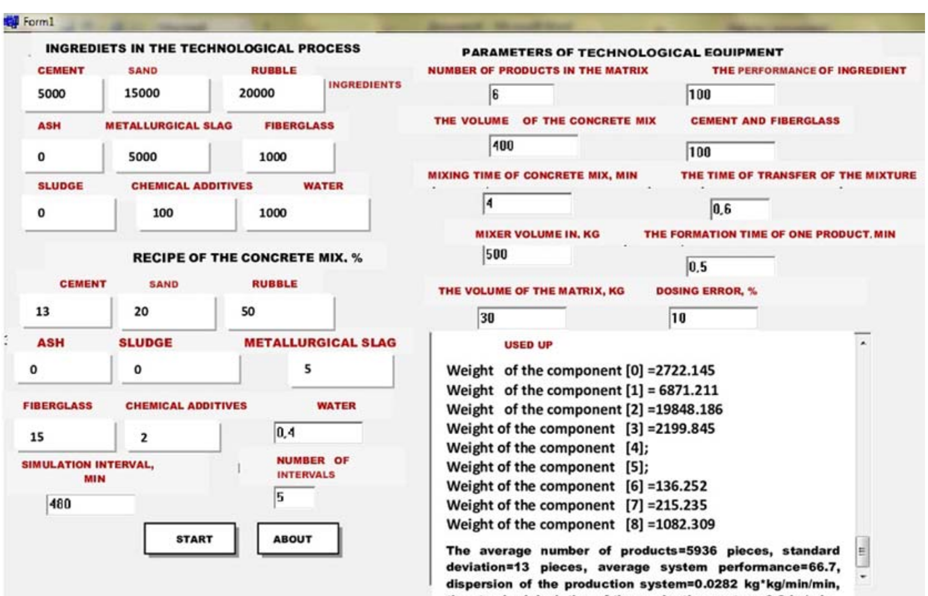


Fig. 14. The results of the program

For the production of the above-presented volume of products, 33,074 kg of concrete mix ingredients, including 215.236 kg of fiberglass, were used.

6. Discussion of the capabilities of the proposed process control program for the production of building products with glass fiber additives

The use of information technology allows us to classify the compositions of the highest quality concrete mixtures with fillers from recycled wind turbine blades, calculate the parameters of technological equipment to achieve optimal performance.

The explanation of the results is as follows:

– the classification of concrete mixtures from a large number of developed formulations and the variation of the ingredients of the concrete mixture (Fig. 8), using software tools, ensures an accurate and high-quality distribution of formulations into classes with the closest characteristics, this is achieved by adopting the most sensitive and influential metrics;

– to date, the process of classifying concrete mixtures with fillers from recycled blades has not been carried out, since in the works considered, only the possibility of processing wind turbine blades with subsequent use in concrete mixtures is investigated;

– the algorithm of the technological process of production of building products (Fig. 9) provides the functionality and feasibility of the technological process of production of building products, the possibility of its practical implementation due to the accurate representation and accounting of all operations of the technological process. The lack of a description of such algorithms in publications allows us to talk about the prospects and further promotion of the use of the algorithm for practical implementation;

– the functionality of the program for controlling the technological process of manufacturing construction products (Fig. 10–13) is provided by an accurate description of the algorithm based on program codes that allow performing all operations of the technological process, with the possibility of selecting the most optimal parameters of technological equipment, which brings the virtual model as close as possible to the real production process with minimal errors, checking the adequacy of the developed model by various statistical methods. The works discussed above are currently limited to research aimed at obtaining high-quality compositions of concrete mixtures and set tasks for the promotion of technologies for the production of building products;

– the efficiency of the production of building products

(Fig. 14) is provided primarily by high-quality compositions of concrete mixtures, accurate dosage of ingredients, compliance with process parameters, optimal parameters of technological equipment, ensuring process control with timely and prompt changes, which ultimately affects both the number of defective products and equipment productivity in general.

The peculiarity of the obtained results lies primarily in the possibility of their implementation in real production and subsequent commercialization, which significantly distinguishes the presented study from previously considered works that are at the stage of sample development and cannot yet be used in the production of construction products.

The results of the study are used in the pilot production of EkostroiNII-PV LLP (Republic of Kazakhstan), and field tests of samples of construction products show good results.

The limitations associated with the direction of our research are related to the materials of the blades of wind turbines used in the study, legislative acts in the field of processing man-made waste.

The disadvantages of the study include the following factors:

– the use of the same type of fiberglass sample;

– absence of glass fiber samples of smaller fractions.

Our research will be continued by experimenting with materials from various manufacturers of wind turbine blades.

The software solutions that exist today are focused on applications in other industries [21].

7. Conclusions

1. The peculiarity and distinguishing features of the results obtained are the production of classes of concrete mixtures, which, according to their characteristics, can be used for the production of building products, which is an advantage compared to the above-mentioned works that are at the stages of laboratory experiments. The results obtained are explained by using optimal metrics and obtaining classes with the highest quality characteristics of concrete mixtures. Concrete mixtures of classes 4,5,6 can be used in the production of building products that perform a high tensile load, and concrete mixtures of classes 3,2 for the production of building products that work on abrasion.

2. The peculiarity and distinguishing features of the results obtained are the development of a flexible algorithm capable of taking into account all the necessary operations of the technological process of manufacturing construction products. The results obtained became possible due to a deep study of the technology of production of building products, taking into account the characteristics of the ingredients used in concrete mixtures, and the operation of technological equipment. The obtained algorithm for the considered technological process allows us to take into account at least 3 classes and objects, which most fully represents the functioning of the entire process of manufacturing construction products.

3. The peculiarity and distinguishing features of the results obtained consist in obtaining a software tool capable of modeling the technological process of manufacturing construction products with fillers from recycled wind turbine blades, for various formulations of concrete mixtures and nomenclatures of construction products, with the selection of the most optimal parameters of technological equipment. The advantages of the presented software tool are flexibility, the ability to quickly change the compositions and the amount of ingredients of concrete mixtures, which ensures quick adjustment of the parameters of the production process. These results are explained by the fact that the resulting software tool is as close as possible to real production. The modeling interval of the program can vary from 480 minutes (working shift) and more, which allows you to determine the required amount of raw materials in the warehouse of the enterprise, calculate the production plan for construction products of various nomenclatures.

4. The peculiarity and distinguishing features of the results obtained consist in obtaining qualitative and quantitative indicators of the productivity of technological equipment in the production of construction products of various nomenclature and formulations of concrete mixtures. The advantage of the obtained results is the prompt receipt of equipment performance data, the exclusion of the influence of the human factor, and a low percentage of calculation error (which is affected only by equipment errors). The results obtained are explained by the full compliance of the program code with the program algorithm, taking into account all assumptions related to the execution of the technological process. The implementation of the program results in the production process reduces the number of defects by up to 15 %, with an increase in equipment productivity by up to 12 %, and the bending strength of the resulting construction products increases by up to 20 % compared to construction products made from traditional raw materials.

Conflict of interest

The authors declare that they have no conflicts of interest in relation to the current study, whether financial, personal, authorship, or otherwise, that could affect the study and the results reported in this paper.

Financing

The study was performed without financial support.

Data availability

All data are available in the main text of the manuscript.

Use of artificial intelligence

The authors confirm that artificial intelligence was not used in the development of the platform.

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