A. V. Vedeneev, O. I. Ignatenko, V. I. Gritsaenko
Byelorussian Steel Works (BMZ) - Management Company of "Byelorussian Metallurgical Company" Holding, Steel Cord and Wire Products Research Centre (Zhlobin, Republic of Belarus)
metsc@bmz.gomel.by

Perspective reinforcing material for fiber concrete

Steel fiber concrete is a type of fiber-reinforced steel concrete. It is produced from fine grain concrete or heavy concrete (concrete-matrix), in which instead of a rebar, steel fibers are used, evenly distributed over all the volume of concrete. Interaction of concrete and steel fiber is achieved by means of adhesion on their surfaces and fiber anchoring by means of periodic profile and its crookedness in longitudinal and transversal direction.

Currently, steel fiber concrete is a perspective construction material which is used in many industrial developed countries in the world. Appearance of new specially produced types of steel fiber – wire fiber of anchor, wavy and straight profile, as well as utilization of powerful chemical modifiers super- and hyper plastifiers made it possible to set steel fiber concrete on a new technological plane which extends its sphere of application and at the same time physical and mechanical characteristics of concrete increase considerably: tensile strength in bending, crack resistance, shock resistance, etc. With appearance and development of monolithic concrete, new material found its niche.

Presently, fiber, as a reinforcing component, is utilized in the following types of construction:

— in monolithic construction when making floors for industrial buildings, storage rooms in logistic centers, flight strips at airports, car parks and motor roads, basins and swimming pools, bank vaults and safes, blastproof fortification objects, as well as in other spheres of construction with high strength properties of concrete structures;

— assembly steel fiber concrete – reinforced tubes of big diameter, metro tubing, elements of wall panels and ceiling panels, railway sleepers, road slabs, small architectural shapes, etc.

Key words: *steel fiber, reinforcement, chemical modifiers, plastifiers, monolithic constructions, concrete, assembly tubes, adhesion, anchoring.*

Wire fiber

Wire fiber proved to be as a very universal material and it is currently widespread a lot at the world market. Utilization of wire as a basic material which is amendable to precise setting of technical data when produced, which assures stability of programmed properties and necessary reiteration of performance properties in final product [1-4].

In straight fiber (Fig. 1) the only anchoring mechanism is adhesion power of fiber surface with concrete. In order to assure a proper anchoring rate, fiber should be long enough (more than 60 mm). When such fiber goes into concrete mixture, it results in its balling (formation of so-called "hedgehogs") and it practically brings to nought reinforcing effect, as well as causes big problems when making concrete mixture, its filling, leveling and consolidation. To solve this issue two options are used – wavy fiber (Fig. 2) and fiber with crooked ends (Fig. 3). Straight fiber with cone anchors is not to be considered due to high production costs [5]. Fiber with crooked ends restrains crack development at the first stage by means of surface adhesion. When adhesion loses, anchoring of crooked fiber ends comes into effect. At that a crack can extend free at central area of fiber till it reaches fiber ends. After that fiber gets pulled out of concrete matrix by means of overload on fiber ends, or concrete crushing in places where it adheres with fiber ends. Aiming to improve anchoring power, a periodic profile can be applied on fiber when it is produced. Fig. 4 shows how different fiber types have influence on crack resistance.

Wavy fiber, in its turn, has more elements of mechanical anchoring, as well as bigger adhesion surface with concrete. At that, its length does not cause those problems which are tied with straight fiber utilization.

It makes it possible even at an early stage of crack formation to assure its restrain by means of more effective tension distribution in the surrounding concrete matrix. Accordingly, it increases service life of concrete. When comparing properties of wire fiber and fiber from sheet products, the preference is high stretchability of wire fiber.

Advantages of high modulus wire fiber

World producers of wire fiber use wire both with low and high carbon content. In patent [6] anchor fiber is described; this fiber has optimized parameters of central length and amplitude of crookedness of crooked ends for its anchoring in concrete aiming to reach max. breaking strength and wire flexibility. Besides, wire hardness comes up to 900–1200 MPa, which corresponds to low module of material flexibility, and consequently insufficiently high elastic resistance to unbending of crooked ends when tensile load is applied. Application of wire ∅ 0,4–0,8 mm can not provide the concrete which is being reinforced with sufficient bending stiffness, but it is one of the most important characteristics of concrete.

Aiming to improve anchoring power under acting tensile load, specialists of RUE 'BMZ' utilize the wire with high elastic modulus of 170,000–270,000 MPa to produce fiber. It considerably improves unbending resistance of fiber deformed areas under acting tensile loads in fiber concrete (Fig. 5) [7].

This diagram shows that when tensile load is applied, then bending stress appears ($\sigma_{изг}$) on deformed areas of fiber. At that, the deformation in elastic area in high modulus fiber occurs in a far less degree than in low modulus one. It follows

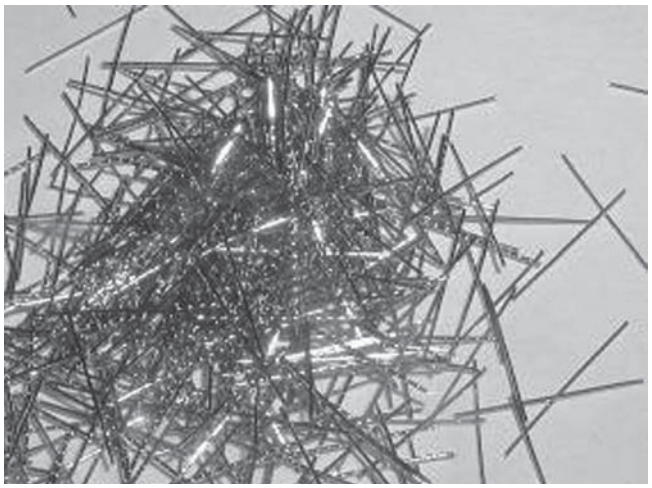

Fig. 1. Microfiber

Fig. 2. Wavy fiber

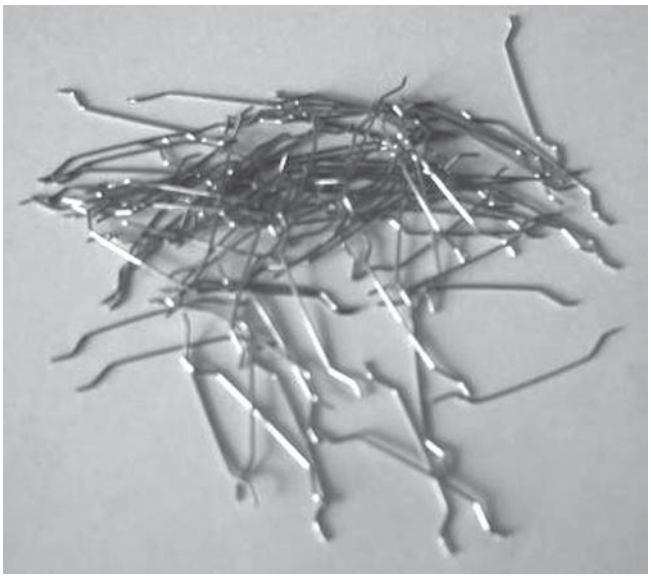

Fig. 3. Anchor fiber

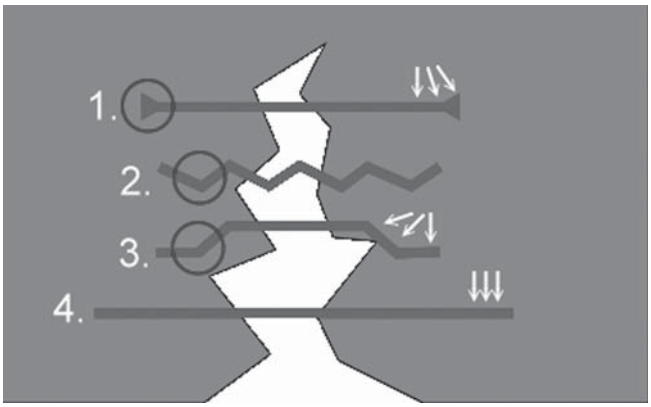

Fig. 4. Influence of different types of wire fiber on crack resistance: *1* – cone anchors fiber; *2*– wavy fiber; *3* – crooked ends fiber, *4* – straight fiber (blue circles – mechanisms of fiber anchoring, white arrows- adhesion surfaces)

that fiber produced from high modulus wire assures better efficiency due to its characteristics are more similar to concrete properties. For further increase in bending stiffness in cross section fiber can be flat. When producing fiber, the ratio between the part of wire with deformed ends and the thickness of flat wire comes up to 30-70, the ratio between flat wire width and thickness comes up to 1.01–3.00. In comparison with fiber from wire of round section, flat shape has bigger contact area with concrete matrix which additionally fastens it in concrete. Chaotic orientation of fiber in concrete assures increase of bending stiffness in the area of a rib up to 75 %. If flat fiber is applied, the value of bending stiffness of concrete will be higher, that in case of fiber produced from wire with diameter corresponding to flat wire thickness.

As an example, let us consider resisting moments (W) of round wire with diameter d and flat wire with thickness $b=d$ and width $h=1.01b$ and $h=3b$.

For round wire: $W=\pi d^3/32=0.098d^3$

For flat wire:

— when bending at rib $W=bh^2/6$, for $h=1.01b$ $W=1.01d^3$, for $h=3b$ $W=4.5d^3$

— when bending at flat area $W=hb^2/6$, for $h=1.01b$ $W=0.168d^3$, for $h=3b$ $W=0.5d^3$

As one can see in table 1, utilization of fiber from flat wire to reinforce concrete gives minimum increase of resisting moments of 1.71 times.

Aiming to improve anchor power under acting tensile load, wire is produced with high elastic modulus equal to 170,000–270,000 MPa. Flat shape of wire assures higher bending stiffness in rib area and it makes contact area with concrete matrix bigger. At that, the ratio between the length of wire part with deformed ends and flat wire thickness equals 30–70, and flat wire width and thickness ratio equals 1.01–3.00 [7].

Production of fiber overseas

Convincing evidence of effective utilization of steel fiber concrete in construction is that it has been used for a long time in foreign countries, large assortment of steel fiber, as well as great many companies producing fiber on a permanent basis. Only in Europe more than 150 thou. tons of steel fiber is used to make around 3 mln cub. m. of steel fiber con-

Table 1. Parameters of flat profile fiber			
Wire sizes, mm	Width/ thickness ration	Bending stiffness, 10^{-3} H*m	
		flat	rib
0,3×0,46	1,56	25	52
0,30	1,0	12	

Table 2. Annual average consumption ofmfiber from wire, t		
Belarus	Ukraine	Russia
250	4.200	10.000

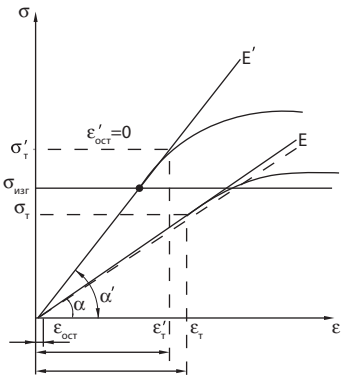

Fig. 5. Residual deformation of wire with different elastic modulus $\sigma_т$, $\sigma_т'$, — yield points of wires with different elastic modulus; $\sigma_{изг}$ — tension at unbending of anchor fiber end under tensile load; $\varepsilon_т$, $\varepsilon_т'$ — elongation at flexible area of wire with different elastic modulus; $\varepsilon_{ост}$ — residual deformation after load in plastic area; E, E— elastic moduluses of different wire materials; (E′ > E)

crete. More than 20 foreign firms and corporations produce steel fiber. By the by, they are, as a rule, major producers of ordinary bar reinforcements, wire reinforcements or metal goods.

Japan is a shining example of it where 7 major firms produce steel fiber, cut from sheet or wire, milled from slab, stretched from the melt. In 2001 more than 25 thou tons of steel fiber was used in Japan.

There are a number of firms in Finland, producing concrete products with steel fiber. Fiber is produced from sheets at one of the major enterprises in Norway. In Europe fiber is produced by such well-known companies as Bekaert N.V., Atamat Ltd., Trefil Arbed, Chirco Prod-Impex Company SRL, etc. Bekaert Fibre Concrete is the largest producer of steel fiber in the world.

The leading German manufacturer of industrial floors Korodur Gmbh produces several types of steel fiber for super-reliable, high-strength concrete floors: CSF 30 and CSF 37 (for industrial floors in mills, warehouses, garages, terminals, markets), CSF 25 (for shotcrete), ISF 20 (for monolith covering).

Foreign experience in utilization of steel fiber concrete over the latest 30 years proved its high technical-and-economic efficiency when used in building structures and facilities of various applications.

Economic effectiveness of steel fiber concrete structures in comparison with reinforced concrete ones is determined by considerable reduction of labour coefficient and specific consumption of materials, higher operating life, longer overhaul period, exception of disadvantages inherent in bar reinforcing.

It was established that economic effectiveness if change over to fiber concrete, for instance for industrial floor structures, because of extension of service life, makes up to $6 per 1 square meter [8].

Production of fiber in CIS

Russian experience in utilization of steel fiber concrete in construction is quite wide. Currently, more than 10 thou

Table 3. Recommended parameters of wire fiber for its even distribution in fiber concrete			
Type of fiber	Three-dimensional reinforcement coefficient, μ		
	0,005	0,01	0,015
Nonuniformity resistant with any charge			
anchor		45; 50; 55	43; 50; 60
wavy	30; 31; 36; 38		
microfiber		52	37; 43
Some limits when utilize			
anchor		53; 60; 63; 67; 75; 86	
wavy	60; 75		
microfiber	60		
Essential limits when utilize			
anchor	100		
wavy			
microfiber			

tons of steel fiber per year is produced in Russia and this volume can be increased several times in already developed productions (Magnitogorsk, Kurgan, St. Petersburg). Most of this fiber is sold overseas (table 2).

OJSC «Silur», as a large producer of steel wire and products from wire, specializes on production of steel fiber from low carbon and high carbon wire. The assortment of produced products is quite wide: straight fiber and profiled fiber, without coating and with coating (brass-plating or galvanization), it differs by the method of cutting of wire. Production capacity is 12 thou. t per year [9]. The main marketplace is Western Europe.

Production of fiber at Byelorussian Steel Works (BMZ)

In 2008 BMZ started industrial production of steel fiber from wire stock and steel cord. The assortment includes: anchor fiber, wavy fiber, micro fiber both with brass coating and without it.

One of critical decisions for cost reduction and receiving of additional profit was formed in preparation of a new technological area to produce fiber from off-cuts of steel cord and wire products. Aiming to implement the investment project, two drawing mills were purchased to transform wire diameters to final size of 1 mm.

Specifically to produce fiber 20 machines were installed to produce anchor, wavy and micro fiber from thin wire diameters 0.2–0.7 mm and separately 4 machines for anchor fiber from wire diameter 0.8–1.1 mm. Final products are packed in cardboard boxes, weight up to 25 kg. 45-48 boxes are placed onto wooden pallet, then get wrapped in stretch-film (Fig. 6). Production output makes up 600 t/month.

Presently, fiber from BMZ has been successfully certified in Belarus and Russia, as well as in a number of European countries.

Specialists from the laboratory of fiber-concrete and fiber-concrete structures in state unitary enterprise «NIIZHB» (Moscow) think that fiber produced from steel cord off-cuts can be used to produce different steel fiber concrete structures first of all due to economic feasibility [10].

The cost of this fiber approximately 3-5 times lower than the cost of cut and milled one. It should be noted that in case of mass production of fiber it is possible to use double scheme: from wastes of wire production as well as from wire specially manufactured. Obligatory condition is that obtained fiber should be with certain strength parameters and 'diameter-length' ratio, and it all should assure stable and predicted properties of steel fiber concrete.

The experiments, carried out in laboratory and industrial conditions, proved service advantages of fiber concrete from wastes of wire and steel cord production.

There are certain technological limits for even distribution of fiber. They, in particular, depend on fiber size and

a b

Fig. 6. Machine line to produce fiber (a) and prepackaged final products (b) in steel wire shop № 3 of Byelorussian Steel Works

three-dimensional reinforcement coefficient. Based on carried out studies, optimal parameters of different types of fiber have been determined, depending on percentage content in concrete. Table 3 shows gradation of fiber subject to uniform distribution in fiber concrete.

In order to avoid nonuniformity of steel fiber concrete mixtures it is recommended to use fiber in accordance with the above mentioned proportions.

When preparing mixtures with fiber with essential limits, mechanical means should be used; utilize special devices assuring necessary productivity (speed) of supply and even distribution of fiber in concrete when it is supplied to a mixer.

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