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Д.В. Сокольский атындағы «Жанармай,
катализ және электрохимия институты» АҚ

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ИЗВЕСТИЯ

НАЦИОНАЛЬНОЙ АКАДЕМИИ НАУК
РЕСПУБЛИКИ КАЗАХСТАН
АО «Институт топлива, катализа и
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НАН РК сообщает, что научный журнал «Известия НАН РК. Серия химии и технологий» был принят для индексирования в Emerging Sources Citation Index, обновленной версии Web of Science. Содержание в этом индексировании находится в стадии рассмотрения компанией Clarivate Analytics для дальнейшего принятия журнала в the Science Citation Index Expanded, the Social Sciences Citation Index и the Arts & Humanities Citation Index. Web of Science предлагает качество и глубину контента для исследователей, авторов, издателей и учреждений. Включение Известия НАН РК в Emerging Sources Citation Index демонстрирует нашу приверженность к наиболее актуальному и влиятельному контенту по химическим наукам для нашего сообщества.

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PROPERTIES OF THE STEEL-FIBER-REINFORCEDCONCRETE WITH DISPERSED REINFORCING WIRE FIBER FROM TECHNOGENIC WASTE

Abstract. The article presents the results of theoretical and, most importantly, experimental studies of some properties of steel-fiber-reinforcedconcrete reinforced with dispersed reinforcement from industrial wastes, namely, ITEX steel wire fiber from SPA INNOTECH from spent steel ropes, a large number of which are used as raw materials for fiber production, has accumulated in the region with the mining industry (East Kazakhstan region). The result of the research was indicators of tensile strength of fiber-reinforced concrete during bending of samples, characteristics of crack resistance, and impact strength indicators of fiber-reinforced concrete reinforced with fiber from industrial waste. Knowing and demonstrating these characteristics will make it possible to more effectively ensure the possibility of selling a new product on the building materials market. This publication has been carried out as part of the sub-project Technology for Manufacturing Fiber from Technogenic Wastes, funded by the Government of the Republic of Kazakhstan and the World Bank, Project for Stimulating Productive Innovations.

Key words.steel fiber, industrial waste, fiber concrete, fiber concrete strength, impact strength, crack resistance.

1. Introduction.

The use of steel-fiber-reinforced concrete (SFRC) is increasing as an effective structural material in construction. Steel wire fiber is currently the most widely used. The production amount and use is constantly growing. In world practice, more than 300 thousand tons of steel fiber are used per year. In the Republic of Kazakhstan (RK), unfortunately, the consumptionamount of this promising material is significantly less. The small consumption of steel fiber reinforced concrete (SFRC) are largely explained by the lack of fiber production and the lack of knowledge by Kazakhstan designers and builders of the possibilities and advantages of this material, the absence of normative documentation related to SFRC in Kazakhstan, the lack of advertising and the lack of focused work on its use, especially from organizations project side.

2. Technologies for producing fiber from steel ropes.

Karaganda Promstroyproekt in the 80s of the last century, relying on the development of the Central Research Institute of Industrial Buildings, NIIIZhB and LenZNIIEP, on the basis of the Kazmetallurgstroy in Temirtau, implemented a method for producing wire fiber from used steel ropes using heat treatment. The ropes were preliminarily annealed at a temperature of 400-10000C, then they were cut into segments of a given length, which were split by grinding. Subsequently, steel-fiber-reinforcedconcrete structures for various purposes were made from the obtained fiber [1-3]. The disadvantage of this method was the loss of strength of wires during their heat treatment and the difficulty of washing and drying the finished fiber due to the lack of special equipment for these works. After the collapse of the USSR, research ceased, without having received wide industrial application.

Currently, in the East Kazakhstan region there are a large number of metallurgical and mining enterprises, in which steel ropes are widely used in bridge, overhead, cranes and mine shafts.The Gosgortekhnadzor of the Republic of Kazakhstan (RK) established the service life of ropes used in the industry for no more than 5 years (according to experts, it can be extended for another 3 years), inspection should also be carried out by specialists in the field of flaw detection at least once every 12 months. According to the presence of damage, a decision can be made to reject the rope earlier than the standard period of operation of the rope. Rope culling standards are set out in the requirements of RD ROSEK 012-97.

Nowadays, the disposal of steel ropes is their delivery to scrap points in the Republic of Kazakhstan. Moreover, all spent ropes belong to the same category - 13A, which is determined by GOST 2787-75. This is not advisable, because the material for the manufacture of ropes is a high-strength wire with a large unused resource.

The method for producing wire fiber from used steel ropes was modernized at the D. Serikbayev EKTU, within the framework of the state R&D (agreement with the Ministry of Education and Science of the Republic of Kazakhstan No. 84-210-13 of 04/10/13) [2]. The introduction of this method into production was carried out by INNOTECH Scientific and Production Association LLP in Ust-Kamenogorsk on the basis of the sub-project Technology for Manufacturing Fiber from Technogenic Waste, funded by the World Bank and the Government of the Republic of Kazakhstan project Stimulating Productive Innovations.

Fiber production is as follows (Figure 1). Spent steel ropes are cut into segments of a given length using thermofriction (preliminary) and abrasive (final) disk cutting. The obtained segments of the rope are then subjected to separation into wires, which is carried out due to the complex compressive-abrasive-vibrational impact on the segments in a large extent of the zone, which allows the separation of the rope segments into wires in one pass through the installation.

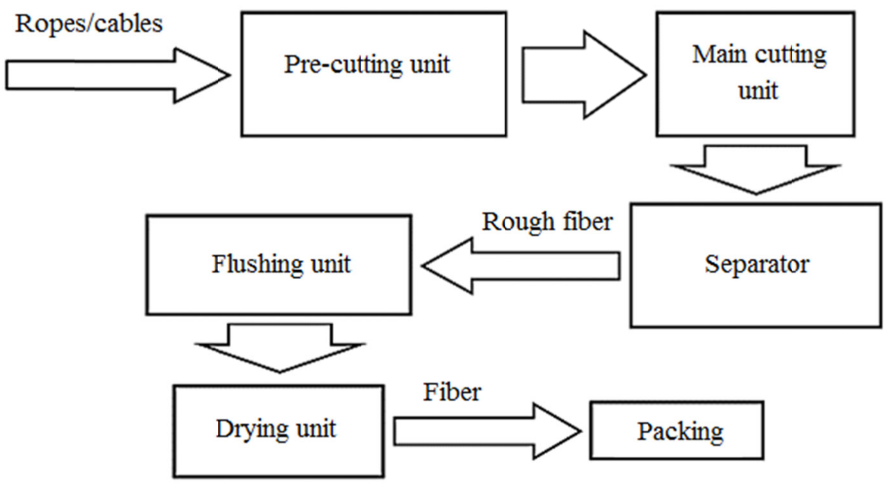

Figure 1 – Line diagram for the manufacture of fiber from waste ropes

Furthermore, dispersed reinforcement in the form of wires obtained as a result of rope separation segments is cleaned of grease and other contaminants by vibration washing in a bath with a special washing liquid with a combination of chemical, mechanical and hydrodynamic effects on pollution. Upon reaching the required quality of fiber cleaning, the washing process stops, the fiber is removed from the bath and sent further for drying or for its intended use. The use of rope cutting with circular knives with an increase in cutting speed and a reduction in cutting forces, splitting of the rope segments into wires due to the complex crushing-abrasive effect on them and their splitting in one pass between the grinding surfaces, and high-quality cleaning of dispersed reinforcement wires in a bath with a washing liquid that vibrates fluctuations [4-7]. It leads to reduce the energy intensity and time of the process of obtaining dispersed reinforcement, to increase the productivity and efficiency of the process, to reduce the costs of its conduct, to increase the surface cleanliness of the wires, to ensure good adhesion of the fiber wires to concrete, and therefore to improve the technological properties of fiber concrete.

3. Experimental research.

To evaluate the strength characteristics of steel fiber reinforced concrete with ITEX wire fiber (trademark registered) from waste ropes produced by Scientific and Production Association INNOTECH LLP, hereinafter referred to as ITEX fiber, an experimental study was conducted. Since dispersed reinforcement of concrete with fiber primarily increases tensile strength, crack resistance, and impact strength, which determines the application field of SFRC, an experimental study was aimed at determining these characteristics. To compare the effectiveness of ITEX fiber with existing analogs, SFRC with an anchor fiber 1/50 Hendix and Dramix 3D 80/60BG was also considered. The amount percentage of reinforcement with wire fiber was adopted as 1%, 1.5% and 2%.The composition of the components for fine-grained concrete matrix was selected in accordance with the recommendations of [3, 8-12] and is shown in table 1.

Technical characteristics of the used fiber Hendix:

Brand - 1/50 Hendix, length - 50 mm, diameter - 1 mm, temporary resistance - 1150 MPa.

Technical characteristics of the used fiber Dramix:

Brand - Dramix 3D 80/60BG, length - 60 mm, diameter - 0.75 mm, temporary resistance - 1225 MPa.

Table 1 – Formulation for concrete matrix per 1 m^3

Component	Quantity (kg / m3)	Ratiocomponents
Cementing agent - Portland cement, grade M450, Bukhtarma cement company (C)	C = 661	
Fine aggregate - quartz sand with a fineness modulus 3.0 (P)	P = 1283	P / C ≈ 1.941
Consolidator - water in accordance with GOST 23732-79 (B)	B = 285	B / C ≈ 0.4312
PlasticizerRheobuild 181A (Pl)	Pl = 4	1% of C

Technical characteristics of ITEX fiber:

Temporary resistance - 1809 MPa.

To analyze the ITEX fiber geometry, 4 samples were taken from different places of the total fiber volume. In the course of measurements, fiber with diameters of 0.5 mm, 1.0 mm and 1.5 mm was detected. The average fiber lengths of the samples are shown in table 2.

Table 2 – Geometrical characteristics of ITEX fiber

Sample number	Fiber length with a diameter of 0.5mm	% contentin the sample	Fiber Length with 1.0mm Diameter	% contentin the sample	Fiber Length with 1.5 mm Diameter	% contentin the sample
№1	6,35 cm	20,5%	6,35 см	72,6%	6,57 cm	6,95%
№2	6,33 cm	23,2%	6,37 см	74,6%	6,57 cm	2,2%
№3	6,34 cm	21,7%	6,38 см	73,6%	6,12 cm	4,7%
№4	6,26 cm	32,8%	6,41 см	59,2%	6,56 cm	8%

Steel fiber was added to the concrete mixture gradually using a tray and was evenly distributed during its preparation in the SBR-132A cyclic gravity concrete mixer. A standard vibrating platform with harmonic vibrations was used to form the samples. The compaction time was 3 s.

The average density of the SFB mixture is 2420 kg/m3.

Delamination coefficient at 2% reinforcement:

- at 3 s of vibration, k_p = 0.938;

- at 6 s of vibration, k_p = 0,882,which meets the requirements of clause 6.1.40 [3], ($k_p \geq 0.85$).

Coefficient of homogeneity at 2% reinforcement:

1 test, k_o = 0.87; 2 samples, k_o = 1.0; 3 samples, k_o = 0.98, which also meets the requirements of clause 6.1.40 [3, 13-18], ($1.1 \geq k_o \geq 0.9$).

To determine the tensile strength during bending, 10 series of control samples were made in the form of square prisms with dimensions of 100*100*400 mm (three samples in each series). Samples were tested at 28 days of age. The testing equipment used to determine the tensile strength during bending is a 2PG-10 hydraulic press. A sample mounted on two press supports was loaded up to failure at a constant rate of load increase (0.05 ± 0.01) MPa / s. The load was applied in thirds of the span and was evenly distributed over the width of the sample (figure 2).

Figure 2 – Installation diagram for determining the tensile strength and crack resistance in bending

The tensile strength of concrete in bending R_{tb}, MP, was determined according to [4]:

$$R_{tb} = \delta \frac{Fl}{ab^2} \quad (1)$$

where F – breaking load, N; a, b, l – the width, height of the cross section of the prism and the distance between supports, respectively, mm; δ – scale factor to bring concrete strength to concrete strength in samples of basic size and shape.

4. The results of experimental studies.

The results of the experimental determination of concrete tensile strength in bending are shown in figure 3.

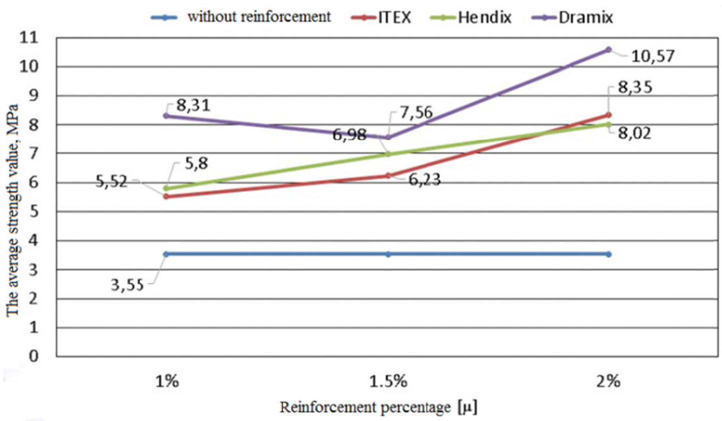

Figure 3 – Graphical comparison of tensile strength in bending

The tensile strength in bending of specimens reinforced with ITEX fiber -1.5% increased by 75% compared with the specimen without reinforcement (that is, 1.8 times), reinforced 2% by 135% (2.3 times). The similar results were shown for the samples reinforced with Hendix fiber: 1.5% - 97% (~ 2 times); reinforcement of 2% fiber - 126% (2.3 times). The samples are reinforced with factory fiber "Dramix", when reinforcing 1%, the strength increased by 134% (2.3 times), while reinforcing 1.5% showed a smaller result - 113% (2 times), which is explained by the uneven distribution of fiber in the samples of this series , 2% reinforcement increased strength by almost 3 times (2.9 times) 198%, which is the best result.

The crack resistance characteristics were determined during nonequilibrium mechanical tests according to [5]. Nonequilibrium tests are characterized by a loss of stability of the sample deformation process at the moment of deformation localization upon reaching the maximum load, with the corresponding development of the main crack.

7 series of control samples of type 1 were manufactured and tested in the form of square prisms with dimensions of 100 * 100 * 400 mm (three samples in each series) for bending tests (figure 2), with initial upper cuts according to [5, 7, 19-21].

Before the test, two loading-unloading cycles were carried out to a value of 10% of the expected maximum load. Then the samples were loaded continuously until they were divided into parts with fixing the value F_c^*.The loading speed was measured by the speed of movement of the loading plate of the press in the range of 0.02-0.20 mm/s.The results of determining the characteristics of crack resistance are shown in figure 4.

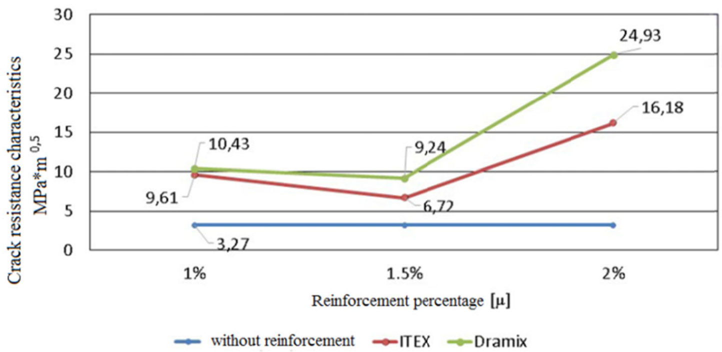

Figure 4 – Graph comparing the performance of crack resistance

Reinforcement of 1% ITEX fiber increased crack resistance by 194% (~ 2.94 times), and Dramix - by 219% (3.19 times), while reinforcing 1.5% fiber in both cases showed a lower result - ITEX106% (2.06 times), Dramix 183% (~ 2.83 times). Reinforcement of 2% fiber - ITEX increased by 395% (4.94 times), Dramix by 662% (~ 7.62 times).

To compare the impact strength, ten series of eight samples were made in the form of a 100*100*100 mm cube: a series of concrete samples without reinforcement, as well as a series of samples reinforced with factory fiber from Hendix and Dramix and fiber from waste ropes ITEX with a volume percentage of reinforcement of 1%, 1.5% and 2%.

The samples were tested on a vertical pile driver after hardening under normal conditions for 28 days. During the tests, the sample was mounted on the metal base of the pile driver, and from above it was hit with a hammer weighing 5 kg, freely falling from a height of 1.07 m (figure 5).

Figure 5 – Installation diagram for determining impact strength (vertical pile driver)

Impact resistance was estimated by the energy spent on the formation of cracks [6, 22-27]:

$$A_{ud} = \frac{PgHn}{L_{tr}}, \tag{2}$$

where P - the hammer mass; g - the acceleration of gravity; H - the hammer height; n - the number of strokes [27-32]; L_{tr}- the length of the cracks formed (average value over all faces of the sample).

In the analysis of impact tests, two indicators were compared: the amount of energy for the formation of the first crack and the amount of energy for the destruction of the sample.The results of determining the resistance of fiber-reinforced concrete to longitudinal impact upon the appearance of the first crack are shown in figure 6.

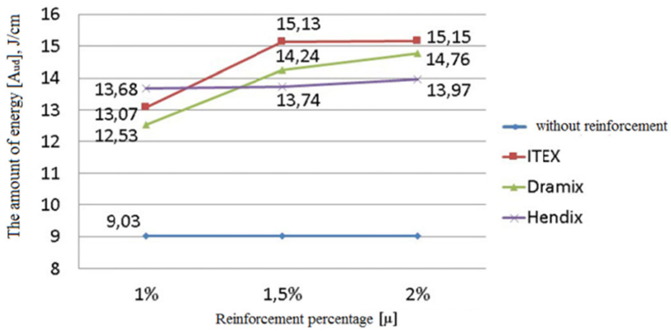

Figure 6 – Comparison of impact strength when the first crack

Figure 6 shows that with percentage reinforcement with steel fiber μ=2% in each series, the impact resistance index increases by an average of 60%, while samples reinforced with fiber of ITEX ropes with a percentage of reinforcement of μ=1.5% and μ=2% show better results than factory fiber samples, respectively.

The results of determining the resistance of fiber-reinforced concrete to longitudinal impact upon fracture of the sample are shown in figure 7.

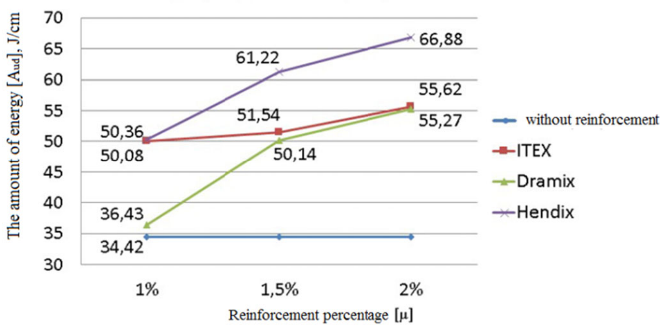

Figure 7 – Comparison of impact strength during fracture of a sample

The comparison of the indices during the destruction of the sample showed that the percentage reinforcement with Hendix fiber μ=2% increases impact resistance by 94%, and ITEX or Dramix fiber - by 60%. At the same time, ITEX fiber shows an average result in comparison with factory fiber. The coefficient of variation according to the calculation results ranged from 13 to 17% for each series.

5. Conclusion.

The results of the tests carried out allow us to justify the prospects of using ITEX steel wire fiber from used ropes as dispersed reinforcement of structures subjected to bending and dynamic stresses. Having close and at certain percentages of reinforcing even better physical and mechanical characteristics compared to the factory options Hendix and Dramix, fiber from spent ropes can be considered a full competitor in the market of dispersed reinforcement in Kazakhstan, whose competitiveness is also increased by its low price (1.3-1.5 times) and a large amount of raw materials in the region (East Kazakhstan region).

The data obtained lead to further commercial prospects for the implementation of the proposed solutions. The presented results served as the basis for the creation of an innovative industrial enterprise for the production of steel fiber from industrial waste.Areas of effective use of steel fiber concrete are given in table 3.

Table 3 – Areas for the effective use of steel fiber reinforced concrete

Typeofconstruction	Reserveofsavings
1 Industrialfloors	1.1 Reducing the thickness of the floor slab 1.2 Reducing the complexity and time of construction due to the lack of the need for the manufacture and installation of reinforcing mesh up to 40% 1.3 Increased wear resistance, impact strength and overall durability 1.4 Cost reduction in business up to 24%, reduced costs up to 32%
2 Pilesdriven	2 High impact resistance, which reduces rejects (pile head destruction) when driving up to 30%
3 Steel-reinforced concrete pressureless pipes	3.1 Reduction by 10-15% of the wall thickness 3.2 Increase in bearing capacity in comparison with standard reinforced concrete up to 2 times
4 Steel-fiber-reinforced concrete thin-walled elements of fixed formwork	4 The use of steel-fiber-reinforced concrete fixed formwork instead of an inventory shield allows reducing labor costs at a construction site by 20–25%, as well as shortening construction time

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ТЕХНОГЕНДІК ҚАЛДЫҚТАРДАН ЖАСАЛҒАН СЫМ ФИБРАСЫМЕН ДИСПЕРСТІ АРМАТУРАЛАНҒАН СТАЛЕФИБРОБЕТОН ҚАСИЕТТЕРІ

Аннотация. Көпірде, аспалы кран және шахта үстіндегі копрларда қолданылатын болат арқанды кәдеге жаратудың жаңартылған тиімді әдісі ұсынылады. Арқанды кәдеге жарату дегеніміз – берік сымнан болат талшығын алу мақсатында қайта өңдеу. Болат арқаннан сым талшығын алу әдісі Дүниежүзілік Банк пен Қазақстан Республикасы Үкіметінің қолдауымен «Өнімдік инновацияларды ынталандыру» жобасы аясында қаржыландырылған «Техногендік қалдықтардан талшық өндірудің технологиясы» шағын жобасы негізінде Өскемен қаласындағы «ИННОТЕХ ғылыми-өндірістік бірлестігі» ЖШС жүзеге асырды.

Талшық дайындау термофрикциялық (алдын ала) және абразивтік (соңғы) дискілі кесу арқылы болат арқанды берілген ұзындыққа кесу арқылы өндіріледі. Арықарай алынған арқанның кесінділері сымдарға бөлінеді, ұзындығы бойынша үлкен аймақтағы кесіндіге күрделі сығу-ысқылау-дірілдік әсер ету есебінен жүзеге асырылады, бұл арқан кесінділерін орнату арқылы бір өту үшін сымға бөлуді жүзеге асыруға мүмкіндік береді. Содан кейін арқан кесінділерін бөлу нәтижесінде алынған сым түріндегі дисперсті арматура ластануға химиялық, механикалық және гидродинамикалық әсерді үйлестіре отырып, ваннада арнайы жуу сұйықтығымен дірілді жуу әдісімен майлаудан және басқа да ластанудан тазартылады. Талшық тазалау сапасына жеткенде жуу процесі тоқтайды, талшық ваннадан шығарылады және одан әрі кептіруге немесе мақсатына қарай пайдалануға жіберіледі.

«ИННОТЕХ ғылыми-өндірістік бірлестігі» ЖШС өндіретін «Itex» талшық деп аталатын пайдаланылған арқаннан жасалған сым талшықтары бар болатфибробетонның беріктік сипаттамасын бағалау үшін эксперименттік зерттеу жүргізілді. Болат фибрабетонның қолдану аймағын анықтайтын бетонның талшықты дисперсті арматурасы ең алдымен, созылу кедергісін, сынуға төзімділігін және соққы беріктігін арттыратындықтан эксперименттік зерттеу осы сипаттамаларды анықтауға бағытталған. «Itex» талшығының тиімділігін қолданыстағы аналогтармен салыстыру үшін «1/50 Hendix» және «Dramix 3D 80/60BG» анкерлік талшығы бар болатфибрабетон қарастырылды. Сым талшықтарын арматуралаудың көлемдік пайызы 1%, 1,5% және 2% болып қабылданды. Үлгілердің иілу кезіндегі созылу беріктігі «Itex» арматураланған талшықта 1,5%, арматураланбаған үлгімен салыстырғанда 75%-ға (яғни 1,8 есе), арматураланған 2%-дан 135%-ға (2,3 есе) өсті. Ұқсас нәтижені «Hendix» талшығымен арматураланған үлгілер көрсетті: 1,5%-97% (~2 есе); 2% талшық арматурасы 126% (2,3 есе). «Dramix» зауыттық талшығымен арматураланған үлгілер 1% арматуралау кезінде беріктігі 134%-ға (2,3 есе) артты, ал 1,5% арматуралау аз нәтиже көрсетті – 113% (2 есе), бұл осы сериядағы үлгілерде талшықтың біркелкі бөлінбеуі негізінде түсіндіріледі, 2% арматуралау беріктігін шамамен 3 есе (2,9 есе) 198% арттырды, бұл жоғары нәтижені көрсетеді.

«Itex»талшығының 1% арматуралау жарыққа төзімділікті 194%-ға (~ 2,94 есе), ал «Dramix» 219%-ға (3,19 есе) арттырды, бұл ретте талшықты 1,5% арматуралау екі жағдайда да аз нәтиже көрсетті: «Itex» 106% (2,06 есе), «Dramix» 183% (~ 2,83 есе). 2% талшықты арматуралау «Itex» 395%-ға (4,94 есе), «Dramix» 662%-ға (~ 7,62 есе) артты.

Үлгінің динамикалық бұзылуындағы көрсеткіштерді салыстыру жұмыстары көрсеткендей, «Hendix» μ = 2% талшықты пайыздық күшейту соққыға төзімділікті 94%-ға, ал «Itex» немесе «Dramix» талшықтары арқылы 60%-ға арттырады. Бұл жағдайда «Itex» талшығы зауыттық талшықпен салыстырғанда орташа нәтижені көрсетеді. Есептеу нәтижелері бойынша вариация коэффициенті әр серия үшін 13-тен 17%-ға дейін жоғарылайды.

Жүргізілген сынақ нәтижелері бүгілуге және динамикалық әсерлерге ұшырайтын конструкциялардың дисперсті арматурасы ретінде істен шыққан арқаннан «Itex» болат сым фибрасын болашақта пайдалануды негіздеуге мүмкіндік береді. «Hendix» және «Dramix» шетелдік нұсқаларымен салыстырғанда арматуралаудың жақын және белгілі бір пайызы кезінде, тіпті жоғары физикалық-механикалық сипаттамаға ие бола отырып, пайдаланылған арқан талшығы Қазақстанның дисперсті арматура нарығында толық құқықты бәсекелес болып саналуы мүмкін, оның бәсекеге қабілеттілігі арзан бағасы (1,3 - 1,5 есе) мен өңірде (Шығыс Қазақстан облысы) шикізат мөлшерін ұлғайтады

Үнемдеу резервін беретін болатфибробетонды тиімді қолданудың келесідей салалары ұсынылады: өнеркәсіптік едендер (еден плитасының қалыңдығын азайту; арматуралық торды дайындау және орнату қажеттілігінің болмауы есебінен құрылыстың еңбек сыйымдылығы мен уақытын 40%-ға төмендету; тозуға төзімділігін, соққыға беріктігін және жалпы төзімділігін арттыру; еңбек құнын 24%-ға, келтірілген шығынды 32%-ға төмендету); қағылған қадалар (жоғары соққыға төзімділік 30%-ға соғылған кезде ақауды (қаданың басын бұзу) сиретеді); болатфибробетонды ағынсыз құбырлар (қабырға қалыңдығының 10-15%-ға азаюы; типтік темірбетон құбырларымен салыстырғанда көтергіш қабілетінің 2 есеге дейін ұлғаюы); алынбайтын қалыптың болатфибробетонды жұқа қабырғалы элементтері (инвентарлық қалқанша орнына болатфибробетонды алынбайтын қалыптарды қолдану құрылыс алаңындағы еңбек шығынын 20-25%-ға төмендетуге, сондай-ақ құрылыс мерзімін қысқартуға мүмкіндік береді).

Түйін сөздер: болат талшығы, техногендік қалдықтар, талшықты темірбетон, талшықты темірбетон беріктігі, соққы беріктігі, жарыққа төзімділік.

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СВОЙСТВА СТАЛЕФИБРОБЕТОНА С ДИСПЕРСНЫМ АРМИРОВАНИЕМ ПРОВОЛОЧНОЙ ФИБРОЙ ИЗ ТЕХНОГЕННЫХ ОТХОДОВ

Аннотация. Предлагается модернизированный эффективный метод утилизации отработанных стальных канатов, используемых в мостовых, подвесных кранах и надшахтных копрах. Утилизация канатов заключается в их переработке с целью получения стальной фибры из высокопрочной проволоки. Метод получения проволочной фибры из стальных канатов внедрён ТОО «Научно-производственное объединение ИННОТЕХ» в г. Усть-Каменогорске на основе подпроекта «Технология изготовления фибры из техногенных отходов», финансируемого в рамках проекта «Стимулирование продуктивных инноваций», поддержи-ваемого Всемирным Банком и Правительством Республики Казахстан.

Изготовление фибры производится посредством разрезания стальных канатов на отрезки заданной длины с помощью термофрикционной (предварительной) и абразивной (окончательной) дисковой резки. Далее полученные отрезки каната подвергаются разделению на проволоки, которое осуществляется за счет сложного сжимающе-истирающе-вибрационного воздействия на отрезки в большой по протяженности зоне, что позволяет осуществлять разделение отрезков каната на проволоки за один проход через установку. Затем дисперсная арматура в виде проволок, полученных в результате разделения отрезков каната, подвергается очистке от смазки и других загрязнений методом вибрационной мойки в ванне со специальной моющей жидкостью при сочетании химического, механического и гидродинамического воздействий на загрязнения. По достижении требуемого качества очистки фибры процесс мойки останавливается, фибра извлекается из ванны и отправляется далее на сушку или для использования по назначению.

Для оценки прочностных характеристик сталефибробетона (СФБ) с проволочной фиброй из отработанных канатов, производимой ТОО «Научно-производственное объединение ИННОТЕХ», далее именуемой фибра «Itex», проведено экспериментальное исследование. Так как дисперсное армирование бетона фиброй в первую очередь повышает сопротивление растяжению, трещиностойкость и ударную прочность, что и определяет область применения СФБ, то экспериментальное исследование было нацелено на определение этих характеристик. Для сравнения эффективности фибры Itexс существующими аналогами рассматривался также СФБ с анкерной фиброй «1/50 Hendix» и «Dramix 3D 80/60BG». Объёмный процент армирования проволочной фиброй был принят 1%, 1,5% и 2%.

Прочность на растяжение при изгибе образцов, армированных фиброй «Itex» 1,5%, повысилась на 75% по сравнению с образцом без армирования (то есть в 1,8 раз), армированные 2% - на 135% (2,3 раза). Схожий результат показали образцы, армированные фиброй «Hendix»: 1,5% - 97% (~ в 2 раза); армирование 2-мя % фибры - 126% (2,3 раза). Образцы же армированные заводской фиброй «Dramix», при армировании 1% прочность повысилась на 134% (2,3раза), при этом армирование 1,5% показало меньший результат – 113% (2раза), что

объясняется неравномерностью распределения фибры в образцах данной серии, 2% армирования повысило прочность почти в 3 раза (2,9 раза) 198%, что является наилучшим результатом.

Армирование 1% фибры «Itex» повысило трещиностойкость на 194% (~ в 2,94 раза), а «Dramix» – на 219% (3,19 раз), при этом армирование 1,5% фибры в обоих случаях показало меньший результат – «Itex» 106% (2,06 раза), «Dramix» 183% (~ в 2,83 раза). Армирование 2% фибры – «Itex» повысило на 395% (4,94 раза), «Dramix» на 662% (~ в 7,62 раза).

Сравнение показателей при динамическом разрушении образца показало, что процентное армирование фиброй “Hendix” μ=2% повышает ударостойкость на 94%, а фиброй “Itex” или “Dramix” – на 60%. При этом фибра “Itex” показывает средний результат в сравнении с заводской фиброй. Коэффициент вариации по результатам расчета составил от 13 до 17% для каждой серии.

Результаты проведенных испытаний позволяют обосновать перспективность использования стальной проволочной фибры “Itex” из отработанных канатов в качестве дисперсной арматуры конструкций, подвергающихся изгибу и динамическим воздействиям. Обладая близкими и при определенных процентах армирования даже лучшими физико-механическими характеристиками по сравнению с зарубежными вариантами “Hendix” и “Dramix”, фибра из отработанных канатов может считаться полноправным конкурентом на рынке дисперсной арматуры Казахстана, чью конкурентноспособность также увеличивает её низкая цена (в 1,3 – 1,5 раз) и большое количество сырья в регионе (Восточно-Казахстанская область).

Рекомендованы области эффективного применения сталефибробетона, дающие резерв экономии:

- промышленные полы (уменьшение толщины плиты пола; снижение трудоёмкости и времени строительства за счёт отсутствия необходимости изготовления и установки арматурных сеток до 40 %; увеличение износостойкости, ударной прочности и в целом долговечности; снижение стоимости в деле до 24%, приведённых затрат до 32%);
- сваи забивные (высокая ударостойкость, что снижает брак (разрушение головы сваи) при забивке до 30 %);
- сталефибробетонные безнапорные трубы (уменьшение на 10–15 % толщины стенок; увеличение несущей способности по сравнению с типовыми железобетонными до 2 раз);
- сталефибробетонные тонкостенные элементы несъемной опалубки (применение сталефибробетонной несъемной опалубки вместо инвентарной щитовой позволяет снизить трудозатраты на строительной площадке на 20–25 %, а также сократить сроки строительства).

Ключевые слова: стальная фибра, техногенные отходы, фибробетон, прочности фибробетона, ударная вязкость, трещиностойкость.

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