MATEC Web of Conferences **107**, 00044 (2017) DOI: 10.1051/matecconf/201710700044
DYN-WIND'2017

Substantiation of concrete core rational parameters for bending composite structures

Glib Vatulia[1], *Svetlana* Berestianskaya[1], *Elena* Opanasenko[1] and *Anastasiya* Berestianskaya[1,*]

[1] Ukrainian State University of Railway Transport, Structural Mechanics and Hydraulics Department, Feyerbakh sq. 7, 61050 Kharkiv, Ukraine

Abstract. In order to provide bending structures rationalization for reducing the materials consumption, labor and power inputs, construction or renovation terms, the authors considered the possibility of utilizing the structures with external steel sheet reinforcement and concrete layer made from fibers of different types. Experimental researches of various authors, both domestic and overseas, have been analyzed during the preliminary investigations. As a result, the steel and basalt fibers were selected for further inquiry, proved their rational sizes, percentage to concrete mass in structures worked under thermal and force impacts. It was developed the algorithm and software, helps to determine the stress-strain state and carrying capacity of composite floor slabs with different end and load conditions. It was concluded the necessity of physical-mechanical and thermal physic properties clarification of heated fibrous concrete. The experiment planning was performed to obtain the temperature dependences of strength and modulus of deformation, thermal conductivity and specific heat capacity of fibrous concrete mix.

1 Introduction

Since the concrete has been ever more extensively used in civil engineering, and concrete structures have been operated in more severe conditions, concrete quality should constantly improve to achieve better strength, crack resistance, fire resistance, etc. Today, in addition to using traditional steel concrete, structures with modified concrete are used more widely with introduction of various additives, including fibers that allow enhancing of the performance of the construction material. Fibers make the material more durable by binding the internal structure. Adding fibers to concrete and their disperse location in the material volume allowed to formulate the concept of the concrete (cement) matrix-based composite material. Qualitative characteristics of fiber-reinforced concrete are several times better than those of the conventional concrete [1].

The scope of application of fibrous concrete is very wide. Each field of application imposes specific requirements to fibrous concrete constructions concerning both mechanical and rheological properties. For instance, one of the important characteristics of flexural elements is bending rigidity. Fibrous concrete enables to increase significantly

* Corresponding author: anastasiia.berestianska@gmail.com

strength against this kind of deformation [2]. In [3] experimental studies of different authors were analyzed and a conclusion on expediency of use of metal and basalt fiber for thin slabs was drawn.

2 Types of fiber reinforcement

2.1 Steel fiber

Steel fiber is a durable and generally recognized material for quality improvement of the concrete [4]. Due to some specific properties, steel fiber reinforced concrete outperform ordinary concrete and has significant share in the total global production (12-16%) of concrete. Metal fiber, unlike the polypropylene and glass ones, improve mechanical characteristics of concrete after strength gain, i.e. have forcing functions.

Steel fiber reinforced concrete has increased tear strength, practically never shows shrinkage or cracks in use. A number of prerequisites should be met to obtain high-performance steel fiber reinforced concrete: fibers should have equal properties and nominal size, have good adhesive bonding to matrix and concrete, be evenly distributed in concrete matrix, and their material should prevent occurrence and progress of corrosion and chemical reaction with the matrix material. Concrete reinforcement with metal fiber promotes improvement of its strength properties: ultimate tensile, compressive and bending strength increase, as well as its impact resistance [5]. Deformability, durability, wear resistance, frost resistance, heat resistance, water tightness, reliability and corrosion resistance of concrete structures increases significantly. Improvement of physical and mechanical properties of steel fibrous concrete enables to reduce weight of concrete construction.

Fiber diameter and its length influence the properties of steel fiber concrete. The cross-section shape of steel fiber can vary, so equivalent diameter is often used. The efficiency of fiber reinforcement increases with decreasing diameter, however, it also makes the mixture preparing and product manufacturing technologies more complicated. The length-to-diameter ratio, shape, as well as the condition of the surface are important characteristics of the fiber which affect its physical mechanical properties and stress-strain behavior. The greater the saturation of the mixture with fiber is, the more contact zones there are and the better the strength and deformation characteristics of the material is. For better adhesive binding of fiber to concrete, it is desirable that it has a periodic section, bent ends or a wavy shape. Based on the analysis made in [6, 7], it was concluded that the use of Chelyabinka fiber is efficient. This fiber manufactured according to TU 1276–001–70832021–2005 of rolled steel (band, sheet) is a steel strip with anchors on the ends in the shape of segments of circle with radius conjugation to the straight sections of the strip. The ends of the strip are turned to each other at an arbitrary angle (Fig. 1).

Fig. 1 Chelyabinka fiber.

Chelyabinka has higher physical and mechanical properties compared to other types of fibers, as evidenced by the results of tests of CNIIS OJSC (Tab.1). According to Volvek Plus, Chelyabinka fiber has better strength characteristics in comparison with other fibers [8].

Table 1. The test results of fiber concrete specimens.

Test type	Chelyabinka *R*, [MPa]	HAREX *R*, [MPa]	DRAMIX *R*, [MPa]	MagFiber-stroy *R*, [MPa]
Compression	49.4	50.0	47.2	49.2
Stretch	3.34	2.82	2.72	2.64
Bend	7.89	6.57	7.41	5.57

According to [9], minimum value of the fibrous reinforcement factor can be determined using the formula:

$$\mu_{\min} = \frac{1.5 \cdot C \cdot R_{bt}}{R_f \cdot k_{or}^2 \left(1 - \frac{30}{R_f} - \frac{l_{f,an}}{l_f}\right)} \qquad (1)$$

where C - taken on the basis of [9];
l_f - fiber length;
R_f - reference resistance to fiber reinforcement strain;
R_{bt} reference concrete resistance to axial tension according to Group I of limit states;
k_{or} - factor of fiber orientation relative to direction of main tension stresses;
$l_{f,an}$ - minimum length of embedding of steel fiber into concrete, corresponds to its rupture when picked from matrix concrete.

2.2 Basalt fiber

Adding basalt fibers increase the tensile strength of concrete. They have a number of benefits, since they are one of the hardest mineral fibers. Basalt fibers are segments of complex basalt fiber as loose monofilaments (Fig. 2). Fiber length can be 3, 6, 13, 15, 18, 25, 27, 30 mm, probably 40, 50 mm, diameter of a single fiber is 13-20 mm.

The studies demonstrate that the concrete quality improves substantially even if a little of basalt fibers is added. Resistance to stress, durability, and resistance to cracking increase, while deformation probability reduces. It is also critical that the use of this material enables to reduce the total weight of the constructions without any to the detriment of strength [10]. Basalt fiber is unique since it is manufactured from the natural stone and has perfect chemical resistance properties. Basalt fiber has a number of significant benefits, ranging from the price and environmental safety, physical technical properties to the difficulty to falsify [11].

Fig. 2. Basalt fiber.

Adding basalt fiber increases ultimate bending, compressive and axial tensile strength, frost resistance, water resistance, fire resistance, surface resistance to abrasion and to impact and dynamic loads of the concrete construction, while the probability of shrinkage cracking reduces.

In [6] the results of experimental studies of different authors were analyzed and a conclusion on rational parameters and percentage of basalt fiber was drawn. According to N.G. Vasilovskaya, I.G. Yendzhiyevskaya and I.G. Kalugin [12], basalt fiber with the length of 12 mm with the content of 0.2% gives the highest ultimate compressive strength – 88.6 MPa (Fig. 3, a) and one of the highest ultimate bending strength – 30.7 MPa (Fig. 3, b).

3 Calculation method of steel concrete slabs at thermal power influences

In the work [13] it was developed a mathematical apparatus for calculating reinforced concrete rectangular slab at thermal power influences with hinged support, and also provided a fire protection of the structure. Methodology of assessing the fire resistance of the main tenets of the theory contains steel-concrete slabs, which takes into account the addition of power, temperature effects, and is a development study [14, 15, 16, 17]. The equilibrium conditions of the element reinforced concrete slabs, obtained in [15] are being used:

$$\frac{\partial^2}{\partial x^2}\left(M_T - M_x\right) + \frac{\partial^2}{\partial y^2}\left(M_T - M_y\right) - 2\frac{\partial^2 M_{xy}}{\partial x \partial y} = q(x,y) \tag{2}$$

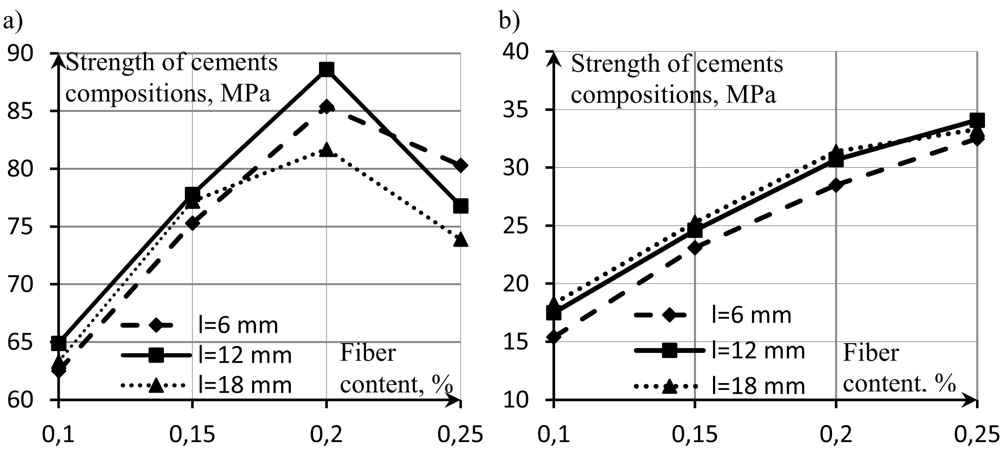

Fig. 3. Strength of cement compositions a) compressive, b) bending.

Temperature bending moments in the concrete and steel sheet are defined as follows:

$$M_T = M_T^c + M_T^s$$

$$M_T^c = -\int_{x_{ti}}^{x_i} \frac{\alpha_c E_c (T - T_0)}{3(1-\nu_c)} x dx \; ; \; M_T^s = -\int_{h_c}^{h_c+\delta} \frac{\alpha_s E_s (T - T_0)}{3(1-\nu_s)} x dx \tag{3}$$

where T_0 is the initial temperature;

α_c, α_s is the thermal expansion coefficients of concrete and steel.

Moments M_x, M_y, M_{xy} are associated with stiffness coefficients and curvature dependences [15];

$$\begin{vmatrix} M_x \\ M_y \\ M_{xy} \end{vmatrix} = \begin{vmatrix} D_{11} & D_{12} & D_{13} \\ D_{21} & D_{22} & D_{23} \\ D_{31} & D_{32} & D_{33} \end{vmatrix} \begin{Bmatrix} K_x \\ K_y \\ 2K_{xy} \end{Bmatrix}, \quad (4)$$

where $D_{i,j}$ – bending rigidity;
K_x, K_y, K_{xy} – curves.

In [3, 17] temperature action patterns and methods of evaluation of the stress-strained state of construction at thermal power influence with regard to different support conditions are considered.

Modeling of deformation process reinforced concrete slabs under load was carried out in steps of 10 kN/m^2. The action temperature was taken into account to the equation of the standard fire and simulated as a supplement to the load at each point of the finite-difference grid. The temperature fields were determined at an interval of time until the moisture evaporates – 0.67 min., after evaporation – 1.67 min. The finite difference method (FDM) was used as a numerical method for solving.

Fire resistance design was characterized by its ability to resist the effects of temperature and determines the time *t*, when the slab loses load bearing capacity. In turn, the bearing capacity was characterized by the following factors taking place in any point of the finite-difference grid: the strength of concrete steel sheet, the strength of contact [16].

We suggest calculating a fiber-reinforced steel concrete slab at thermal power influence using the above method. It applies physical-mechanical and thermal physic properties of fibrous concrete. Therefore, experimental studies are planned which would allow to find modulus of elasticity, Poisson ratio and limit strength of fiber-reinforced concretes with different kinds of fibers at different temperatures, as well as thermal conductivity. The experiment was planned before conducting so that the necessary number of samples could be determined.

Conduction of the study can be presented in diagram form as a “black box” (Fig. 4). The object is influenced by factors x - types of reinforcement; $y = f(x)$ – response of the system for the impact of such factors – ultimate strength, i.e. the result of the experiment. Function $f(x)$ is a mathematical model of object behavior to be determined. This function is called regression.

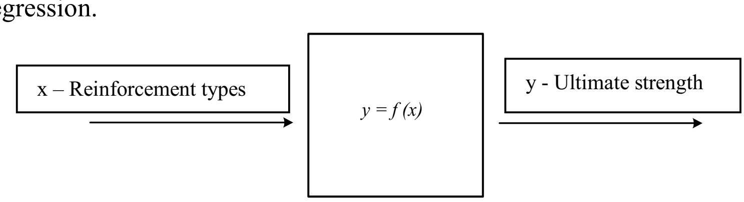

Fig. 4. Study diagram.

A fixed set of factor levels defines one of the possible states of the "black box". At the same time, this is the condition for conduction of one of the possible experiments. If we go through all possible sets of states, the total number of different experiments N will be obtained [18, 19].

Strength (for example, cubic) of fibrous concrete depending on the material heating temperature and the type of fiber is to be determined. The percentage and length of the fiber is taken in accordance with the data of the reference sources and is not subject to study. Thus, the factors are the temperature and the type of fiber; the response of the system is the ultimate strength of fibrous concrete.

We consider three types of reinforcement (steel fiber, basalt fiber and a control concrete sample without fiber). The dependence of the strength on temperature will be determined for the following temperatures: 20°C, 60°C, 90°C, 120°C, 200°C, 400°C, 600°C, 800°C.

The number of possible different experiments N is determined by expression

$$N = p^k \times n = 72, \quad (5)$$

where $p = 3$ – number of levels;

$k = 2$ – number of factors;

$n = 8$ – number of temperature values.

4 Conclusion

As a result of the analysis of the experimental studies by various authors, steel and basalt fibers were selected for further investigation. Their rational dimensions, percentage ratio to the mass of concrete in structures are justified. We came to the conclusion is that it is necessary to refine the physic mechanical and thermophysical properties of heated fiber concrete. For this purpose the experiment was planned, that made it possible to determine the required number of samples to obtain the temperature dependences of the strength and modulus of deformation, the thermal conductivity, and the specific heat of the fiber concrete mixture.

References

1. F.N. Rabinovich, *Kompoziti na osnove dispersno-armirovannykh betonov,* Izdatel'stvo Assotsiatsii stroitel'nikh vuzov 559, (2004)
2. E.V. Opanaseko, A.A. Berestyanskaya, Zbirnik naukovykh prats Natsionalnogo universytetu vodnogo gospodarstva ta pryrodokorystuvannya **30**, 57 (2015)
3. G.L. Vatulya, S.Yu. Berestyanskaya, E.V. Opanasenko, A.A. Berestyanskaya, Journal of Civil Engineering and Construction **5, 2**, 98 (2016)
4. V. Bhikshma, K. Manipal, Asian Journal of Civil Engineering **13 (2)**, 155 (2012)
5. K.V. Talantova, *Stroitel'nye konstruktsie s zadannymi svoystvami na osnove stalefibrobetona*, avtoreferat DSc in Technical Sciences, 30 (2010)
6. M.A. Verevicheva, A.A. Berestyanskaya, S.V. Derizemlya, Sbornik nauchnih trudov Dnepropetrovsk PGASA **82**, 60, (2015)
7. A.A. Berestyanskaya, VII Mezdunarodnyy molodezhnyy forum, eResurs, 215 (2015)
8. Volvek-Plus [ofic. sayt]. URL: http://wolwekplus.ru
9. *Design of concrete structures - Part 1-2: General rules - Structural fire design*, EN 1992-1-2. Eurocode 2, 99 (2004)
10. I.V. Borovskikh, *Vysokoprochnyy tonkozernistyy bazal'tofibrobeton*, avtoreferat PhD in Technical Sciences 24, (2009)
11. S.E. Artemenko, *Polymer composite materials made from carbon, basalt, and glass fibers, structure and properties, fiber chemistry* **35 (3)**, 226 (2003)
12. N.G. Vasilovskaya, I.G. Yendzhievskaya, I.G. Kalugin, Vestnik Tomskogo gosudarstvennogo arkhitekturno-stroitelnogo universiteta **3**, 153 (2011)
13. S.Yu. Berestyanskaya, *Napryazhenno-deformirovannoe sostoyanie stalebetonnykh plit pri silovikh i temperaturnikh vozdeistviyakh*, avtoreferat PhD in Technical Sciences, (2003)
14. E.D. Chikhladze, A.I. Zhakin., M.A. Verevicheva, Izv. VUZov. Stroitelstvo **1**, 111 (1998)

15. E.D. Chikhladze, A.I. Zhakin, M.A. Verevicheva, Sbornik nauchnikh trudov KSART, **40**, 97 (2000)
16. E.D. Chikhladze, A.D. Arslankhanov, Stroitelnaya mekhanika **2**, 22 (1990)
17. E.D. Chikhladze, G.L. Vatulya, Proceedings of the 5th International Conference on Dynamics of Civil Engineering and Transport Structures and Wind Engineering - Zilina, 181 (2011)
18. E.A. Lyubchenko, O.A. Chudnova, *Planirovanie i organizatsyya eksperimenta*, Izd. TGEU (2010)
19. K.M. Khamkhanov, *Osnovy planirovanie eksperimenta*, Metodicheskoe posobie (2001)