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A.D. SELEZNEV[1], N.V. KUZNETSOVA[1], V.A. EZERSKIY[2]
[1]Tambov State Technical University, Tambov, Russia
[2]Bialystok University of Technology, Bialystok, Poland

CEMENT BUILDING MATERIALS WITH POWDERED OPTICAL DISCS AS A FILLER

Abstract. *The object of study is a cement composite material with powdered utilized optical discs. The objective is to establish the dependences of the main strength characteristics – compressive strength, bending strength, and density – on the amount of waste added into the mixture and the water-cement ratio.*

The compositions of the mixtures for the production of the cement composite material samples consisted of the following components: cement, sand, powdered waste in the form of utilized optical discs and water.

Based on the results of testing the samples, mathematical models have been developed which describe the dependences of the physical and mechanical properties of the cement composite material samples on the fraction of waste and water-cement ratio. It was found that with an increase in the amount of powdered waste added into the mixture, it reduces the compressive strength, bending strength, and density of the samples under study, however, the optimization of the water-cement ratio makes it possible to obtain equal strength compositions with a different fraction of waste.

Component compositions of cement composite material mixtures with the addition of powdered utilized optical discs in the amount of 10 to 25 % of the total filler mass, which can provide construction products with a compressive strength class B20, are presented.

Keywords: *cement composite material, optical disc, water-cement ratio, compressive strength, bending strength, density, waste utilization.*

А.Д. СЕЛЕЗНЕВ[1], Н.В. КУЗНЕЦОВА[1], В.А. ЕЗЕРСКИЙ[2]
[1]ФГБОУ ВО «Тамбовский государственный технический университет», г. Тамбов, Россия
[2]Белостокский технический университет, г. Белосток, Республика Польша

ЦЕМЕНТНЫЕ СТРОИТЕЛЬНЫЕ ИЗДЕЛИЯ С ИСПОЛЬЗОВАНИЕМ ИЗМЕЛЬЧЕННЫХ ОПТИЧЕСКИХ ДИСКОВ В КАЧЕСТВЕ ЗАПОЛНИТЕЛЯ

Аннотация. *Объектом исследования является цементный композиционный материал с добавлением утилизируемых оптических дисков. Цель исследования: установление зависимостей основных прочностных характеристик – прочности на сжатие, прочности на изгиб и плотности – от количества вводимых в смесь отходов и водоцементного отношения.*

Составы смесей для изготовления образцов цементного композиционного материала состояли из следующих компонентов: цемент, песок, измельченные отходы в виде утилизируемых оптических дисков и вода.

По результатам испытаний образцов были разработаны математические модели, описывающие зависимости физико-механических свойств образцов цементного композиционного материала от доли отходов и водоцементного отношения. Установлено, что с увеличением количества вводимых в смесь измельченных отходов снижается прочность на сжатие, прочность на изгиб и плотность исследуемых образцов, однако оптимизация водоцементного отношения позволяет получить равнопрочные составы с различной долей отходов.

Представлены компонентные составы смесей цементного композиционного материала с добавлением измельченных утилизируемых оптических дисков в количестве от 10 до 25 % от общей массы заполнителя, которые могут обеспечить получение строительных изделий с классом прочности на сжатие B20.

Ключевые слова: *цементный композиционный материал, оптический диск, водоцементное отношение, прочность на сжатие, прочность на изгиб, плотность, утилизация отходов.*

Introduction

Despite the decline in the popularity of optical storage media, nowadays they are a significant part of the market of storage media and still have a wide range of usage in various life spheres. There are reasons to believe that in the near future their production and usage will not be stopped. In this regard, the question of their secondary use and recycling arises, because a significant number of discs to be disposed have already stored. According to approximate estimates, at present, the number of optical discs in the world to be disposed of is 250 billion discs or 3.9 million tons (about 3 million m^3).

Optical discs are a polycarbonate base with the thickness of 1.2 mm and the diameter of 120 mm, covered with a thin layer of metal protected by a layer of varnish or paint. The properties of optical polycarbonate used for the production of discs make it possible to consider it as a valuable secondary raw material for the production of polycarbonate and other polymeric materials [1-4], however, optical transparency is lost during recycling, which does not allow using it for the production of new optical discs.

Existing methods for the utilization of optical discs involve their recycling into raw materials for the production of lower-quality polycarbonate materials [3, 4]. However, in this case, the presence of impurities, such as paint, varnish, metal film, in the waste is unacceptable, because they affect negatively the quality of the final product. At the same time, the process of separating impurities from polycarbonate makes the recycling of discs technologically complex and energy-consuming, while the issue of using stored waste remains open.

According to the authors, a more rational solution to the problem of disc utilization may be to use them in powdered form for partial replacement of fine filler in concrete [5].

According to the waste classifier, the main component of the optical disk composition, polycarbonate, belongs to hazard class V, which makes it possible to use recyclable discs as an inert filler in a cement composite material, like other powdered industrial waste fillers [6-14]. It should be noted that in the case of the utilization of optical discs in the production of fine-grained concrete, they do not require thorough cleaning from aluminum film and other impurities. Thus, the proposed utilization method may be less energy-consuming and more economically effective.

The idea of using powdered optical discs as a filler in concrete is not new [15-18], however, in this paper, it is proposed to use powdered waste as an alternative to building sand, without using coarse filler, for example, gravel or crushed stone.

Thus, in this work, the object of study is a cement composite material with the addition of utilized optical discs. The subject of study is compressive strength, bending strength and density of the samples under study.

The aim of the study is to assess the possibility of using utilized powdered optical discs as a partial replacement of filler in cement composite material; defining the dependences of the main strength characteristics of concrete — compressive strength, bending strength, and density — on the amount of waste added into the mixture and the water-cement ratio; obtaining recipes and technologies of the production of cement construction products using powdered optical discs as a fine filler with strength characteristics which meet current technical standards.

Methods

The mixtures compositions for making cement composite material samples were made from the following components: cement, sand, powdered optical discs waste and water.

Portland cement M500 produced by OAO Sebryakovtsement (Mikhailovka) was used as a binder. The amount of cement was taken to be constant in a ratio of 1: 3 by weight to thefillerfor all component compositions of the mixtures.

Quartz sand with a fineness modulus of 1.0 (very fine according to GOST 8736-93) from a local field (Krasnensky quarry in the Tambov region) was used as a fine filler.

Waste in the form of powdered optical discs was added instead of sand in an amount from 0 to 50 % of the total weight of the filler (table 1). In the experiment, it was decided to use fractions of 0.315 – 2.5 mm, because this fraction is formed in the greatest amount during powdering of discs in a knife grinder. To obtain a finer fraction, it is necessary to increase the grinding time, which significantly increases the energy consumption of the technology.

In the process of preparing cement-sand mixtures, the amount of water (GOST R 51232-98) was taken depending on the water-cement ratio (table 1).

Table 1 - Variation intervals of factors x_1 and x_2

Factors	Variation levels		
	-1	0	+1
The proportion of powdered optical discs waste from the filler weight (factor x_1)	0	0.25	0.5
Water-cement ratio(W/C, factor x_2)	0.45	0.55	0.65

Dispersion of the mixture components and compaction during molding was carried out manually.

To carry out tests for central compression and bending, samples in the form of 40x40x160 mm bars were made. After 24 hours, the samples were removed from the molds, and their strength increase continued under the conditionsfor 27 days: temperature 20 °C ± 2 °C, air humidity 90 % ± 5 %.

The experimental determination of the samples compressive strength under central compression and bending was carried out according to the methods of GOST 10180-2012. The density of the samples was determined according to GOST 12730.1-78.

Results and Discussion

Based on the data obtained as a result of testing the samples, mathematical models have been developed that describe the dependences of the physical and mechanical properties of the samples of cement composite material on the above factors. One of the important results of the experiment is the ability to select the most optimal values of the mixture factors x_1 (fraction of waste from the weight of the filler) and x_2 (water-cement ratio).

Thus, mathematical models of the dependences of compressive strength Y_1, MPa, bending strength Y_2, MPa, and density Y_3, kg/m^3 were constructed, which, after excluding insignificant coefficients, have the form:

$$\hat{Y}_1 = 25.52 - 4.28x_1 - 0.81x_2 + 1.29x_1x_2 - 1.29x_1^2 - 1.38x_2^2,$$

$$\hat{Y}_2 = 4.32 - 1.41x_1 + 0.54x_1x_2 + 0.44x_2,$$

$$\hat{Y}_3 = 1962.8 - 256.9x_1 + 4.3x_2 + 36.1x_1x_2 + 5.8x_1^2,$$

where factors x_1 and x_2 are presented in coded values (table 1).

Graphical interpretations of the presented models are shown in figures 1-3.

In the absence of waste ($x_2 = -1$), equation (1) will take the form:

$$\hat{Y}_1 = 28.51 - 2.1x_2 - 1.38x_2^2,$$

The function has an extremum at $x_3 = -0.761$ (W/C = 0.47) and takes a value equal to $R_{c,r}$ = 29.31 MPa, which can be taken as the reference compressive strength. This component composition corresponds to the bending strength $R_{b,r}$ = 5.81 MPa (reference bending strength) and density ρ_r = 2249 kg/m^3 (reference density).

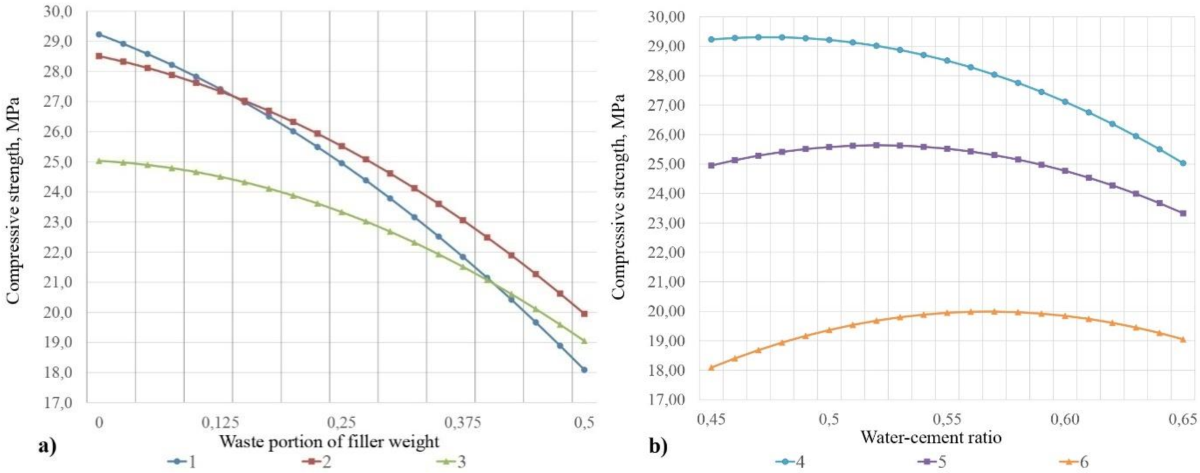

Figure 1 – The dependence of the cement material samples compressive strength on the proportion of waste x_1 and water-cement ratio x_2: a) x_2 = const, b) x_1 = const:

1 – $x_2 = 0.45$, 2 – $x_2 = 0.55$, 3 – $x_2 = 0.65$, 4 – $x_1 = 0.5$ – $x_1 = 0.25$, 6 – $x_1 = 0.5$

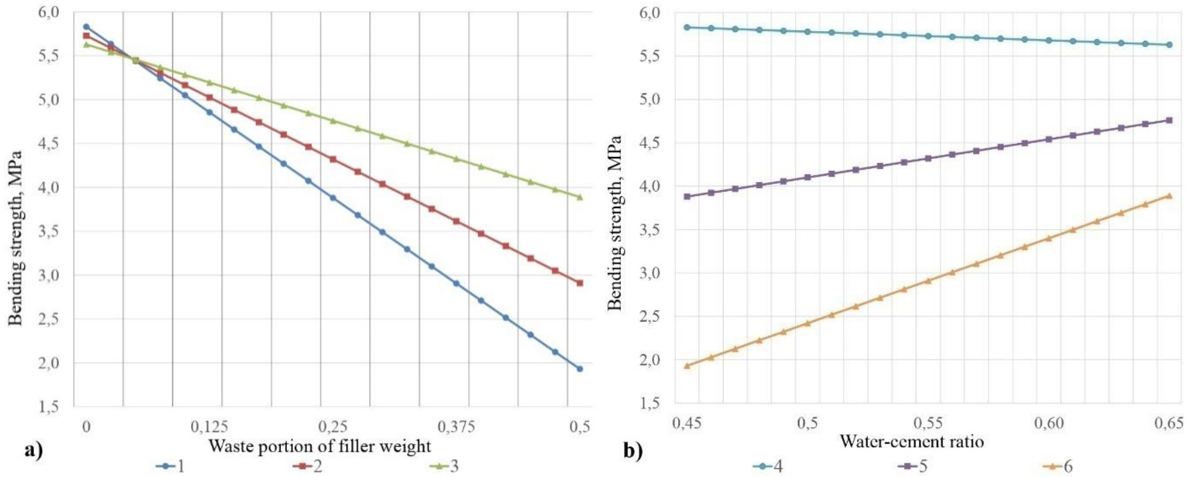

Figure 2 – The dependence of the cement material samples bending strength on the proportion of waste x_1 and water-cement ratio x_2: a) x_2 = const, b) x_1 = const:

1 – $x_2 = 0.45$, 2 – $x_2 = 0.55$, 3 – $x_2 = 0.65$, 4 – $x_1 = 0.5$ – $x_1 = 0.25$, 6 – $x_1 = 0.5$

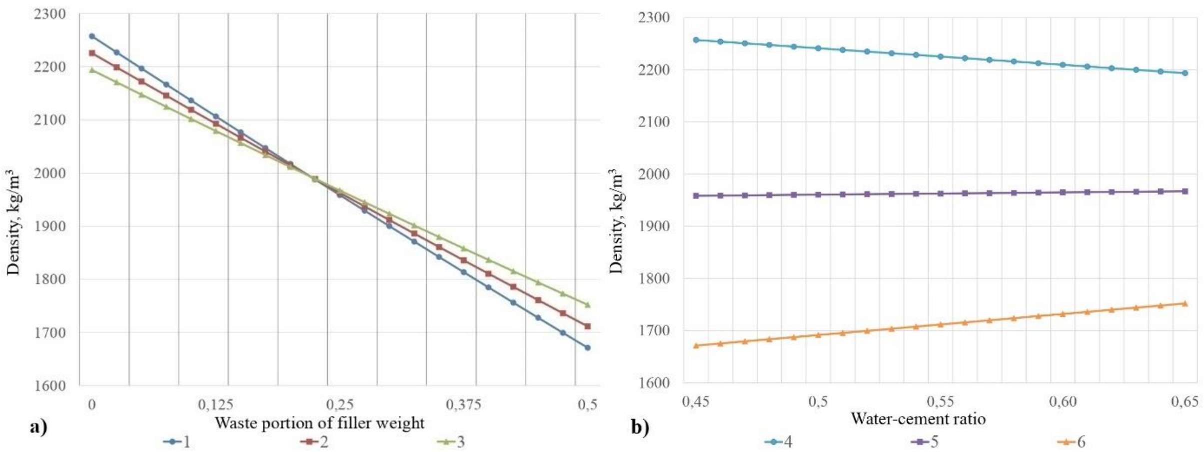

Figure 3 – The dependence of the cement material samples density on the proportion of waste x_1 and water-cement ratio x_2: a) x_2 = const, b) x_1 = const:

1 – $x_2 = 0.45$, 2 – $x_2 = 0.55$, 3 – $x_2 = 0.65$, 4 – $x_1 = 0.$ 5 – $x_1 = 0.25$, 6 – $x_1 = 0.5$

While maintaining the above W/C, the addition of powdred waste leads to a decrease in compressive strength. For example, the addition of waste in an amount of 0.10 of the filler weight leads to a slight decrease in strength by 4.4 % (from 29.31 to 28.01 MPa); at 0.30, the decrease is 17.5 % (from 29.31 to 24.17 MPa); at 0.50 – 36.3 % (from 29.31 to 18.68 MPa).

It should be noted that an increase in the proportion of waste shifts the optimal value of W/C upwards. If, for samples without waste, this ratio is 0.47, it is 0.49, 0.53 and 0.57, respectively for compositions with a waste fraction of 0.10, 0.30 and 0.50. The increase in the optimal value of the water-cement ratio during the addition of waste is explained by the fact that its actual value with a constant W/C and an increase in the waste fraction decreases, because due to the low bulk density of the waste (approximately 700 kg/m^3), the total mass of a filler and cement in the mixture is reduced.

A decrease in the water-cement ratio in the samples with waste leads to a decrease in bending strength and density, because, perhaps, the actual amount of water is not enough to distribute it evenly in the mixture volume, as a result of which the material porosity increases and the adhesion of particles to each other decreases. So, with a waste fraction of 0.5 by weight of a filler, an increase in the water-cement ratio from 0.45 to 0.65 leads to an increase in bending strength by 102 % (from 1.93 to 3.89 MPa), and density by 4.8 % (from 1671 to 1752 kg/m^3).

In the analysis of the results, it was found out that, all other conditions being equal, the addition of waste in the form of powdered optical discs reduces the strength of the cement composite material.

Nevertheless, an increase in the water-cement ratio to the optimum value of W/C = 0.51 in samples with a waste fraction of 0.20 from the filler weight makes it possible to approach the sample compressive strength to the value of the reference strength of the sample without waste (the decrease is 8.9 % from 29.31 to 26.53 MPa). It should be noted that there is a decrease in density by 10.3 % (from 2249 to 2016 kg/m^3) and cement consumption by about 11.3 % (from 530 to 475 kg/m^3).

The possibility of using the maximum possible amount of waste without significant deterioration of the physical and mechanical properties of fine-grained concrete is noteworthy. So, with a waste fraction of 0.30 (W/C = 0.53), the compressive strength decreases by only 15.8 % (from 29.31 to 24.67 MPa), and the bending strength decreases by 32.3 % (from 5.81 to 3.93 MPa), while the density decreases by 15.1 % (from 2249 to 1909 kg/m^3), which leads to a decrease in cement consumption by 15.1 % (from 530 to 450 kg/m^3).

Obviously, a further increase in the waste proportion becomes impractical, because the compressive and bending strengths are significantly reduced.

It is possible that the optimization of the granulometric composition of the powderedwaste and the addition of a plasticizer will improve the strength characteristics of the material and increase the proportion of waste added into the mixture, which necessitates additional studies.

Based on the presented experimental studies, the following component compositions of fine-grained concrete with the addition of powdered optical discs with filler-binder ratio of 3 : 1 by weight (table 2) can be determined, while the same strength characteristics can be achieved with different component compositions .

Table 2 – The physical and mechanical properties of the cement composite material with a filler in the form of powdered optical discs

№ composition	Waste fraction	W/C	R_{compr}, MPa	R_{bend}, MPa	ρ, kg/m^3	Concrete bending strength grade
1	0,00	0,47	≈ 29,0	5,8	2249	B22,5
2	0,05	0,49		5,4	2187	
3	0,10	0,49	≈ 28,0	5,1	2129	B20
4	0,15	0,50		4,8	2072	
5	0,20	0,51	≈ 26,0	4,5	2016	
6	0,25	0,52		4,2	1962	
7	0,30	0,53	≈ 24,5	3,9	1909	B15
8	0,40	0,55	≈ 22,5	3,5	1811	
9	0,50	0,57	≈ 20,0	3,1	1720	

After additional studies of the properties of the cement composite material with the addition of powdered optical discs, these component compositions can be used for the manufacture of products or as monolithic materials:

– floor screed (additional definition of abrasion when used as a topcoat);

– paving slabs (additional definition of water absorption, frost resistance and abrasion);

– wall blocks (additional definition of fire resistance and heat resistance for internal walls; additional definition of water absorption, frost resistance and thermal conductivity for exterior walls).

In the production of 1 m^3 of cement composite material with a waste fraction of 0.30 of the filler weight, 0.544 m^3 of powdered optical discs (approximately 20 thousand pieces) can be utilized.

Conclusions

1. Partial replacement of building sand in a cement composite material with powdered optical discs in a fraction of 0 to 50 % by weight of a filler leads to a decrease in the strength of the samples, however, optimization of the water-cement ratio allows obtaining equal strength compositions with a different proportion of waste.

2. The compressive strength of the samples of cement composite material with a fraction of waste of 20 % is 26.53 MPa, which is only 8.9 % lower than the strength of samples without waste.

3. The bending strength largely depends on the water-cement ratio: at W/C = 0.45 and a waste fraction of 0.25 on the filler mass, the bending strength decreases by 33 % (from 5.81 to 3.88 MPa) , with a fraction of waste of 0.5, the decrease is 67 % (from 5.81 to 1.93 MPa); with an increase in water-cement ratio to 0.65 in samples with waste, the decrease is 18 % (from 5.81 to 4.76 MPa) and 33 % (from 5.81 to 3.89 MPa) with a waste fraction of 0.25 and 0.5, respectively.

4. The density of the samples decreases linearly with an increase in the fraction of waste: with a percentage of waste 0.5, the decrease is 26 % (from 2249 to 1671 kg/m^3).

5. The compositions of mixtures of cement composite material with the addition of powdered utilized optical discs in an amount of 10 to 25 % of the total mass of filler and a water-cement ratio of 0.47 to 0.52 can provide construction products with a compressive strength class of B20.

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Information about authors:

Seleznev Artem Denisovich
Tambov State Technical University, Tambov, Russia,
graduate student of thedep "Architecture and Building Construction".
E-mail: selezen95@yandex.ru

KuznetsovaNataliaVladimirovna
Tambov State Technical University, Tambov, Russia,
candidate in technical sciences, associate professor, associate professor of the department "Architecture and Building Construction".
E-mail: nata-kus@mail.ru

EzerskiyValeriyAlexandrovich
Bialystok University of Technology, Bialystok, Poland,
doctor in technical sciences, professor, professor of the department "Fundamentals of Construction and Construction Physics".
E-mail: wiz75micz@rambler.ru

Информация об авторах:

Селезнев Артем Денисович
ФГБОУ ВО «Тамбовский государственный технический университет», г. Тамбов, Россия,
аспирант кафедры «Архитектура и строительство зданий».
E-mail: selezen95@yandex.ru

Кузнецова Наталия Владимировна
ФГБОУ ВО «Тамбовский государственный технический университет», г. Тамбов, Россия,
кандидат технических наук, доцент, доцент кафедры «Архитектура и строительство зданий».
E-mail: nata-kus@mail.ru

Езерский Валерий Александрович
Белостокский технический университет, г. Белосток, Республика Польша,
доктор технических наук, профессор, профессор кафедры «Основы строительства и строительной физики».
E-mail: wiz75micz@rambler.ru