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Strength Indicators of Fiber Reinforced Concrete with Carbon Nanomaterials

S. N. Leonovich[1)], **E. A. Sadovskaya**[1)]

[1)]Belarusian National Technical University (Minsk, Republic of Belarus)

Abstract. Concrete composites with low defects, dense and homogeneous, with a high degree of adhesion between the cement matrix and aggregates, as well as a high ratio between static tensile and compressive strengths and plasticity have the best crack resistance characteristics. This ratio increases in the case of the use of fiber-reinforced concrete. Modern research in nanotechnology focuses on the management of matter at the nanoscale level, which makes it possible to create materials with new properties. Due to the high aspect ratio, flexibility, high strength and rigidity, carbon nanotubes (CNTs) exhibit reinforcing properties. Due to their nanoscale features, CNTs interact with a complex network of calcium-silicate-hydrate binder (C – S – H), contribute to a decrease in porosity and compaction of the cement stone structure, increase the shear forces of matrix adhesion in the contact zone. Thus, there are all prerequisites to assert that fiber concrete with a cement matrix modified with carbon nanotubes will have the required high strength characteristics and crack resistance due to multilevel dispersed reinforcement and the efficient operation of fiber in a nanomodified concrete matrix. This article presents the results of testing samples made of cement stone, concrete and fiber concrete with carbon nanotubes. The presence of carbon nanotubes in cement stone contributes to an increase in compressive strength by 11 %, tensile strength during bending by 20 %. The test results of samples made of reinforced fiber concrete modified with nanocarbon materials have shown an increase in tensile strength during bending up to 109 %, tensile strength during splitting up to 82 %, axial tensile strength up to 78 %.

Keywords: reinforced fiber concrete, tensile strength, carbon nanotubes

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Прочностные показатели фибробетона с углеродными наноматериалами

Докт. техн. наук, проф. С. Н. Леонович[1)], **Е. А. Садовская**[1)]

[1)]Белорусский национальный технический университет (Минск, Республика Беларусь)

Реферат. Лучшими характеристиками трещиностойкости обладают бетонные композиты с малой дефектностью, плотные и гомогенные, с высокой степенью адгезии между цементной матрицей и заполнителями, а также высоким

Адрес для переписки
Леонович Сергей Николаевич
Белорусский национальный технический университет
просп. Независимости, 65,
220013, г. Минск, Республика Беларусь
Тел.: +375 17 368-61-56
sleonovich@mail.ru

Address for correspondence
Leonovich Sergey N.
Belarusian National Technical University
65, Nezavisimosty Ave.,
220013, Minsk, Republic of Belarus
Tel.: +375 17 368-61-56
sleonovich@mail.ru

отношением между статическими прочностями на растяжение и на сжатие и пластичностью. Данное отношение повышается в случае использования фибробетонов. Современные исследования в нанотехнологиях фокусируются на управлении материей на наномасштабном уровне, что позволяет создавать материалы с новыми свойствами. Благодаря высокому соотношению сторон, гибкости, высокой прочности и жесткости углеродные нанотрубки (УНТ) проявляют армирующие свойства. Из-за своих наноразмерных особенностей УНТ взаимодействуют со сложной сеткой кальциево-силикатно-гидратного связующего (C – S – H), способствуют уменьшению пористости и уплотнению структуры цементного камня, увеличению сдвиговых усилий сцепления матрицы в зоне контакта. Таким образом, есть все предпосылки утверждать, что фибробетон с модифицированной углеродными нанотрубками цементной матрицей будет обладать требуемыми высокими прочностными характеристиками и трещиностойкостью за счет многоуровневого дисперсного армирования и эффективной работы фибры в наномодифицированной бетонной матрице. В данной статье представлены результаты испытаний образцов из цементного камня, бетона и фибробетона с углеродными нанотрубками. Наличие углеродных нанотрубок в цементном камне способствует увеличению прочности на сжатие на 11 %, на растяжение при изгибе на 20 %. Результаты испытаний образцов из дисперсно-армированного бетона, модифицированного наноуглеродным материалом, показали прирост прочности: на растяжение при изгибе – до 109 %, на растяжение при раскалывании – до 82 %, на осевое растяжение – до 78 %.

Ключевые слова: фибробетон, прочность на растяжение, углеродные нанотрубки

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Introduction

One of the main disadvantages of concrete, as the most commonly used building material in the world, is the fragility of destruction and low crack resistance. The study of fracture mechanisms is necessary to understand the fracture processes, which makes it possible to identify the parameters of the structure of materials that determine its crack resistance [1]. Crack resistance is an important factor in assessing and regulating the characteristics of concrete, as it helps to maintain the structural integrity of concrete and prevents its destruction. Concrete composites with low defects, dense and homogeneous, with a high degree of adhesion between the cement matrix and aggregates, as well as a high ratio between static tensile and compressive strengths and plasticity have the best crack resistance characteristics [2].

One of the promising ways to increase crack resistance is the introduction of various dispersed fibers. Dispersed fibers, evenly distributed throughhout the entire volume of the material, create a spatial framework and contribute to the inhibition of developing cracks under the action of destructive forces.

The expediency of using fiber is due to the following factors: the properties of dispersed reinforced concrete can be similar to the properties of concrete with twice the amount of reinforcement, but at the same time be cheaper; fiber reinforcement allows you to strengthen the corners of structures and adjust the thickness of the element in a larger range, which allows the use of fiber concrete in non-standard structures.

Replacement of cement with various materials, such as fly ash [3, 4], microsilicon [5, 6] cannot improve the microstructure of the cement matrix at the nanoscale, reducing internal defects (pores, cracks). Modern research in nanotechnology focuses on controlling matter at the nanoscale level, which makes it possible to create materials with new properties [7]. Examples of advanced nanomaterials used in the construction industry to improve the properties of building materials include calcium nanocarbonate (nano-CaCO□), nanosilicon (nano-SiO_2) and aluminum oxide nanoparticles (nano-Al_2O_3). One of the most frequent nanomaterials of the new generation is nanocarbon. Due to the high aspect ratio, flexibility, high strength and rigidity, carbon nanotubes (CNTs) exhibit reinforcing properties – they fill nanopores and connect grains of calcium hydrates (nanoarming) [8]. Due to their nanoscale features, CNTs interact with a complex network of calcium-silicate-hydrate binder (C–S–H), contribute to a decrease in porosity and compaction of the cement stone structure, increase the shear forces of matrix adhesion in the contact zone [9]. Thus, there are all prerequisites to assert that fiber concrete with a cement matrix modified with carbon nanotubes will have the required high crack resistance characteristics due to multilevel dispersed reinforcement [10–13] and the efficient operation of fiber in a nanomodified concrete matrix.

Laboratory tests

The following materials were used in the studies presented in this article: portland cement, sand with fineness modulus 1.8–2.0, granite crushed stone with a fraction of 5–10 mm and 5–20 mm, carbon nanotubes (CNTs) – the average diameter of tubes and fibers is 10–40 nm, the average length of tubes and fibers is 0.01–20.0 microns, CP-WBK superplasticizer (SP) in the form of an aqueous solution – polycarboxylate copolymer 39–41 %.

The results of compression and tensile tests [14, 15] for bending cement stone (W/C = 0.21) with carbon nanotubes (0.0004 %) dispersed in a superplasticizer [16] showed an increase in compressive strength by 11 % and bending strength by 20 % (Fig. 1).

Tests on samples of coarse–grained concrete (cement – 445 kg, sand – 820 kg, crushed stone 5–20 – 1035 kg, additive – 0.8 %, W/C = 0.29) the optimal amount of uniformly dispersed CNTs in the superplasticizer in the area of low concentrations equal to 0.00075 % of the cement mass was determined (Fig. 2).

Various types of fibers of domestic production were considered as dispersed reinforcement of the macro level (Fig. 3). Determination of the optimal amount of each type of fiber was carried out by analyzing the results of tensile strength tests and the workability parameter of the resulting fiber mixture (Fig. 4). It was found that the recommended optimal amount of fiber FSC-0.9-50 is 0.75–1.00 % by volume of the mixture, fiber FSA-1.0-60 is 1.0–1.5 %, fiber FPS-0.6-40 is 0.4–0.6 %.

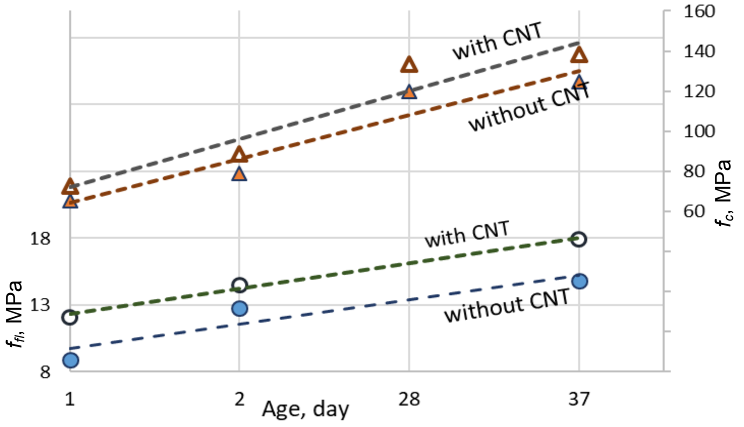


Fig. 1. Kinetics of strength gain of cement stone without CNT and with CNT

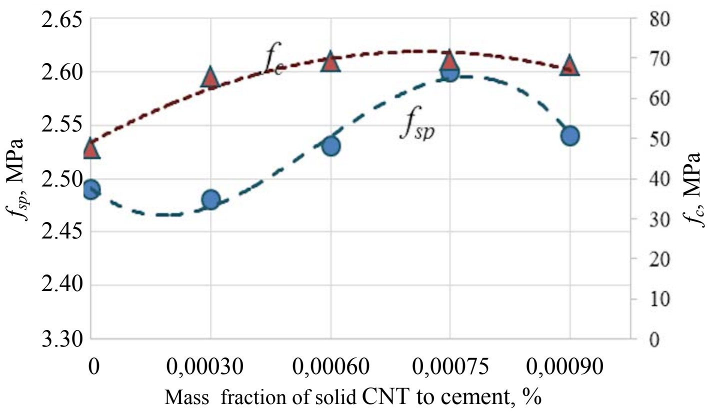
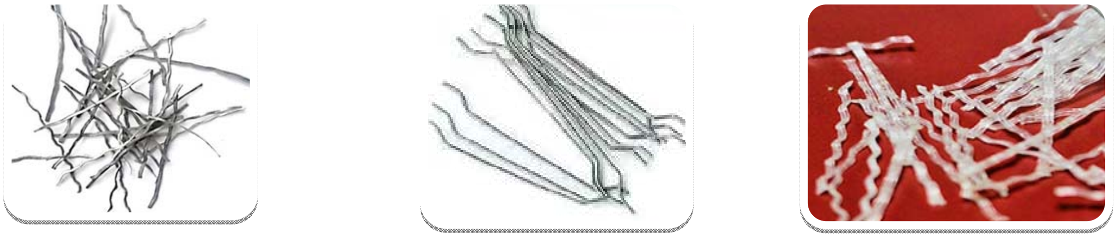


Fig. 2. Strength indicators of nanomodified CNT concrete



Corrugated sheet steel fiber
FSC-0.9-50

Fiber steel wire anchor
FSA-1.0-60

Polymer sinuous fiber
FPS-0.6-40

Fig. 3. Fiber

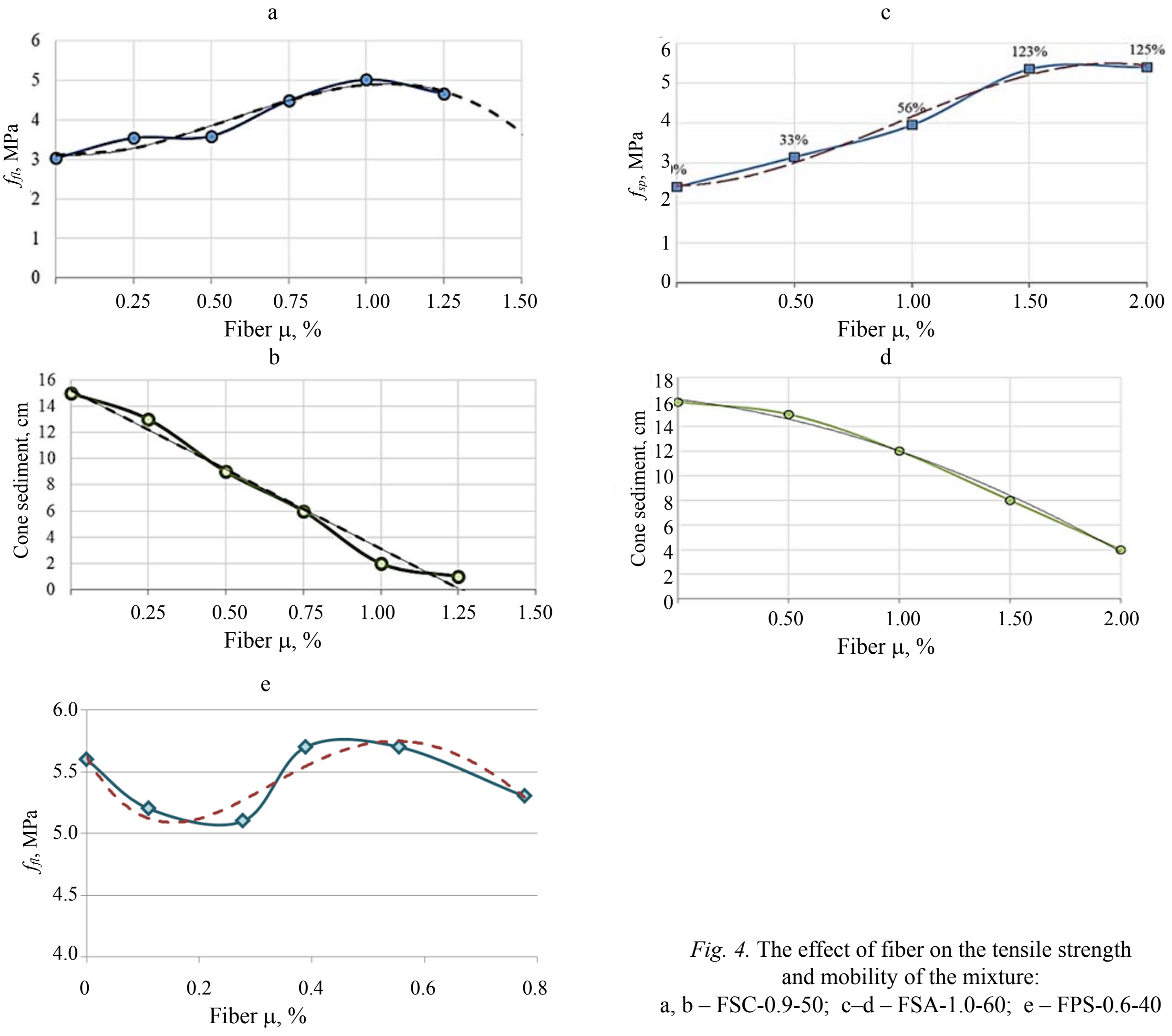


Fig. 4. The effect of fiber on the tensile strength and mobility of the mixture:
a, b – FSC-0.9-50; c–d – FSA-1.0-60; e – FPS-0.6-40

In order to create a dispersed reinforced concrete composite with the required crack resistance parameters based on the nanocrete compositions already used in the construction of the Belarusian NPP, while maintaining the required quality parameters to the original ones: compressive strength, water resistance, frost resistance, workability of the mixture (Table 1). Fiber was added to the resulting nanomodified concrete mixtures (concrete matrices): FSC-0.9-50 in an amount of 80 kg (F1), FSA-1.0-60 in an amount of 80 kg (F2), FPS-0.6-40 in an amount of 3.5 kg (F3).

From the obtained fiber-concrete compositions with a nanomodified concrete matrix, test samples were made: cubes with an edge of 100 mm, prisms of 100·100·400 mm, prisms of 70·70·280 mm. The resulting cube samples were tested for compressive strength. The test results are shown in Fig. 5.

Table 1

Nanomodified concrete compositions (nanocrete matrices)

Designation of the composition	Cement, kg	Crushed stone Fr. 5–20, kg	Crushed stone Fr. 5–10, kg	Sand, kg	Chemical additive with CNT (% by weight of binder)	Solid carbon, % by weight of cement	W/C
A	400	1020	–	820	3.2 (0.8)	0.00060	0,40
B	445	1035	–	820	2.22 (0.5)	0.00038	0,40
C	460	–	880	950	3.22 (0.7)	0.00038	0,40
D	485*	–	825	800	4.65 (0.7)	0.00060	0,44

* Additionally included 40 kg of expanding sulfoaluminate additive (ESAA) according to STB 2092–2010 and 45 kg of condensed silica (MCS-85) according to TU 5743-048-02495332.

Analysis of the results shows that the introduction of fiber reinforcement into the concrete matrix with CNT does not contribute to a significant increase in compressive strength. The maximum increase is observed in the compositions of B-F1 – 22 %, A-F1 – 17 %, B-F2 – 12 %, D-F2 – 10 %.

Samples-prisms of 100·100·400 mm were tested for tension during bending according to a four-point loading scheme. The half-prisms obtained after the tests were tested for tension during splitting [17, 18]. The test results are shown in Fig. 6.

The analysis of the obtained results shows that the increase in tensile strength during bending is observed in all cases of fiber reinforcement. The highest value in the compositions of A-F2 is 109 %, A-F1 is 104 %, A-F3 is 81 %, B-F2 is 48 %, B-F1 is 38 %, B-F1 is 59 %, B-F2 is 55 % [17]. An increase in tensile strength during splitting is observed in samples reinforced with metal fiber: F1 – 24–82 %, F2 – 35–70 %.

According to the obtained test results of the samples-70·70·280 mm breeze for axial tension (Fig. 7), the greatest increase in strength is observed in the composition with a concrete matrix with the highest strength value: D-F1, D-F2 – 77 %; D-F3 – 35 %.

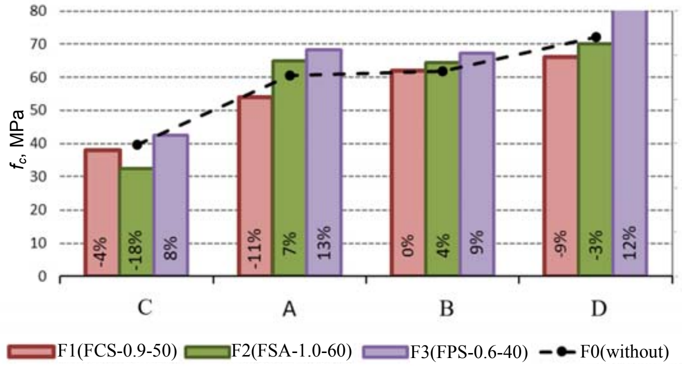
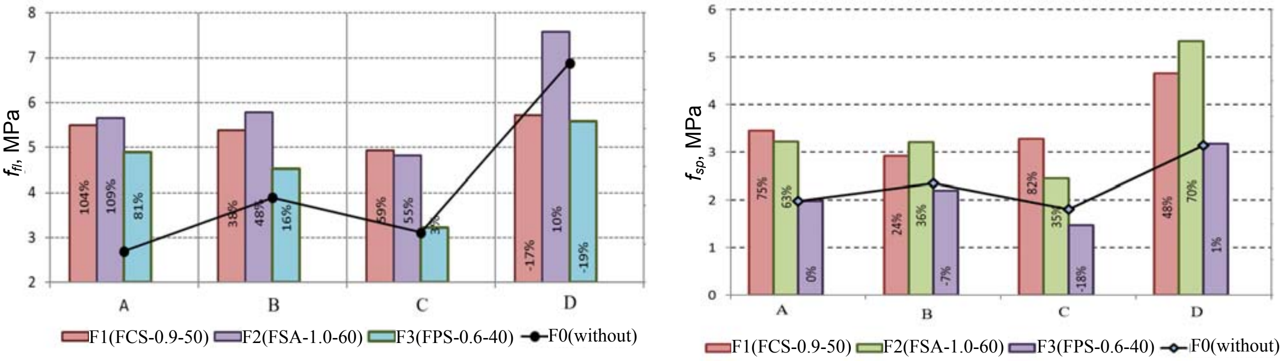


Fig. 5. Compression test results



a

b

Fig. 6. Results of tensile tests: a – during bending; b – during splitting

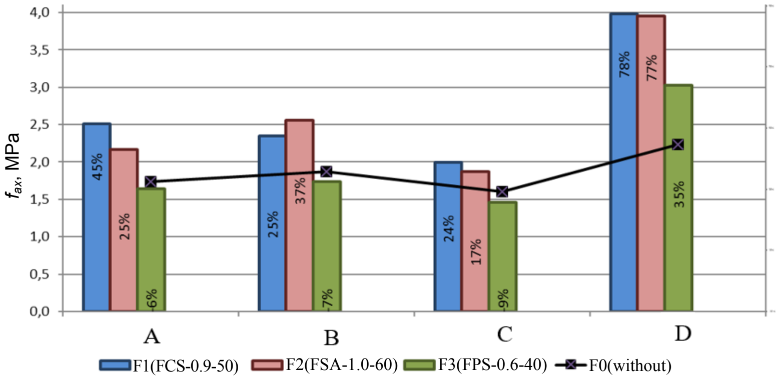


Fig. 7. Results of axial tension tests

CONCLUSION

The use of dispersed reinforcement at the nanoscale is one of the methods for obtaining high-performance concretes that allow designing elements of buildings and structures with the required strength indicators and at the same time resistant to cracking and durable.

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