Case Studies in Construction Materials 16 (2022) e00814

Contents lists available at ScienceDirect

Case Studies in Construction Materials

journal homepage: www.elsevier.com/locate/cscm

Case study

Effect of low-modulus polypropylene fiber on physical and mechanical properties of self-compacting concrete

Daniyar Akhmetov [a], Sungat Akhazhanov [a,b], Ainur Jetpisbayeva [c,*], Yuri Pukharenko [d], Yelena Root [a], Yelbek Utepov [e], Akbulat Akhmetov [f]

[a] NIISTROMPROJECT (LLP), Radostovec st. 152/6, 050000 Almaty, Kazakhstan
[b] E.A. Buketov University of Karaganda, Faculty of Mathematics and Information Technology, Universitetskaya st. 28, 100028 Karaganda, Kazakhstan
[c] Satbayev University, 22 Satbaev st., 050013 Almaty, Kazakhstan
[d] Saint Petersburg State University of Architecture and Civil Engineering, Department of Building Materials and Metrology, 2-ya Krasnoarmeyskaya st. 4, 190005 St. Petersburg, Russia
[e] L.N. Gumilyov Eurasian National University, Department of Civil Engineering, Satpayev st. 2, 010008 Nur-Sultan, Kazakhstan
[f] M. Auezov South Kazakhstan University, Tauke Khan ave. 5, 160012 Shymkent, Kazakhstan

ARTICLE INFO

Keywords:
Self-compacting concrete
Low-modulus fiber
Workability
Flexural strength
Shrinkage

ABSTRACT

The article presents the results of laboratory experiments investigating the necessity and expediency of disperse reinforcement of self-compacting concrete (SCC) to increase its physical and technical parameters and the study of deformative properties of SCC with the use of fibers. For collaboration with manufacturers to improve physical and mechanical properties and durability, to deduce basic laws, researchers on the basis of previously published results, offered disperse reinforcement of SCC by polypropylene fibers of 6, 9, 12, 15 mm in size and quantity from 0.5 to 2 kg per 1 m^3 of concrete mixture. From the work done it can be concluded that the addition of 1–2 kg per 1 m^3 of fiber with 9÷15 mm in size improves the physical and technical properties of SCC, such as flexural strength by 10%, and shrinkage deformations reduced to 75% compared to the concrete without fiber. In the course of this study, it was found that the disperse reinforcement with low-modulus fiber increases the characteristics of SCC in production. Based on the results obtained, practical recommendations for the optimal size and amount of fiber in SCC were presented in order to derive the optimal price-quality ratio, as well as to improve the quality of concrete works at high temperatures > 20 °C.

1. Introduction

Researchers throughout the world are concerned with improving the properties of self-compacting concretes (SCC). Much attention is paid to the selection of SCC compositions with increased physical and technical properties, performance and durability [1–3].

The composition of materials for SCC differs from materials for conventional concretes. SCC is characterized by an increased content of fine aggregate, filler and binder (cement and active additive). A well-matched SCC with a reasonable number of constituents

* Corresponding author.
E-mail addresses: dan-akhmetov@yandex.kz (D. Akhmetov), stjg@mail.ru (S. Akhazhanov), a.jetpisbayeva@satbayev.university (A. Jetpisbayeva), tsmm@spbgasu.ru (Y. Pukharenko), project_manager@niistrom.kz (Y. Root), utepov-elbek@mail.ru (Y. Utepov), aakbulat@mail.ru (A. Akhmetov).

https://doi.org/10.1016/j.cscm.2021.e00814
Received 17 September 2021; Received in revised form 18 November 2021; Accepted 24 November 2021
Available online 26 November 2021

has a homogeneous structure and its properties are more stable than those of conventional concrete. However, producers of self-compacting concrete continue to involve scientific institutes in order to study the prospects for improving the properties of this type of concrete, as well as to deduce the basic patterns that can be adopted in changing the production program for this material, for example, in conjunction with the transition to new raw materials [4–6].

Having studied the technical specifications prepared by the manufacturers of SCC, we proposed to consider the synergistic properties of two types of concrete: self-compacting concrete and fiber concrete - a material consisting of a cement matrix (dense or porous, with or without filler) with a distribution over its volume of oriented or chaotically arranged disperse fibers of different origin. For dispersed reinforcement of fiber concrete mostly metallic (mostly steel) and non-metallic (mineral, polymeric, etc.) fibers of different shapes, lengths and cross-sections are used [7]. Fibre concretes have always been notable for their high deformational properties, such as concrete flexural strength, low shrinkage, and high abrasion resistance. Having analyzed the literature on the subject, reviewed the latest works of well-known concrete scientists on the study of SCCs and based on our own developments, the research team decided that at present there is an opportunity to create SCCs with high physical and technical properties [8].

The novelty of this work lies in the study to assess the physical and technical properties of fiber-reinforced SCC (hereinafter FSCC) and the analysis of the service life of products and structures made of this material. While the previously published papers mainly consider the issue of the possibilities of reinforcement of conventional heavy concrete with fiber, reflecting the solution of one specific problem, for example: a) increasing the flexural strength by using disperse reinforcement by polyolefin macrofibers [9]; b) Solving the problem of brittle fracture of high-strength concrete [10]. Also performed the study of the mechanical, fracture and durability characteristics of self-compacting high-strength concrete (SCHSC) containing recycled polypropylene plastic particles (RPPP) with and without silica fume [11].

The next important aspect is the service life of building materials, which should be 75–100 years, and premature loss of their operational properties will lead to significant capital expenditures for their repair and restoration. One of the perspective ways to increase physical-technical and operational characteristics of concrete is the addition of polymeric low-modular fiber. The use of this material can increase the tensile strength of the cement matrix, which provides a higher tensile strength at bending of cement concrete. It is recommended to use polypropylene fiber in fiber concrete technology to reduce delamination of mixtures, increase water resistance, frost resistance, impact strength, abrasion resistance. In addition, polypropylene fiber is characterized by corrosion resistance compared to steel fiber, easily corroded in the alkaline environment of concrete [12].

The experience of NIISTROMPROJECT, LLP (Almaty, Kazakhstan) engineers over the years of control at construction sites and prefabricated concrete factories, as well as continuous monitoring of products and structures during operation proved that it is necessary not only to reach the specified parameters of concrete, but also to ensure their safety during the entire operating period of the building or structure. With the aim of improving deformation and performance properties of SCC under the loads and reducing the number of failures (Fig. 1) and cracks (Fig. 2) on it, the engineers set the following tasks in current study:

- Obtaining the reference parameters of the main components of the concrete mixture;.
- Study of the effect of fiber reinforcement parameters on the workability of SCC;.
- Study of the effect of fiber reinforcement parameters on the compressive and flexural strength of SCC.
- Study of the effect of fiber reinforcement parameters on the drying shrinkage of SCC.

Engineers understood that success in these studies required a systematic approach to predict and directly control the properties of this material depending on the objectives of the researchers [13].

From the theses of the 2nd International Conference on Composite Materials FIBROMIX 2019, held in St. Petersburg, one of the ways to increase the physical-technical and performance characteristics of concrete is the introduction of polypropylene fiber. It is recommended to use polypropylene fiber in the technological process of concrete production to reduce the delamination of mixtures, increase water resistance, frost resistance, corrosion resistance, impact strength, abrasion resistance [14]. In addition, polymeric fiber is characterized by corrosion resistance compared, for example, with glass fiber, easily corroded in the alkaline environment of

Fig. 1. Concrete failure during improper operation.

Fig. 2. Cracks as a result of concrete shrinkage in summer time.

concrete at pH> 7. At the same time, a number of researchers believe that low-modulus fibers, contributing to the improvement of many physical, mechanical and technological characteristics of the resulting fiber concrete, do not lead to an increase in strength [9, 15]: the destruction of the matrix occurs almost immediately beyond the action of elastic deformations, and the low-modulus component of the composite does not prevent this process, but, occupying some part of the area, weakens the working cross-section of the specimen. However, more detailed studies of the fracture process of fiber concrete with polypropylene fibers show that in the subsequent stages of deformation, the behavior of such fiber changes, as evidenced by the graph (Fig. 3), constructed from the results of studies obtained and published earlier in [12].

The figure shows that the strength of composite at low content of fibers in mixture does not change, at increase of fiber content some decrease of strength is observed, however at further increase of their quantity, this decrease is compensated by compaction and hardening of cement stone structure near the fiber surface and it can increase on 15–20%. Further there is a decrease in the strength of the composite due to the appearance of defects and delamination in its structure caused by technological difficulties. Such ambiguous behavior of low-modulus fibers in the composite requires further research, which became the goal of the present work, as such results are practically absent in the technical literature in relation to SCC.

When choosing this type of fiber for research, attention was also paid to the economic aspect of the relevance of research, that the required amount of polymer fiber is much cheaper than metal fiber for the same volume.

2. Materials and methods

2.1. Study methodology

The work was guided by theoretical and empirical research methods. The theoretical study was based on the fundamental laws of concrete science and building chemistry, as well as comparative analysis of the implemented in production compositions of SCC mixtures [15]. In determining the direction of the study, the focus was on the use of low-modulus reinforcing polypropylene fibers of a certain size. Empirical study was aimed at experimental confirmation of the theoretical hypothesis of the possibility of using polypropylene fibers in SCC. The study was conducted in four stages (Fig. 4).

The study methodology was based on international standards and aimed at conducting a numerous series of laboratory tests by varying the size and content of low-modulus fiber and processing the resulting rheological and physical-technical characteristics of the

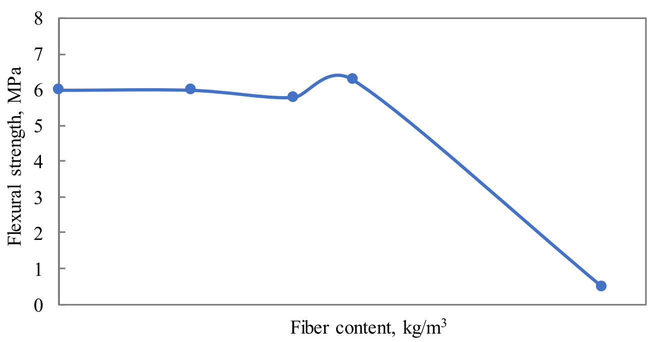

Fig. 3. Character of changes in the flexural strength of fiber concrete depending on the volumetric content of low-modulus fiber [12].

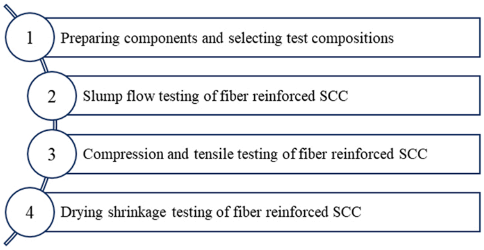

Fig. 4. Study stages.

concrete mixture, as well as strength and deformation parameters of the final SCC conglomerate. All studies and tests were conducted in accordance with the regulatory documentation in force in the territory of the Republic of Kazakhstan.

2.2. Materials and test compositions

The cement M400D20 produced by "Standard Cement" LLP (Shymkent, Kazakhstan) was used as a binder for the studied concrete mixtures. To confirm the compliance of the selected binder to the norms and requirements of [16,17] a number of tests were carried out. Specified in these standards methods allow to determine the following parameters:

1) Grinding fineness:

The investigated binder showed a grinding fineness of 94.4%.

2) Normal density and setting time of cement dough:

The binder tests showed a normal density of 27.30%. The beginning of setting came after 2 h 11 min, the end of setting came after 4 h 10 min from the moment of mixing. The values obtained are in accordance with the standards.

3) Compressive and flexural strength (at the age of 28 days) [18]:

In determining the strength characteristics, the binder under study showed the following results at the age of 28 days: bending – 5.6 MPa; compression – 42.4 MPa. The obtained parameters correspond to the standards.

The sand from the manufacturer "Giyada" LLP (Almaty region, Kazakhstan) complying with the standard [19] was used for the tests. According to this standard, as a fine aggregate for heavy concrete, under the definition of which also falls the SCC, sands with a maximum amount of dust and clay inclusions for the groups of increased coarseness, coarse and medium in the amount of 3% can be used. However, according to the results of laboratory and production tests [20], in order to obtain satisfactory characteristics of the concrete mixture and the final SCC conglomerate, it is necessary to use sand, the number of dust-like inclusions in which does not exceed 1.5%. The test to determine the amount of dust and clay inclusions of the sand under consideration was carried out by the method of weeding according to [21]. According to the test results, the content of dust and clay inclusions in the studied sand was 1.08%. Also, according to [21] by sieving and determining the grain composition of the aggregate, the coarseness modulus of the studied sand was determined, which amounted to 2.6. These values are acceptable for the use of the studied aggregate as in heavy concretes, and in the SCC in particular.

Crushed stone of 5–10 mm and 10–20 mm fractions produced by "Baltabay" LLP (Almaty region, Kazakhstan) with the known physical and technical characteristics was taken as a coarse aggregate. This aggregate meets the requirements of the regulatory document [22], which defines the basic requirements for crushed stone from dense rocks used as aggregate for heavy concrete, including SCC.

The chemical additive based on polycarboxylate esters of the 2nd generation AR Premium produced by "Ariranggroup" LLP (Nur-Sultan, Kazakhstan) with the following characteristics was used as a hyperplasticizer (Table 1).

Due to the fact that polypropylene fiber is not produced in Kazakhstan, low-modulus polypropylene fiber of various size from "FibroLux" LLP (St. Petersburg, Russia) with the following characteristics was used for volumetric reinforcement in the study (Table 2).

A total of 17 different compositions were prepared for testing (Table 3). An existing factory-made composition of SCC of class B30 that does not contain any fiber reinforcement was used as a reference. Other 16 were selected based on the reference composition in various combination of the size and content of low-modulus polypropylene fiber: for each of the compositions with the addition of fiber in sizes of 6, 9, 12 and 15 mm the volumetric consumption was varied in the amounts of 0.5, 1, 1.5 and 2 kg/m^3 respectively.

Table 1
Technical characteristics of AR Premium AH hyperplasticizer.

Indicator	Value of the indicator
Appearance	Homogeneous liquid of light-yellow color
Density at 25 °C, kg/m^3	1030–1070
Hydrogen Index, pH	4
Content of Cl-ions, not more than	0.1

Table 2
Technical characteristics of polypropylene fiber.

Indicator	Normative value	Actual value
Chemical formula	Polypropylene	Polypropylene
Type	Monofiber	Monofiber
Fiber length, mm	6–15	Complies
Fiber diameter, μm	18–21	20
Shape	Round	Round
Surface	Treated with a special composition that promotes dispersion and adhesion to cement mortar	Treated with Silastol CUT 70
Density, g/cm^3	0.91	0.91
Fiber frequency mln/kg	19.8	Complies
Tensile strength (medium), MPa	320–600	Complies
Young's modulus, MPa	3500–3900	Complies
Color	White	White

Table 3
Test compositions.

No.	Composition types	Component consumption, kg/m^3								Average density, kg/m^3
		Cement	Sand	5–10 mm crushed stone	10–20 mm crushed stone	Additive	Microsilica	Fiber	Water	
0.1	Reference composition	540	944	625	175	6.5	54	0	260	2395
1.1	6 mm fiber, 0.5 kg/m^3	540	944	625	175	6.5	54	0.5	260	2402
1.2	6 mm fiber, 1 kg/m^3	540	944	625	175	6.5	54	1	260	2299
1.3	6 mm fiber, 1.5 kg/m^3	540	944	625	175	6.5	54	1.5	260	2268
1.4	6 mm fiber, 2 kg/m^3	540	944	625	175	6.5	54	2	260	2249
2.1	9 mm fiber, 0.5 kg/m^3	540	944	625	175	6.5	54	0.5	260	2320
2.2	9 mm fiber, 1 kg/m^3	540	944	625	175	6.5	54	1	260	2294
2.3	9 mm fiber, 1.5 kg/m^3	540	944	625	175	6.5	54	1.5	260	2280
2.4	9 mm fiber, 2 kg/m^3	540	944	625	175	6.5	54	2	260	2253
3.1	12 mm fiber, 0.5 kg/m^3	540	944	625	175	6.5	54	0.5	260	2351
3.2	12 mm fiber, 1 kg/m^3	540	944	625	175	6.5	54	1	260	2343
3.3	12 mm fiber, 1.5 kg/m^3	540	944	625	175	6.5	54	1.5	260	2298
3.4	12 mm fiber, 2 kg/m^3	540	944	625	175	6.5	54	2	260	2278
4.1	15 mm fiber, 0.5 kg/m^3	540	944	625	175	6.5	54	0.5	260	2351
4.2	15 mm fiber, 1 kg/m^3	540	944	625	175	6.5	54	1	260	2328
4.3	15 mm fiber, 1.5 kg/m^3	540	944	625	175	6.5	54	1.5	260	2315
4.4	15 mm fiber, 2 kg/m^3	540	944	625	175	6.5	54	2	260	2310

Table 4
Classification of the SCC in terms of workability [23].

Class	Slump flow, cm
SF 1	55–65
SF 2	66–75
SF 3	76–85

2.3. Slump flow testing

A standard Abrams cone is used to determine slump flow. The cone and the metal sheet are moistened, then the cone is placed on the metal sheet with the smaller base against the surface of the sheet. Concrete mixture is poured until the cone is completely filled in one step. The cone is lifted for 5–7 s, and after the mixture has completely stopped, the two largest diameters of the spread are measured. The arithmetic mean value of the two largest diameters of the blob is the result of the test. According to [23], the SCC is classified into three classes according to its workability (Table 4).

The slump flow tests were carried out in stages, starting with the reference composition and determining the optimal slump flow, with each subsequent test low-modulus polypropylene fiber of 6 mm in size and content of 0.5 kg per 1 m^3 was added to the mixture, adding at each subsequent test of 0.5 kg up to a content of 2 kg per 1 m^3. Further increase in the amount of fiber is inexpedient, since it leads to a sharp decrease in the physical and technical characteristics of the mixture and may become economically unprofitable [24]. Further tests were carried out with the fiber of 9 mm in size and 0.5 kg per 1 m^3 in content, increasing the fiber content at each subsequent test by 0.5 kg up to the content of 2 kg per 1 m^3, then the tests were repeated with 12 mm and 15 mm fiber respectively.

2.4. Compressive and flexural strength testing

The compressive and flexural strength tests of specimens were carried out at their curing age of 28 days according to [25]. The specimens were molded according to [26] from each of the compositions shown in Table 3 in cubic and prism shapes, for compressive and flexural strength tests respectively (Fig. 5).

The flexural strength values of prism specimens were determined with the accuracy of 0.01 MPa by the Eq. (1) [25] below.

$$R_{tb} = \delta \frac{Fl}{ab^2}, \tag{1}$$

where: F – breaking load, N; a, b, l – width, height of the cross-section of the prism and the distance between the supports, mm; δ – scaling factor for converting the strength value to those in specimens of basic size and shape.

2.5. Drying shrinkage testing

The shrinkage deformation was determined on prismatic specimens 100 * 100 * 400 mm in size, taking into account the maximum aggregate coarseness according to [26]. When determining the shrinkage deformations, the series must consist of at least 3 prism specimens which, according to the algorithm adopted, were molded from the mixture of the reference composition and then from each subsequent test composition. Then, after a 24-hour storage in a humid environment, the specimens were removed from the molds and then tested according to [27] (Fig. 6).

Based on the results of determining the relative shrinkage deformation of specimens, the mean value of the relative shrinkage deformation for a series of specimens is determined according to Eq. (2) below [27]:

$$\overline{\varepsilon}(t) = \frac{\sum_{i-1}^{n} \varepsilon_1(t)}{n} \tag{2}$$

where: $\varepsilon_1(t)$ – the mean value of the relative shrinkage deformation for each specimen of the series; n – number of specimens per series.

a) b)

Fig. 5. Strength tests: a) compressive; b) flexural.

Fig. 6. Shrinkage testing of specimens.

3. Results and discussion

As a result of the processing of the data obtained on the slum-flow tests, a diagram of the effect of the size and fiber content on the workability of self-compacting fiber concrete was plotted (Fig. 7).

The results of the tests show the general picture of worsening of workability indicators of mixtures with fiber reinforcement compared to the reference composition, which agrees with [24]. Concrete mixtures with fiber showed an average decrease in workability of up to 20% compared to those without fiber. The best indicators of workability (class SF 2) showed SCC mixtures with the use of 6 mm low-modulus polypropylene fiber and its amount in the mixture up to 1 kg per 1 m^3. This indicates the possibility of its use in densely reinforced and difficult to access structures. The remaining mixtures with a fiber size above 6 mm and their content up to 2 kg per 1 m^3 have satisfactory performance on the workability (class SF 1), and, accordingly, can be recommended for use. Here it should be noted about the predicted critical content of low-modulus fiber of different sizes, after which the concrete mixture ceases to be self-compacting.

After obtaining the test data and calculating the strength of the specimens, a graph of the effect of the size and content of low-modulus polypropylene fiber on the compressive and flexural strengths of self-compacting fiber concrete was plotted (Figs. 8 and 9).

The main performance indicators of concrete are the compressive and flexural strength. From previously published studies [15] it can be deduced that concretes with volumetric fiber reinforcement have a slight decrease in compressive strength compared to un-reinforced concrete. The tests carried out confirm the correctness of these deductions, since with an increase in the content of fibers

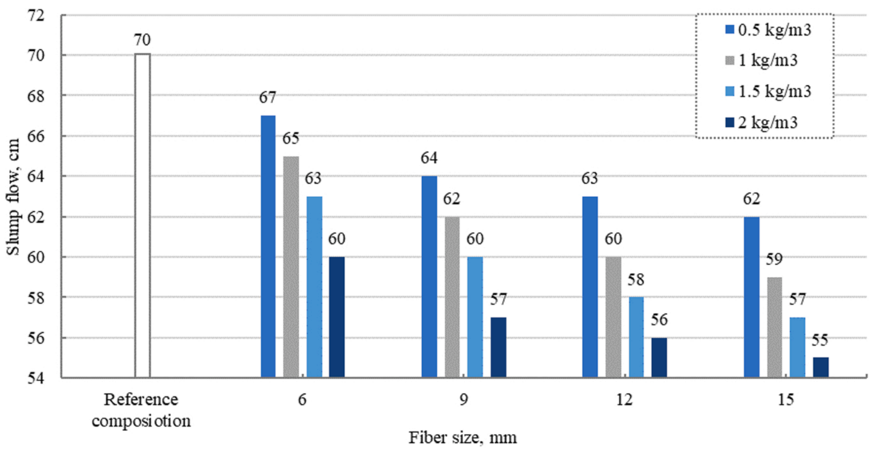

Fig. 7. Effect of fiber size and content on the workability of self-compacting fiber concrete.

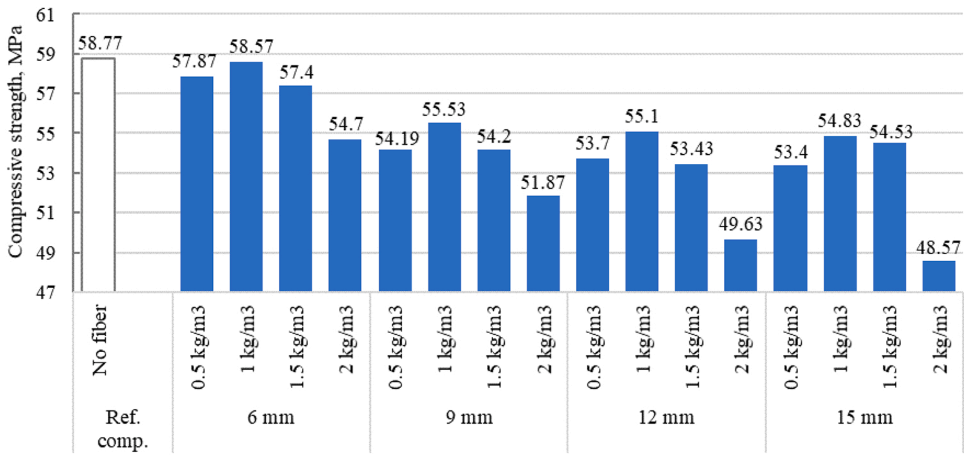

Fig. 8. Effect of fiber size and content on compressive strength of self-compacting fiber concrete.

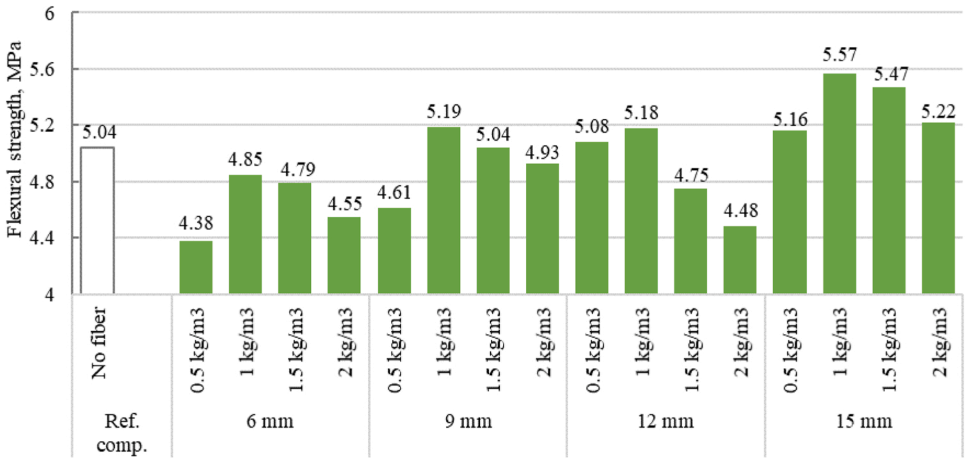

Fig. 9. Effect of fiber size and content on flexural strength of self-compacting fiber concrete.

there was a tendency of decreasing the compressive strength in average to 5% for concrete with 1 kg fiber per 1 m^3, i.e., from 58.77 to 56 MPa. Apparently, this decrease in strength can be explained by additional micro-defects in the concrete body resulting from the introduction of fibers into the concrete mixture, but this assumption requires further study at the micro level by means of electronic instruments. More interesting from a scientific perspective are the results of flexural tests, since the main purpose of the introduction of fibers is to increase the characteristics of concrete under bending loads.

According to the flexural strength data obtained, it can be deduced that with an increase in the size of the polypropylene fiber used there is an increase in this parameter, which agrees with [14], where it is noted that the decisive factor influencing the flexural strength is the content of reinforcing fibers, which have a high flexural strength. However, it should be noted that specimens of concrete with fiber size of 6 mm and content of 0.5÷2 kg/m^3 have flexural strength lower than those of the reference composition specimen. It is associated with weak anchoring ability of short fibers and low index of adhesion of polypropylene with cement stone, which should be considered when further using polypropylene fiber of these sizes in SCC. It follows from the studies of [28] that an increase in flexural strength is observed in specimens of concrete with fibers from 12 mm in size and 1 kg/m^3 content, where the flexural strength increased to 15%. This agrees with the results obtained in this study, where the highest values were obtained for concrete with fiber reinforcement of 12 and 15 mm in size and a content of 1÷1.5 kg/m^3. Thus, according to the results of the study, it can be noted that the use of low-modular polypropylene fibers of a certain size and optimum content is justified in terms of increasing the weakest characteristic of concrete – flexural strength. This is consistent with previously published work [11], where the use of RPPP significantly improved the fracture and ductility properties, whereas aggravated other measured properties of SCHSCs.

According to the results of shrinkage tests of specimens obtained a graph of the effect of the size and content of low-modulus polypropylene fiber on the shrinkage deformations of SCC (Fig. 10).

According to the graph above, the best shrinkage values showed specimens of SCC with 15 mm fiber and 2 kg/m^3 content. A further increase in fiber content is inexpedient from an economic perspective.

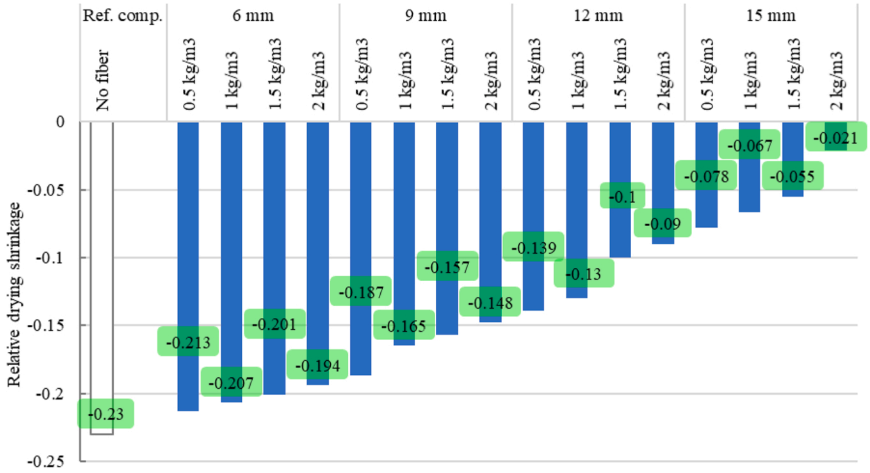

Fig. 10. Effect of fiber size and content on shrinkage of self-compacting fiber concrete.

One of the frequent problems encountered at the construction site is the appearance of drying shrinkage cracks in the concrete structures. Due to the fact that SCC is a specific concrete with an increased content of cement dough, it was necessary to experimentally confirm the working hypothesis that the use of SCC with volumetric fiber reinforcement will reduce the risk of drying shrinkage cracks. The results of the tests carried out to determine the shrinkage deformations of SCC with volumetric fiber reinforcement were compared with previously published studies in this field [29], which provide evidence that, in addition to increasing the resistance to impact loads, shrinkage cracking of cement stone can be reduced by means of fiber reinforcement [30]. Microcracks always occur in curing concrete as a result of early forced stresses and intrinsic stresses, as a result of concrete shrinkage or heat dissipation during hydration of the cement. In most cases they occur in the porous "cement stone/grain aggregate" contact zone. If the base of the crack hits the fiber, further crack propagation is prevented for some time as the fiber absorbs the tensile forces acting on the base of the crack; the crack stabilizes. Since many short, very thin, invisible micro-cracks occur, a large number of fibers with small diameters is primarily an important factor for effectively preventing the development of such cracks. The fiber size in this case is of secondary importance, since at this stage of crack development there is no relative movement between fibers and cement stone matrix, which agrees with the results of our studies, from which it follows, that with the increase of size and content of fiber there is a general tendency of decrease in shrinkage deformations and accordingly the probability of cracking in a structure made of SCC with fiber reinforcement decreases and the introduction of a certain amount of fiber into the composition of SCC increases the resistance of the conglomerate to the appearance of shrinkage deformations and reduces its cracking. Thus, as a result of tests, all specimens of concrete with fiber showed results for shrinkage deformations lower than those of concrete without fiber, on average up to 71%.

4. Conclusions

According to the results of the tests it can be concluded that the research team has achieved its objectives such as:

- The optimum composition of FSCC was obtained and the effect of fiber-reinforced parameters on the workability of SCC was studied. The dependence of the rheological properties of high ductility fiber-reinforced concrete on the size and amount of low-modular polypropylene fiber was obtained from the practical application – up to 2 kg. This amount seems critical, since a further increase in quantity leads to a sharp decrease in the workability of the mixture - it ceases to be self-compacting. Moreover, further increase of fiber content is not expedient.
- Experimental evaluation of the effect of the size and amount of reinforcing fiber on the compressive and flexural strength to improve the deformative and performance properties of concrete working under the appropriate loads was carried out. The composition of FSCC with the use of dispersed fiber reinforcement in an amount of 1 kg per 1 m^3 and size of 15 mm has achieved flexural strength values of 10,5% higher than those of conventional self-compacting concretes of the same grade, which agrees with the previously published works [9].
- The dependences of drying shrinkage value on fiber reinforcement parameters have been determined experimentally and the pattern determined, from which it follows that dispersed reinforcement from 0.5 kg and 6 mm and ending with 2 kg and 15 mm of polypropylene fiber allows to reduce this index from − 0.23 mm/m to 0.021 mm/m. This agrees with previously published works [12] and allows a high degree of probability to predict the behavior of concrete and monitor the formation of cracks in conditions of sharply continental dry and hot climate of the Republic of Kazakhstan in the summer period (at ambient temperature from 20° to 45°C).

After summarizing and analyzing the results of the conducted tests, the conclusion can be made about the expediency of disperse reinforcement of concrete, i.e., the addition of 1÷2 kg of polypropylene fiber with the size of 11 or 15 mm improves the physical, technical and deformation characteristics of the operating SCC compositions, in particular, increasing the flexural strength up to 10.5% and reducing the value of shrinkage deformations to 71%. Volumetric fiber reinforcement with low-modular polypropylene fiber of SCC mixtures can be recommended for use in production. The resulting linear patterns can be useful in making practical recommendations for the optimal choice of size and fiber content in self-compacting concrete to obtain the optimal price-quality ratio, especially when working in the summer time.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgment

This research was funded by the Science Committee of the Ministry of Education and Science of the Republic of Kazakhstan (Grant No. AP08857436).

References

[1] N. Ranjbar, A. Behnia, B. Alsubari, P. Moradi Birgani, M.Z. Jumaat, Durability and mechanical properties of self-compacting concrete incorporating palm oil fuel ash, J. Clean. Prod. 112 (2016) 723–730, https://doi.org/10.1016/j.jclepro.2015.07.033.
[2] K. Ma, J. Feng, G. Long, Y. Xie, X. Chen, Improved mix design method of self-compacting concrete based on coarse aggregate average diameter and slump flow, Constr. Build. Mater. 143 (2017) 566–573, https://doi.org/10.1016/j.conbuildmat.2017.03.142.
[3] A.S. Gill, R. Siddique, Durability properties of self-compacting concrete incorporating metakaolin and rice husk ash, Constr. Build. Mater. 176 (2018) 323–332, https://doi.org/10.1016/j.conbuildmat.2018.05.054.
[4] I. Sfikas, Self-compacting concrete: history & current trends, Concrete 51 (2017) 12–16.
[5] I. Ismail, N. Jamaluddin, S. Shahidan, A review on performance of waste materials in self compacting concrete (SCC), J. Teknol. 78 (2016) 29–35, https://doi.org/10.11113/jt.v78.8233.
[6] W. Zhu, Permeation properties of self-compaction concrete, in: Self-Compacting Concr. Mater. Prop. Appl., Elsevier, 2020, pp. 117–130, https://doi.org/10.1016/B978-0-12-817369-5.00005-2.
[7] S. Iqbal, A. Ali, K. Holschemacher, T.A. Bier, Mechanical properties of steel fiber reinforced high strength lightweight self-compacting concrete (SHLSCC), Constr. Build. Mater. 98 (2015) 325–333, https://doi.org/10.1016/j.conbuildmat.2015.08.112.
[8] Y. Utepov, D. Akhmetov, I. Akhmatshaeva, Effect of fine fillers from industrial waste and various chemical additives on the placeability of self-compacting concrete, Comput. Concr. 25 (2020) 59–65, https://doi.org/10.12989/cac.2020.25.1.059.
[9] O.M. SMIRNOVA, A.M. KHARITONOV, Strength and strain-stress properties of fiber concrete with macro-fiber on the basis of polyolefins, Stroit. Mater. 766 (2018) 44–48, https://doi.org/10.31659/0585-430X-2018-766-12-44-48.
[10] E.B. Opanasenko, A.A. Berestianska, Types of fiber reinforcement, Resour. Mater. Struct. Build. Facil. 30 (2015) 57–64.
[11] R.H. Faraj, A.F.H. Sherwani, A. Daraei, Mechanical, fracture and durability properties of self-compacting high strength concrete containing recycled polypropylene plastic particles, J. Build. Eng. 25 (2019), 100808, https://doi.org/10.1016/j.jobe.2019.100808.
[12] Y.V. Pukharenko, D.A. Panteleyev, M.I. Zhavoronkov, Research of the concrete deformation process reinforced by a low-module fiber. Fundam. Surv. Appl. Res. Russ. Acad. Archit. Build. Sci. Sci. Support Dev. Archit. Urban Plan. Constr. Ind. Russ. Fed., ACB, St. Petersburg, 2020, pp. 358–366.
[13] D. Matveyev, I. Ivanov, T. Chernykh, L. Kramar, Development and study of self-compacting concrete characteristics using the materials of the chelyabinsk region, Bull. South Ural State Univ. Ser. "Constr. Eng. Arch. 16 (2016) 55–60, https://doi.org/10.14529/build160307.
[14] Z. Yao, X. Li, C. Fu, W. Xue, Mechanical properties of polypropylene macrofiber-reinforced concrete, Adv. Mater. Sci. Eng. 2019 (2019) 1–8, https://doi.org/10.1155/2019/7590214.
[15] Y.B. Utepov, D.A. Akhmetov, Y.N. Root, M.A. Yermuhanbet, Reinforcement of self-compacting concrete with polypropylene fiber, Bull. Civ. Eng. 16 (2019) 220–227, https://doi.org/10.23968/1999-5571-2019-16-6-220-227.
[16] Interstate standard GOST 10178-85, Portland cement and portland blastfurnace slag cement. Specifications, (1985). http://docs.cntd.ru/document/871001094.
[17] EN 196–3:2016, Methods of testing cement - Part 3: determination of setting times and soundness, (2016).
[18] EN 196–1 Edition: 2015-08-01, Methods of testing cement Part 1: determination of strength, (2015).
[19] Interstate standard GOST 8736-2014, Sand for construction works. Specifications, (2014). ⟨http://docs.cntd.ru/document/1200114239⟩.
[20] Y.N. Root, S.K. Nurpeisov, Influence of physical and technical characteristics of fine aggregate on the properties of self-compacting concrete, Her. Kazgasa. 3 (2017) 168–172. ⟨http://www.kazgasa.kz/ru/page/-vestnik-kazgasa⟩.
[21] Interstate standard GOST 8735-88, Sand for construction work. Testing methods, (1988). http://docs.cntd.ru/document/1200003348.
[22] Interstate standard GOST 8267-93, Crushed stone and gravel of solid rocks for construction works. Specifications, (1993). http://docs.cntd.ru/document/1200000314.
[23] EFNARC, Specification and guidelines for self-compacting concrete, (2002).
[24] S. Grzesiak, M. Pahn, M. Schultz-Cornelius, S. Harenberg, C. Hahn, Influence of fiber addition on the properties of high-performance concrete, Materials 14 (2021) 3736, https://doi.org/10.3390/ma14133736.
[25] ASTM C39 / C39M - 21, Standard test method for compressive strength of cylindrical concrete specimens, (2021). http://docs.cntd.ru/document/1200100908 (Accessed January 7, 2019).
[26] ASTM C31 / C31M - 21a, Standard practice for making and curing concrete test specimens in the field, (2021).
[27] Interstate standard GOST GOST 24544-81, Concretes. Methods of shrinkage and creep flow determination, (1982).
[28] G.W. Leong, K.H. Mo, Z.P. Loh, Z. Ibrahim, Mechanical properties and drying shrinkage of lightweight cementitious composite incorporating perlite microspheres and polypropylene fibers, Constr. Build. Mater. 246 (2020), 118410, https://doi.org/10.1016/j.conbuildmat.2020.118410.
[29] G. Ramakrishna, T. Sundararajan, Impact strength of a few natural fibre reinforced cement mortar slabs: a comparative study, Cem. Concr. Compos. 27 (2005) 547–553, https://doi.org/10.1016/j.cemconcomp.2004.09.006.
[30] D.A. Akhmetov, A. Aniskin, Y.B. Utepov, Y.N. Root, G. Kozina, Determination of optimal fibre reinforcement parameters for self-compacting concretes, Teh. Vjesn. Tech. Gaz. 27 (2020) 1982–1989, https://doi.org/10.17559/TV-20200630163212.