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Development of a fiber-reinforced concrete mixture composition for 3D printing

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Abstract: 3D printed concrete has many new limitations and factors that create a weak interfacial bond, often referred to as a "cold bond" due to the lack of mixing between layers. The multilayer nature of 3D printing can lead to more porous and weak connections, causing anisotropy in mechanical properties, reducing overall load-bearing capacity, and affecting the performance and physical-mechanical characteristics of 3D-printed structures. Therefore, developing the correct concrete mixture formulation for 3D printing is an important task that involves achieving an optimal balance between all necessary characteristics and ensuring a long service life for the structure, which guarantees high-quality finished products.

The process of developing concrete mixtures is a complex task that requires extensive experimental research. The main parameters that need to be evaluated to determine the suitability of a concrete mixture for 3D printing include workability, fluidity, plasticity, and extrusibility. Additionally, the material for 3D printing must have sufficient fluidity to allow for easy extrusion through the nozzle. Furthermore, the composition of the mixture must be designed to withstand the loads of subsequent layers. Materials with high fluidity used in 3D printing are often prone to deformation and failure. If the mixture is too thick, it can lead to reduced adhesion between layers due to insufficient moisture. Therefore, in 3D printing technology, the rheological properties and optimal fluidity of the mixture are crucial for a successful printing process.

Keywords: metal cord, metal fiber, cement forecast, accelerated contraction method, cement system, cement activity

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1. INTRODUCTION

Freshly placed 3D concrete must meet higher rheological, hydration, and strength requirements than conventional concrete. The selected composition must ensure continuously extrude without damaging the surface, not cause concrete sticking or nozzle clogging, and build up the concrete mass with acceptable deformation before hardening [1, 2].

For successful extrusion, the setting and curing process is crucial. This requires considering the curing rate and the structural integrity of the layers. If curing is too slow, subsequent layers will settle on the weaker underlying layers, causing surface defects and deteriorating the strength of the entire structure. Speeding up the process of hydration is achieved by adding curing accelerators, such as plasticizing additives [3, 4].

The formable mixture must have sufficient plasticity and workability to allow it to be easily shaped into thin layers without forming voids or delamination. Each new layer must be securely bonded to the previous layers, ensuring the structural integrity of the building. This requires precise selection of the mixture composition and careful monitoring of environmental conditions (temperature and humidity).

The concrete mixture formed using additive technology must have a low viscosity to ensure continuous extrusion of the mixture through the printer nozzle during printing, and a high yield strength to prevent the material from spreading after application. At the same time, the material must harden quickly to support the weight of subsequent layers applied above [1].

To ensure high strength of concrete and improve its properties (dimensional stability, mobility), the basic approach is to maximally reduce the water-cement ratio while maintaining the mobility of the mixture, which is achieved by using highly effective plasticizing and water-reducing additives.

Another important component of fine-grained concrete is dispersed reinforcement to prevent cracking, increase wear resistance, and improve physical and mechanical properties. In this study, metal cord was used as a reinforcing element [5, 6].

This work proposes a comparison of metal cord with factory metal fiber. There is an assumption that the use of metal cord will become an alternative for steel fiber, due to the small diameter of the fiber, since the use of thin metal reduces the cost of the material and improves the performance of the structure, due to the fact that thin fiber is easier to distribute throughout the volume of concrete, reducing the risk of weak zones [7, 8]. In this regard, it is necessary to determine the optimal percentage of metal cord in the concrete mixture, which will ensure the strength of the structure without excessive increase in production costs.

2. METHODS AND MATERIALS

In this work, a finely ground cement with a specific surface area of 550 m²/kg was required for the experiments to be feasible. The cement was ground to provide plasticity, cohesion, and uniformity to the mixture during layer-by-layer extrusion (3D printing). The grinding was performed in a laboratory setting using a planetary mill called "Vibrotechnik MPP1-4" (Fig 1).



Fig. 1. Laboratory planetary mill "Vibrotechnik MPP1-4".

This mill is designed for ultra-fine grinding of materials of various strengths and hardnesses to a fine-grained state in a periodic mode using dry or wet methods. With this equipment, it is possible to achieve a specific surface area of 560 m²/kg for cement grinding in a relatively short grinding time of 4 minutes.

The specific surface area of the materials was determined using a specialized instrument, the PSX-10m (Fig. 2). The measurement method involves determining the time required for a fixed volume of air to pass through a sample layer.

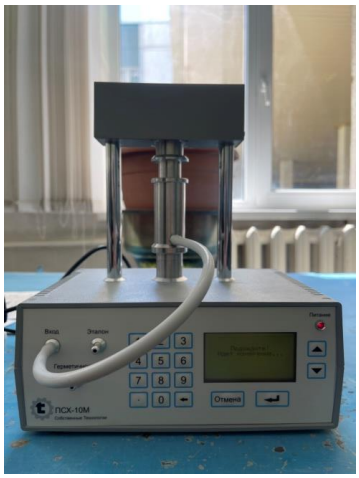


Fig. 2. Device for determining the specific surface area PSX-10m.

The normal consistency and setting time of the cement paste were determined using the Vika device according to the method described in GOST 310.3-76 "Cements. Methods for Determining Normal Consistency, Setting Time, and Uniformity of Volume Change" (Fig. 3).





Fig. 3. Vika device for determining the normal consistency and setting time of cement paste.

The metal cord used in the process is obtained from the mechanical processing of tires. The disposal of worn-out car tires is based on mechanical crushing, first the bead rings are cut off from the tires, the rubber is cut into several parts, and it is launched on the line for the mechanical processing of tires (Fig. 4). The resulting waste is crushed using a shredder to the size of "chips" (up to 10 cm²). Then they are processed on a special magnetic separator, which allows to completely separate the metal cord, and the rubber is crushed and passed through different sieves to sort by fractions. This recycling method is implemented at the enterprise (Ecoutilization-31 LLC, Belgorod region).



Fig. 4. Car tire recycling plant.

The resulting metal cord was cut and cleaned of rubber residues using the MN-0.25 knife mill (Fig. 5). The grinding process involves the impact and reflection of the material between the fixed and rotating knives. The ground material is then discharged through a sieve into the discharge port.



Fig. 5. Knife mill MN-0.25.

The required material size is determined by the diameter of the screen holes, the gap between the fixed and rotor knives, and the properties of the material itself. The loading and unloading pipes have flanges for connecting the mill to the associated equipment.

The study of the characteristics of concrete mixtures and hardened concretes was carried out using certified equipment and instruments that had undergone mandatory metrological testing. The analysis of the effect of plasticizing additives on the properties of concrete mixtures was conducted using comprehensive testing methods regulated by current national standards.

The mobility index of cement suspensions with the added plasticizer was studied using the NIIZhB methodology, which involves measuring the spread diameter of the cement suspension.

The shape stability and formability of the concrete mix for printing on a 3D printer were determined according to the methodology, namely, the index of the bearing capacity of the freshly formed layer (shape stability, plastic strength) – PS, as well as the rheological index – RTI. To assess the printability of the concrete mix intended for 3D printing, a measurement technique was used based on determining the amount of piston immersion of a special device for calculating the dough

vagueness index (RTI). The test procedure involves placing the mortar in an inverted cone-shaped vessel, applying pressure from a piston of a specific weight placed on top, and then compacting the mixture through vibration (30 cycles of shaking). The depth of the piston's immersion is measured in millimeters, reflecting the mobility and workability of the mortar and corresponding to the RTI (RTI) value of the mixture.

The load-bearing capacity of the freshly formed layer for 3D printing was determined using a Vika device equipped with attachments that allow for the assessment of resistance to deforming loads based on the pressure that the fresh solution can withstand before noticeable deformation occurs (deformation is 10%).

The time required for the structure to set is the time it takes for the mortar to gain sufficient strength after mixing to withstand loads that are approximately ten times its own density without significant deformation. This time is also determined using the Вика device, but it records the time interval from the start of the mortar preparation to the establishment of a stable structure.

The compressive strength of the concrete was determined using the standard procedure for selecting and developing the composition, which involves testing cubes with dimensions of 70×70×70 mm in accordance with GOST 10180−2012 "Concretes. Methods for determining strength based on control samples". Deviations from the dimensions of the cubes' edges did not exceed ±1%. The samples were produced in batches of 5 samples each. The concrete mixture was compacted using a laboratory vibrating platform of type 435A.

The compressive and bending strength was determined on beam samples measuring 4 ×4×16 cm, in accordance with the regulatory documentation GOST 31108–2020.

To obtain the result, the concrete cubes are crushed using a hydraulic press PGM-100MG4 (Fig. 6), which is designed for testing compressive and bending strength of building materials at loading rates specified by the relevant standard.



Fig. 6. Hydraulic press PGM-100MG4.

The cement contraction meter "CEMENT-PROGNOS" is designed to measure the volume deformations (contraction) of cement and predict its contraction activity according to the measurement methods MI 2486–98 and MI 2487–98 (Fig.7).



Fig. 7. Contracture measurement device (volume deformations) of cement "CEMENT-PROGNOS".

Experimental studies were conducted at an ambient temperature of (20 ± 5) °C, with an air humidity of less than 80% at a temperature of up to +35°C without condensation, as well as an atmospheric pressure of 84 to 106.7 kPa. During the studies, the measuring chamber should not be exposed to direct sunlight, and the chamber should not experience vibrations. The measuring device is manufactured in the third class of accuracy according to GOST R 52931–08.

The study of the surface character, shape, and microstructure of the obtained samples of fine-grained concretes was carried out using a TESCAN MIRA 3 LMU scanning electron microscope (Fig. 8). The microscope is equipped with an AZTECH Advanced Inca Energy 350 X-ray energy-dispersive microanalyzer (XEM) with an X-MAX 80 detector.



Fig. 8. Scanning Electron Microscope "TESCAN MIRA 3 LMU".

The clarity and detail of the images obtained by scanning electron microscopy is determined by the surface topography of the material under study and the composition of the elements that make up its structure.

The elemental composition of the surface layer was studied using X-ray spectral analysis (energy-dispersive method), which is based on the principle of the emission of characteristic X-ray spectra by

solid bodies under the influence of accelerated electrons with an energy of 1-30 keV. When interpreting the measurement results, the chromium layer, which was used solely to improve electrical conductivity, was taken into account and excluded from the final data.

3. RESULTS AND DISCUSSION

The effectiveness of the plasticizers for the concrete mixture was evaluated by the optimal amount of the introduced additive, determined by the highest value of the spread of the mini-cone. The tests were carried out according to the standard GOST 10181-2014. The results of the studies on the selection of the most suitable plasticizer and its percentage content for cement systems are presented in Table 1 and Fig. 9.

Table 1. Determination of the most suitable plasticizer and its percentage content for a composite binder.

Additive content, wt.%	Consumption of materials on a mini-cone		The spreading diameter of the mini cone, D, mm		
	PC, г	water, г	MC-Techniflow 80	MC-PowerFlow 3100konz	MC-Techniflow 71
0.1	100	29	62	63	63
0.2	100	29	83	70	72
0.3	100	29	96	81	77
0.4	100	29	123	105	99
0.5	100	29	138	114	109
0.6	100	29	145	120	125
0.7	100	29	158	131	128
0.8	100	29	167	147	141
0.9	100	29	170	158	151
1	100	29	-	167	160

Based on the analysis of the conducted studies, it was found that at a dosage of 0.8% of the MC-TECHNIFLOW 80 additive by weight of the concrete mixture, the maximum blurring of the cone was achieved at 167 mm, and this dosage is considered to be optimal [9].

Using other plasticizers requires higher concentrations to achieve the same plasticizing effect. Adding a plasticizer to cement systems increases its activity. Additionally, it affects the timing of setting, including the start and end times, as well as the normal consistency, which is important to consider when using concrete in various construction applications.

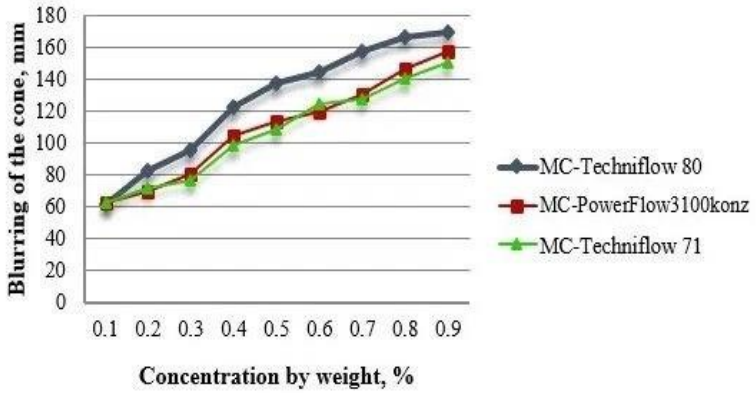


Fig. 9. The effect of a plasticizer on the properties of a cement system.

To increase the physical and chemical activity of the material, the cement was ground without and with the addition of MC-TECHNIFLOW 80 to a specific surface area of 550 m^2/kg.

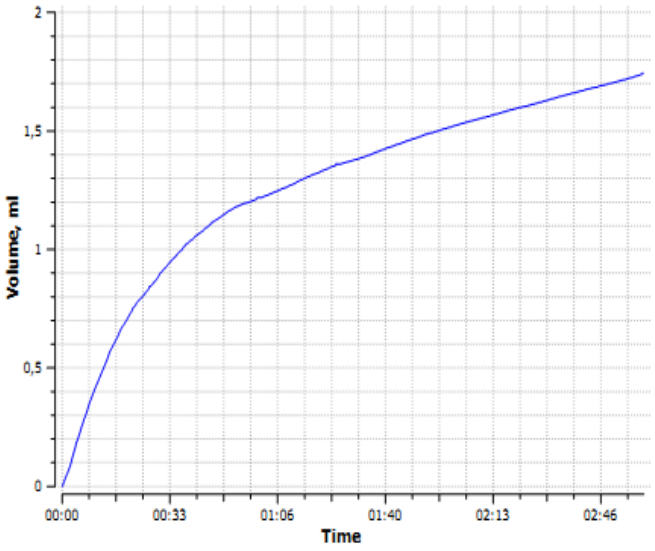
The activity of the cement systems was determined using the accelerated contractionometric method for determining and predicting the activity of cement according to the CEMENT-PROGNOS method. The measuring device was manufactured in the third class of accuracy according to GOST R 52931-08. Figures 10 and 11 show the obtained data.

The analysis of the data presented in Fig. 10 and 11 showed that the control cement (Fig. 10) has a predicted strength lower than the modified sample with an additive of 0.8% of the cement mass (Fig. 11), which is 44.6 and 54.3 MPa, respectively. The graph (Fig. 11) shows a smooth increase in contraction compared to the control sample, with a contraction value of 3.79 ml/g for the sample and 1.66 ml/g for the control cement (Fig. 10).

ACCELERATED DETERMINATION AND PREDICTION OF CEMENT ACTIVITY BASED ON ITS CONTRACTION MI 2486–98 AND MI 2487–98

Test parameters	
The mass of cement in a glass of Co, g	605
Duration, hh:mm	03:00
Period, s	10
Expected brand	M-500
ddV, мл (supplier)	1.5
Duration of hardening, day	28

Test results	
Contraction ΔV(C_o3), ml	1.00
Contraction ΔV1k3, ml	1.66
Braking	Да
Correction for braking, ml	1.50
Average temperature Tav, °C	17.12
Temperature correction, ml	0.07
Final contraction, ml/g	3.23
Activity R, MPa	44.6
The coefficient of coincidence	1.00
Activity with matching coefficient, MPa	44.60
Specific contraction, ml	0.037



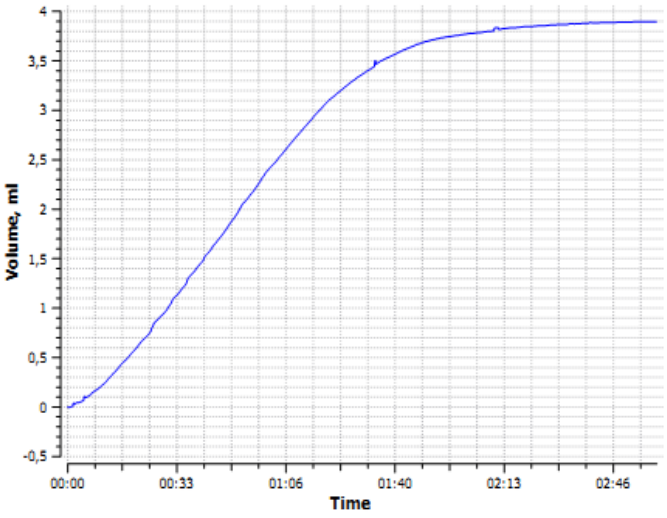
I conducted the test_____

Fig. 10. Accelerated determination and prediction of control cement strength.

ACCELERATED DETERMINATION AND PREDICTION OF CEMENT ACTIVITY BASED ON ITS CONTRACTION MI 2486–98 AND MI 2487–98

Test parameters	
The mass of cement in a glass of Co, g	617
Duration, hh:mm	03:00
Period, s	10
Expected brand	M-500
ddV, мл (supplier)	1.5
Duration of hardening, day	28

Test results	
Contraction ΔV(C_c3), ml	2.34
Contraction ΔV1k3, ml	3.79
Braking	Нет
Correction for braking, ml	0.00
Average temperature Tav, °C	16.76
Temperature correction, ml	0.10
Final contraction, ml/g	3.89
Activity R, MPa	54.3
The coefficient of coincidence	1.00
Activity with matching coefficient, MPa	54.30
Specific contraction, ml	0.044



I conducted the test_____

Fig. 11. Accelerated determination and prediction of the strength of ground cement with an additive.

The data obtained using the "Cement-Forecast" method showed that ground cement with an additive of 0.8% is more active, while the sample of cement without additives is less active, according to the criteria of reducing the contraction value and increasing the predicted strength of cement after 28 days of hardening compared to the control sample.

Thus, the addition of a plasticizer at a rate of 0.8% of the cement weight accelerates the setting time of the cement paste and reduces the water requirement. The introduction of the additive increases the strength of the cement stone by 15% compared to the control samples.

To develop high-quality fiber concrete compositions and to optimize the structure of the concrete matrix, a metal cord was introduced into the cement-sand mixture, which is a brass-plated wire obtained by recycling worn-out car tires with d = 0,2 mm and l = 10...15 mm.

To introduce the metal cord into the concrete mixture in laboratory conditions, the method of gradual mixing was used. This method allows for the uniform distribution of the metal material throughout the mixture, ensuring a high degree of homogenization of the concrete [10].

In order to determine the optimal percentage of metal cord in the concrete mixture, experimental concrete samples with a size of 70 × 70 × 70 mm and a composition of CB:S = 1:3 W/C 0.4 were molded and tested, with different percentages of metal cord by weight of the concrete mixture (025%, 0.5%, 0.75%, 1%). For comparison, samples were also molded using industrial metal fiber produced by Lazar LLC, l = 15 mm, d = 0.5 mm. The following systems were obtained: "C-S-W-P-MC" and "C- S-W-P -MF", where C – cement, S – sand, W – water, P – plasticizer, MC – metal cord, and MF – metal fiber.

After molding, the samples were cured for 28 days under normal conditions: temperature (20±2) °C, and relative humidity (50±20) %. The compressive strength of the samples was evaluated on the 28th day of curing. At least five samples were prepared for each composition. The strength value was determined as the arithmetic mean of the five samples, with a coefficient of variation of no more than 5%. The test results of the studies are presented in Table 2 and Fig. 12-15.

Table 2. Results of strength tests on samples with different percentages of MC and MF.

Composition	Components						W/C	Strength of samples R, MPa					
								when compressed			when bending		
	C, кг/м³	P, кг/м³	S, кг/м³	MC, кг/м³	MF, кг/м³	W, л/м³		7 day	14 day	28 day	7 day	14 day	28 day
1	500	4	1500	-	-	200	0.4	35.7	39.4	43.2	6.9	7.4	8.1
2	500	4	1494.5	5.5	-	200	0.4	39.5	42.3	49.1	8.8	9.2	9.5
3	500	4	1489	11	-	200	0.4	42.8	47.6	53.8	9.8	10.3	10.7
4	500	4	1483.5	16.5	-	200	0.4	41.9	46.3	51.9	8.5	8.9	9.3
5	500	4	1478	22	-	200	0.4	39.6	44.2	50.9	8.1	8.5	8.9
6	500	4	1494.5	-	5.5	200	0.4	40.1	42.9	49.9	9.0	9.4	9.7
7	500	4	1489	-	11	200	0.4	43.2	47.9	54.1	10.1	10.5	10.9
8	500	4	1483.5	-	16.5	200	0.4	42.3	47.2	52.7	8.7	9.1	9.4
9	500	4	1478	-	22	200	0.4	40.4	45.5	51.5	8.3	8.6	9.1

According to the test results, it has been experimentally proven that the use of metal cord or metal fiber increases the compressive and flexural strength compared to the unreinforced mixture. The compositions with the highest compressive and flexural strength are compositions 3 and 7, which contain 0.5% metal cord and 0.5% metal fiber by weight of the concrete mixture.

The content of metal cord or metal fiber in the amount of 0.5% of the mass of the concrete mixture in the fiber–concrete mixture contributes to an increase in compressive and bending strength (Fig. 12-15).

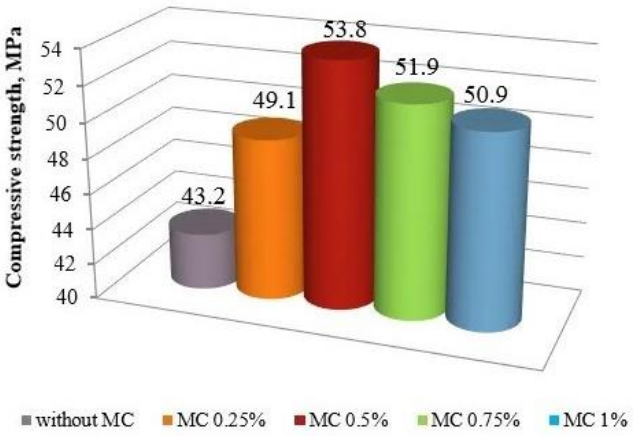


Fig. 12. Compressive strength of samples containing metal cord.

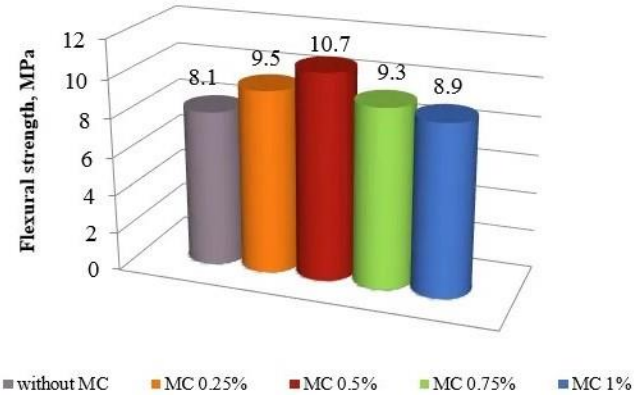


Fig. 13. Flexural strength of samples containing metal cord.

It has been experimentally proven that the greatest increase in strength and deformation characteristics is observed when the reinforcement of MC or MF is 0.5% of the mass of the concrete mixture. This is due to the fact that the cement stone is compacted between the fibers, resulting in a strong concrete mixture with a rapid hardening period at the initial stage.

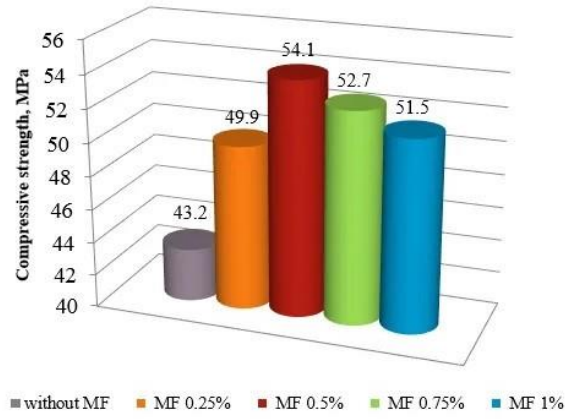


Fig. 14. Compressive strength of samples containing metal fibers.

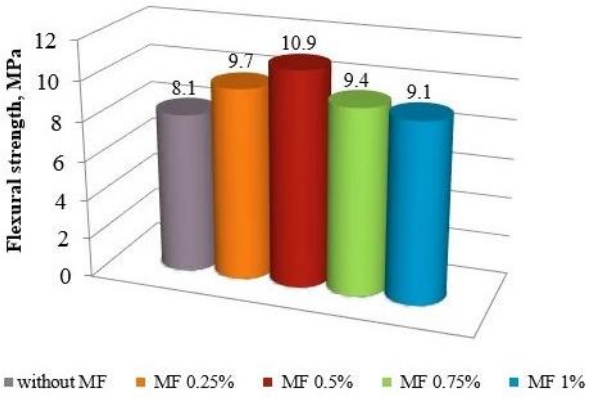


Fig. 15. Flexural strength of samples containing metal fibers.

It has been established that with an increase in the amount of fiber fibers at 0.75% and 1% reinforcement from the mass of the concrete mixture with metal cord or metal fiber, there is a decrease in strength due to "over-reinforcement" and it is not advisable to further increase the content of MC or MF fibers.

The analysis of the conducted studies showed that the strength using metal fiber in the concrete mixture will be higher than the strength using metal cord, but the difference in strength indicators is insignificant and is 0.5% in compression and 2% in bending, which allows us to conclude that it is advisable to use metal cord in the concrete mixture.

It is also worth noting the economic and environmental effects of using metal cord as a fiber in concrete. At large production scales, the addition of metal cord, even at a rate of 0.5% of the concrete mixture's weight, can have a positive economic impact, which is crucial for large organizations seeking cost-saving solutions. Additionally, it can help address the issue of waste management.

Thus, based on the results obtained, the optimal percentage of metal cord in the fiber-reinforced concrete mixture was 0.5% of the concrete mixture's weight, as compositions 2-5 with the use of metal cord performed significantly better than those without it, and composition 3 had the highest strength values (Fig. 16) compared to compositions 1, 2, 4, and 5.

The optimal content of metal cord was determined to be 0.5% of the concrete mixture weight, which increased the strength characteristics by up to 20% in compression and up to 25% in bending.

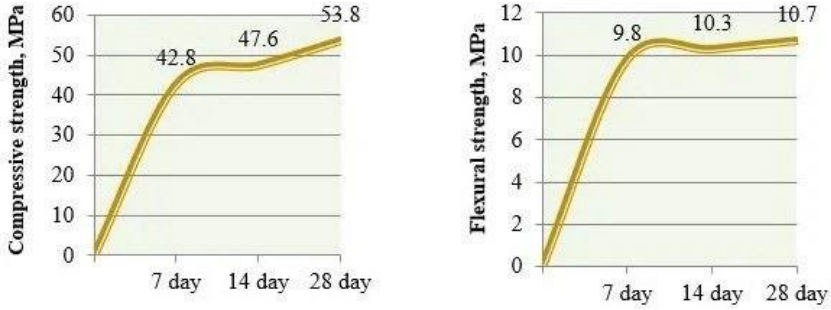


Fig. 16. Kinetics of fiber concrete strength development using MC 0.5% of the concrete mixture mass.

As a result of the conducted experimental studies, it has been proven that the use of metal cord in the composition of dispersed-reinforced concretes has a positive effect on the structure formation of fiber concrete, improving its performance characteristics, as well as increasing the physical and mechanical properties of fine-grained fiber concrete, which helps to obtain a competitive building material [11].

As a result of the conducted research, it was found that the introduction of MF fibers into the concrete mixture increases the compressive strength by 20.1% and the flexural strength by 25.6%, while the introduction of MC fibers increases the compressive strength by 19.7% and the flexural strength by 24.3% (Table 2). Therefore, the use of metal cord as a discrete reinforcement, as well as metal fiber, provides high physical, mechanical, and operational properties to the fiber mortar. This indicates the possibility of using metal cord in concrete solutions, which will reduce the cost of the final product, as the cost of metal fiber is significantly higher.

To study the microstructure, the following samples were compared: cement stone with metal fiber and MC-TECHNIFLOW 80 plasticizer; cement stone with metal cord and the same plasticizer.

Electron microscopic images of the studied cement stones are shown in Figure 17. In the studied images (Fig. 17, *a* and *b*), it can be seen that the structure of the samples under consideration has a characteristic porosity typical of this type of composite, but the pore size, shape, and total volume differ from each other. These differences are caused by the size and shape of the solid structural elements, the degree of their agglomeration and compaction, as well as the spatial arrangement of the components.

Fig. 17, *a* shows the microstructure of the cement composition "C-S-W-P-MF", where the contact layer of concrete with fiber has pores and voids, which indicates a weak adhesion of the fiber surface to the concrete due to the smoother surface of the metal fiber itself. The micrographs of this concrete sample also show a loose structure with plate-like and needle-like formations, which are characteristic of the early stage of hydration, indicating incomplete hydration processes in the samples that were cured in air.

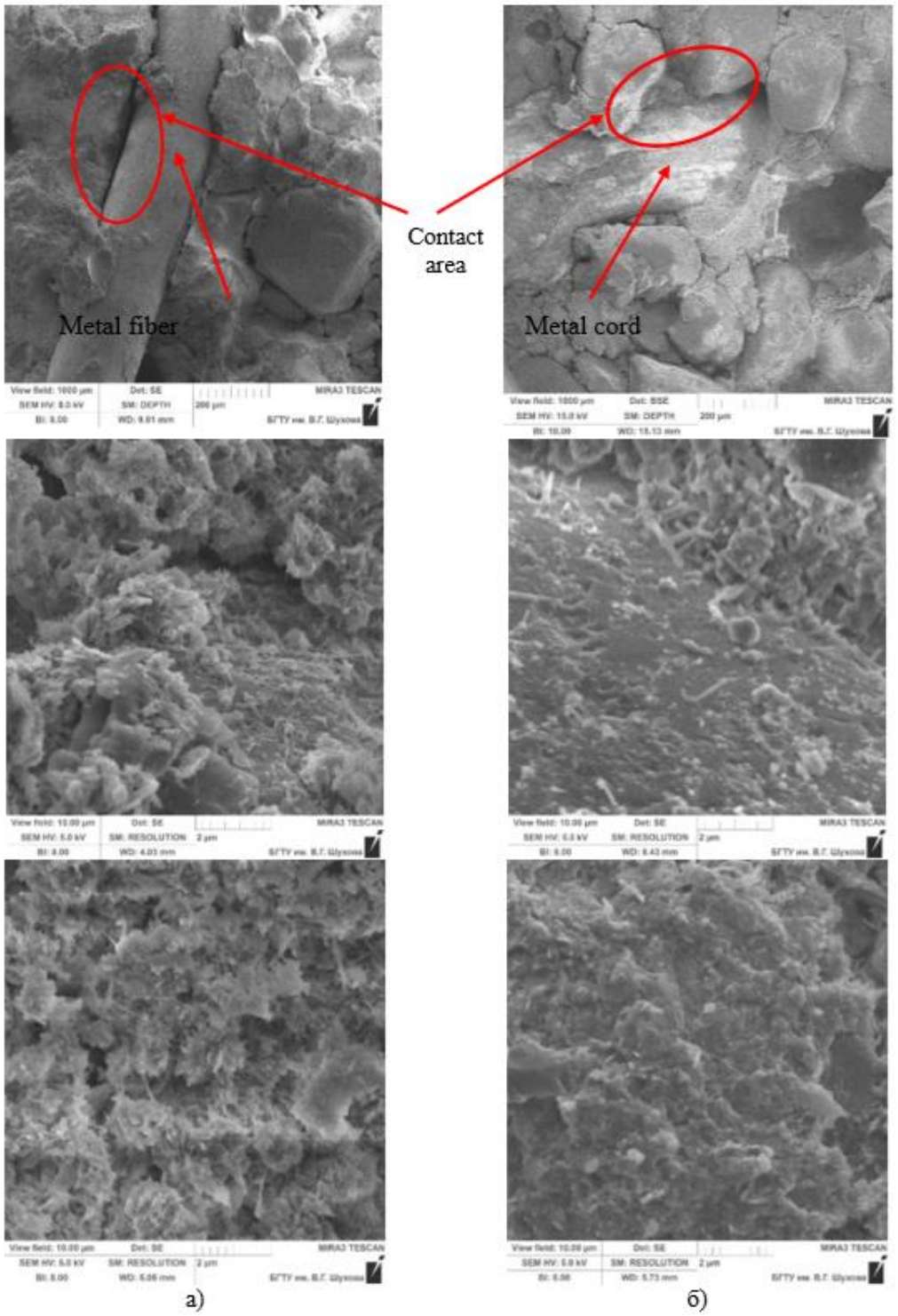


Fig. 17. Electron microscopic images of the studied cement stones (beginning): *a* – composition “C – S – W – P – MF”, *b* – composition “C – S – W – P – MC”.

Micrographs of the cement composition "C-S-W-P-MC" are shown in Fig. 17, *b*, which shows that the concrete layer in contact with the fiber filler has a denser and more uniform structure with a minimum number of pores and voids than in Fig. 17, *a*, which indicates good adhesion and strength. The adhesion strength of the cement stone to the metal cord is mainly due to the adhesion to the irregularities on the surface of the metal cord, and the layers of the cement stone that are in contact with the filler are usually of higher density and strength [12].

It is known that the dispersion of new formations and their quantity increase during the hydration of the binder in the presence of surfactants in comparison with the hydrating binder without the additive. At the same time, the density increases and the structural porosity of the cement stone is ordered. This is explained by the fact that the adsorbed surfactant molecule slows down the growth of the new formation, which in turn generates the appearance of new active centers and the repetition of the process.

Thus, the introduction of fiber (metal cord) into the cement mixture has a positive effect on the microstructure of the cement stone, improving the structure of the concrete composition by controlling the stratification and continuity of the mixture. The metal cord included in the structure of concrete contributes to the improvement of the reinforcing properties of concrete, as well as the improvement of the mechanical characteristics of concrete after it has gained strength.

For the successful formation of layers of the structure by extrusion, the printability and form-stability of concretes were determined using a method developed at the Shukhov State Technological University, as well as the rheotechnological index (RTI). The peculiarity of the compositions for 3D printing lies precisely in the combination of these properties:

1) printability (printability, extrusion) implies a set of qualitative and quantitative characteristics of both the mixture and the printer, which must be provided to transform the mixture into a structure or product;

2) form stability, which is proposed to be characterized by two complementary indicators:

– the bearing capacity of the freshly formed layer;

– the time of structure fixation, which is estimated through the ability of the mixture to withstand a certain number of sequentially stacked layers.

The properties of the bearing capacity of freshly formed layers of cement systems "C-S-W-P" (composition *1*) and "C-S-W-P-MC" (composition *2*) were studied. It was found that during the first 10 minutes, the plastic strength (form stability of concrete) increases almost equally for both types of mixture. After 30 minutes of hardening, composition *2* shows a sharp increase in strength compared to composition *1*. Then, after 50 minutes, it can be observed that composition *2* shows a significantly faster increase in plastic strength compared to composition *1*, with a minimum rate of strength increase over time. Thus, the plastic strength after 50 minutes is 27.5 kPa for composition *1* and 35.2 kPa for composition *2* (Fig. 18, Table 3). Composition *2* has the most characteristic indicators of plastic strength for the stable flow of strength development processes and their stability.

The plastic strength of the freshly formed layer, Pa, is determined by the formula:

$$PS = \frac{F}{S}, \quad (1)$$

there: F – the force with which the mixture begins to be extruded from the mold, kg;

S – the surface area of the die used for the compression process, m^2.

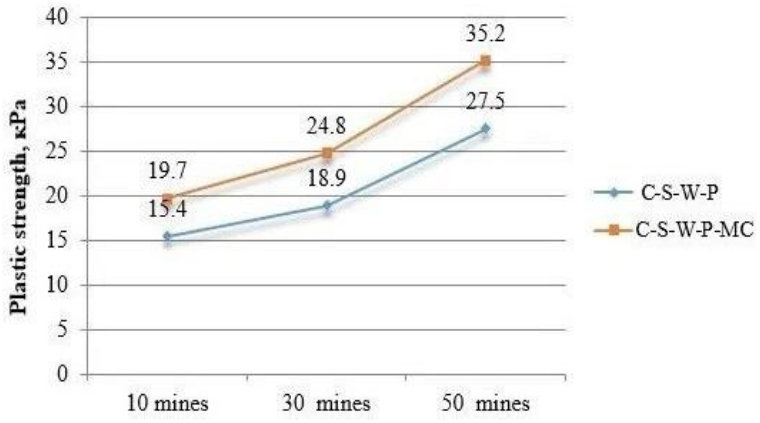


Fig. 18. Performance indicators of the load-bearing capacity of the freshly formed layer of cement systems.

As can be seen from Figure 18, the initial load-bearing capacity of composition *1* is slightly lower than that of composition *2*, which increases more rapidly during the first 10 minutes. Over the next 20 minutes, the load-bearing capacity of the cement composite continues to increase progressively, as the fibroconcrete mixture approaches its setting point.

The study of the rheological properties of the cement systems confirmed that the selected mixture is suitable for 3D printing technology. It was found that the lowest RTI value was observed in composition *2* (Table 3).

Table 3. Relationship between rheological and strength characteristics of cement systems.

Composition	Water absorption, %	Plastic strength, кPa for time, min			RTI
		10	20	40	
1	3.9	15.4	18.9	27.5	33
2	3.6	19.7	24.8	35.2	28

These properties of the mixture ensure high-quality laying during 3D printing, and contribute to the creation of a durable, uniform concrete layer with maintained form stability [13].

To assess compliance with the specified technical requirements, the process of pumping a cement-based system of the type "C-S-W-P-MC" was studied. It was found that this mixture can be pumped efficiently, without loss of layer thickness or the formation of gaps, and there is no risk of nozzle clogging or reduced adhesion strength between layers of the construction structure. This is important to prevent the concrete mixture from separating or breaking, and to ensure that the material is evenly distributed to the printer.

During the visual analysis of the studied cement mixture, good adhesion of adjacent layers, absence of cracks and uniform hardening over the entire volume of the formed samples were noted, which confirms the optimality of the developed fiber concrete formulation. It was also noticed a decrease in the water absorption rate of composition *2*.

Thus, it was established that the use of metal cord in the fiber concrete mixture will contribute to increasing the formability of the mixture, which makes it possible to apply subsequent layers during 3D printing [14, 15].

The analysis of the obtained data confirms the effectiveness of using the developed composition of the fiber concrete mixture in 3D printing technology.

4. CONCLUSIONS

A rational composition of fiber-reinforced concrete has been developed using metal cord obtained during the processing of used automobile tires with sufficiently achieved physical, mechanical and operational characteristics for its use in 3D printing technology and for successful extrusion.

The optimal percentage of reinforcement of fiber-reinforced concrete with a metal cord 10...15 mm long and 0.2 mm in diameter, amounting to 0.5% of the mass of the concrete mixture, has been experimentally established, at which the greatest increase in strength and deformation characteristics is observed. Replacing 0.5% of the mass of the concrete mix with a metal cord made it possible to increase the compressive strength of concrete by 19.7% and bending strength by 24.3% compared to the control cement concrete without fiber. This is due to the fact that the cement stone is compacted between the fibers of the metal cord.

The effectiveness of using metal cord as a reinforcing element in fiber-reinforced concrete has been proven by the XEM method. It has been experimentally confirmed that the strength of the adhesive bond of cement stone with metal cord is provided mainly due to its rough surface, as a result of which cement particles mesh with the irregularities of the metal cord surface with minimal formation of pores and voids, which helps to increase the density and strength of concrete.

It has been found that the use of metal cord in a concrete mix for 3D printing contributes to the production of a denser concrete mix with a high packing density and an increase in the plastic strength of the printed layers to 30%. Due to its thin diameter, metal cord has a positive effect on the structure formation of fiber concrete, as a result of which metal cord fibers are evenly distributed inside the concrete, which contributes to shape stability mixtures and improvement of the strength characteristics of concrete.

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