World Applied Sciences Journal 24 (10): 1280-1285, 2013
ISSN 1818-4952

DOI: 10.5829/idosi.wasj.2013.24.10.7001

High Strength Fiber Concrete for Industrial and Civil Engineering

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Submitted: Aug 1, 2013; **Accepted:** Sep 9, 2013; **Published:** Sep 15, 2013

Abstract: The paper deals with the use of steel fibers to disperse reinforcement of fine-grained concretes. The authors conducted experimental studies of steel fiber samples on cement and composite binder. As a binder the authors used fine ground cement and a binder with low water demand. It has been found that the use of composite binders and high-density arrangement of aggregate grains significantly increases the strength characteristics. The optimal aggregate selection allowed to obtain fiber concretes on Kursk Magnetic Anomaly technogenic sands with compressive strength of 104.8 MPa and 23.2 MPa for bending structures.

Key words: Fine grained concrete · Technogenic sand · Fiber-concrete

INTRODUCTION

For construction sites of World Football Cup 2018 in Russia in the coming years it is necessary to double the production of high-quality building structures such as beams, plates, girders, etc. In addition, currently intensive construction of buildings is taking place, resulting in the need of using concrete with high-performance characteristics, such as compressive and tensile strength, wear resistance, corrosion resistance, crack resistance, cold resistance, etc. To solve this problem the authors have developed compositions of fine-grained steel fiber concrete on the basis of technogenic sand - screening of crushing quartzitic sandstone enriched with sand taken from Tavolzhanska village, composite binders, fine aggregate and superplasticizer - GLENIUM 115.

Basic Part: Studies on fiber concrete were made by a Russian engineer V.P. Nekrasov at the beginning of the XX century. In Russia, the basis of knowledge of steel fiber was formulated by the following scientists: Y.M. Bazhenov, I.V. Volkov, V.P. Vylekzhanin, L.G KURBATOV, I.A. Lobanov, A.P. Pavlov, Y. Puharenko, F.N. Rabinovich, V.P. Romanov, K.V. Talantova, G.K. Khaidukov, O.N. Hegay and others [1-6].

Great contribution to the development of steel fiber concrete studies was made by scientists in Austria, Australia, Belgium, Germany, Holland, Spain, Canada, China, Poland, the USA, France, Czech Republic, Switzerland, South Africa, Japan and other countries. Among them the following researches should be mentioned: J.P. Romualdi, B. Gordon, G.B. Batson, M. Jeffrey, I.A. Mandel, I.L. Carson, W.F. Chen, D.I. Hannant, B. Kelly, P.S. Mangat, A.E. Naaman, R.N. Swamy, D. Colin Johnston, D.R. Lankard, V. Ramakrishnan, G. Ruffert, K. Kordina, W.A. Marsden, J. Vodichka и др [7-13].

The value of fibers consists in the fact that they do not only give new properties to concrete, but also open a way of entirely new manufacturing techniques of construction products. Reinforcing is made directly in concrete mixing units, i.e. cement is loaded into a concrete mixer with sand, crushed stone and fibers themselves, mixed and reinforced concrete mix prepared is ready to apply, which is poured into a form. Time of product manufacture is reduced almost by half. In connection with substantial improvement of physical and mechanical properties material consumption of structural elements reduces, resulting in reduction in weight of buildings and structures.

Earlier studies on the possible uses of technogenic KMA sand showed that the research carried out were mainly focused on the study the material composition and structure of KMA waste rocks, developing composition and manufacturing techniques of cement concrete based on them, which made it possible to transfer shaly rock mass, quartzite sandstone, sands located in the mining area while extracting ferrous quartzites from waste category into the category of mineral resources [1, 6].

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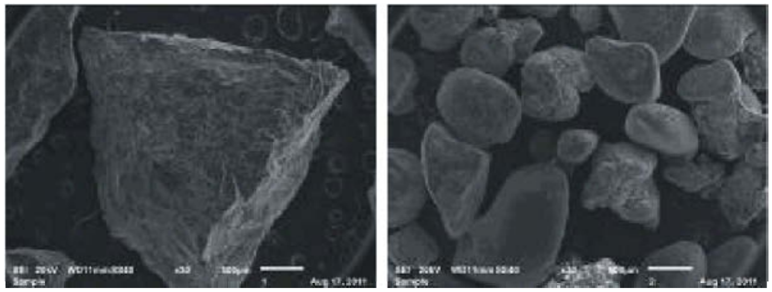

(a) (b)

Fig. 1: Grains: *a*) technogenic sand; *b*) natural sand

Table 1: Physical and mechanical characteristics of composite binders

Type of binder	Standard viscosity of cement paste %	Periods for cement paste setting, h. Start	End	C / B	Binder activity, (MPa) Under bending	Under compression
CEM I 42.5Í	26,2	2-40	4-40	0,4	7,2	48,9
TMC-100	25,3	2-20	4-30	0,35	10,2	61,3
LWCB -100	22,8	2-10	4-10	0,28	12,4	80,2

Properties of technogenic sand, concrete and concrete mixes based on them are dependent on many factors due to the properties of the original rocks, grinding methods and enriching techniques. The most significant influence is made by strength, structure and composition of the rock. When comparing the properties of natural and technogenic sand, there are fundamental differences between these materials. Natural sands are mostly quartz, with a round shaped grains and smooth surface, technogenic sands have significant differences in composition and properties of the original rock, grain shape and surface roughness (Fig. 1).

Aggregate roughness is closely related to water absorption of the rock: the higher is surface roughness, the more its water absorption is. By wetting of aggregate surface we can judge on its activity. The more active the aggregate surface is, the thicker is the layer of water attracted and held. At low C / O great thickness of the water retained should reduce the segregation of water cement paste and thus improve the adhesion in a solution or concrete [1].

With a C / B high value makes impossible the formation of thick film in the liquid-phase on aggregate surface, as film thickness ratio in the liquid phase around the grains of aggregate and cement is determined by the ratio of hydraulic activity. For high viscosity of water cement paste (due to increased C / B value) and sand with high water retention ability incomplete wetting of aggregate surface may occur and as a result, partial adhesion of the cement paste to aggregate surface, which greatly reduces adhesion value between them.

The main task in the production of fine-grained concrete, including fiber concrete, is cutting clinker component, since the lack of coarse aggregate results is excess cement consumption. The most significant factors in reducing the amount of cement in the fine particulate-reinforced concretes are reducing water demand of the concrete mix and increased binder activity. In connection with this a promising way of improving the efficiency of such concrete is the use of composite binders [1, 6].

For experimental studies we designed binders with following compositions: fine grained cement binder (TMC-100) was obtained by additional grinding to obtain a specific surface.

*S*sp=500 м^2/kg of portlans cement CEM I 42,5H by GOST (state standard) 31108–2003.

Low water consumption binder (LWCB-100) was prepared by joint grinding to a specific surface of 500 m^2/kg of Portland cement CEM I 42,5 N and plasticizer SP-1 in the optimal dosage (Table 1).

The study of rheological properties of the composite binders were performed by evaluating the method of full rheological curves matching studied in static straight-line flow.

Comparing grain composition of TMC-100 and LWCB -100, we can conclude that with the same specific binder surface, there are more grains sized from 5 to 20 microns in LWCB -100 compared with TMC-100, respectively, the proportion of particles smaller than 5 microns in TMC-100 is slightly higher than in LWCB -100.

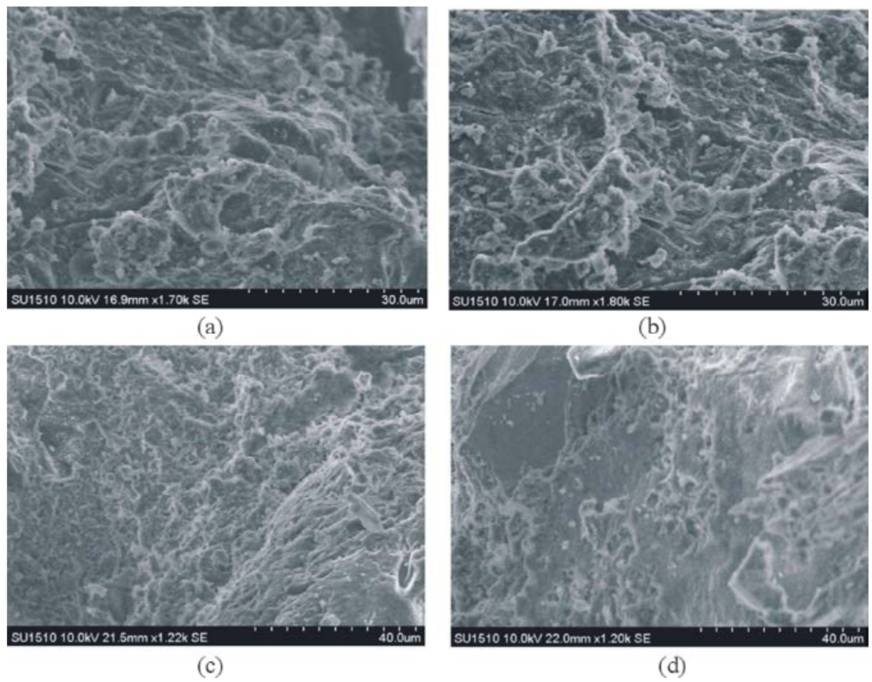

Fig. 2: Microstructure depending on binder characteristics:
a, b – morphology of new formation of cement stone Cem I 42,5H;
c, d – morphology of new formation of LWCB -100; magnified: *a, б* - x16000, *c, d* - x32000

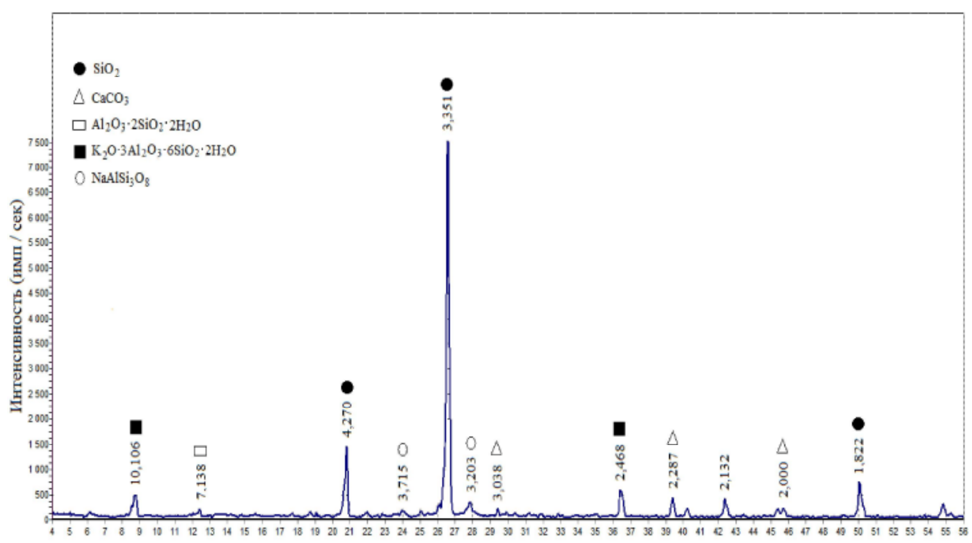

Fig. 3: X-ray pattern of micro aggregate from crushed quartzite sandstone screening

Grain composition of binder LWCB -100 obtained has a higher content of particles sized 5 to 20 microns, which provides its higher activity.

The data obtained also allow to assess the grinding efficiency: cement grinding with plasticizer SP-1 in the amount of 0.6% by weight of cement occurs more intensively; thus, the desired specific surface area 500 m2/kg is achieved after 2 hours milling, instead of 3 hours, as in the case of cement grinding without aggregates, which is explained by disjoining action of the aggregate itself (Fig. 2).

Microsilica aggregate is prepared by grinding to a specific surface Ssp = 700 m^2 / kg crushed quartzite sandstone screening used, x-ray analysis was conducted to study its properties (Fig. 3).

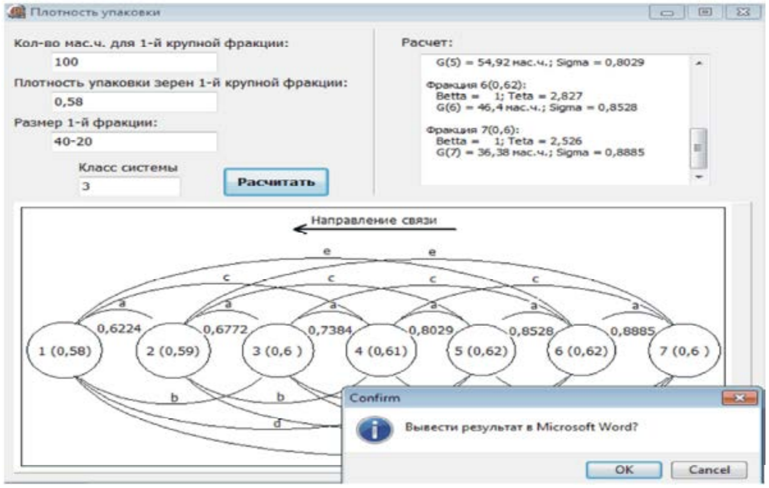

Fig. 4: Software layout

Table 2: Physical and mechanical characteristics of fine grained concrete, reinforced with steel wave fiber

		Material consumption, kg/м³						
Type of binder	Binder, kg	Crushing screenings, kg	Sand from Tavolzhanka пк, кт	Water, L	Steel wave fiber, kg	ΓSuerplasticizer GLENIUM 115, kg	Compression strength, MPa	Ultimate tensile strength, MPa
Cem I 42,5H	510	1180	555	170	-		50,2	13,7
Cem I 42,5H * HCSFC	510	1185	555	172	-		56,5	14,2
Cem I 42,5H	510	1180	555	172	72		57,4	16,8
Cem I 42,5H * HCSFC + ** MA	510	1185	555	174	72	4	72,2	21,1
Fine ground concrete-100	510	1180	555	160	72		71,4	21,0
Fine ground concrete -100 * HCSFC + ** MA	510	1185	555	162	72	4	94,7	22,2
LWCB-100	510	1180	555	150	72		82,2	21,9
LWCB-100 * HCSFC + ** MA	510	1185	555	152	72	4	104,8	23,2

* HCSFC – highly compact grains of fine steel fiber concrete

**MA – micro aggregate

Analysis of X-ray pattern showed that micro aggregate predominantly consists of quartz, greenschist metamorphism degree, the specifics of which is a crystal lattice defects and the presence of inclusions. In the process of technological transformations, during crushing and grinding the particles of quartzite sandstone become partially amorphous, transforming into an active mineral admixture [1].

A promising way of improving the efficiency of fine-grained steel fiber concrete is using composite binders and high compaction of aggregate grains. This study allowed to develop an algorithm and program for calculating the composition of fine-grained steel fiber concrete based on technogenic sand, enriched by sand Tavolzhanka, enabling to get more compact aggregate grains (Fig. 4).

Using fine aggregate (7% of binder weight) and fiber reinforcement, as well as optimization of cement stone (including high compaction of aggregate grains), the use of superplasticizer made it possible to obtain compressive strength of 100.2 Mpa in 28 days (more than 60% higher than regular concrete.) Introduction of fine aggregate contributed to more efficient and rapid reaction. This aggregate increased cement stone density, filling pores and improving adhesion with the aggregate and fiber. The effect of filling pores created by aggregate micro particles significantly reduces capillary porosity and concrete permeability.

The above studies [14-18] revealed that 3% reinforcing by weight makes it possible to obtain maximum physical and mechanical characteristics, due to compaction of cement stone between the fibers.

Experimental studies have shown that further increase in the percentage of fiber reinforcement results in slight increase in strength, deformability and performance characteristics. This can be explained by decreasing in

;thickness of the concrete layer so that the material tends to segregation. Therefore, for further study of fine fiber reinforced concretes 3% reinforcement ratio is accepted 3.

Steel fiber concrete with the use of wave fiber as a reinforcing material has the best strength and deformability characteristics [14-18]. It is known that the increase in crach resistance while fiber reinforcing processes is explained by "slowdown" of crack spread (destruction of edges between the fiber and the matrix, pulling fibers from the matrix) taking place in sequence. Due to this, there occurs additional resistance to crack formation and its development. In turn, wave shaped fibers will be hardly extracted from the composite resulting in reducing of crack formation even in the initial stage and better distribution of stresses in concrete itself.

Experimental studies have been conducted to obtain high strength steel fiber concrets. The results are shown in Table 2.

CONCLUSIONS

High density of mix components made on the basis of composite binders influences the structure of steel fiber concrete, allowing to increase the strength characteristics of bended elements. Rational aggregate selection, the use of composite binders, optimum shape steel fiber and superplasticizer enabled obtaining fiber concrete with compressive strength of 104.8 MPa and tensile strength in bending - 23.2 MPa.

Conclusion: Composition of fine fiber-reinforced concrete on the basis of composite binder has a high physical and mechanical deformability and performance. This is explained by better spatial concentration of particles in the composite obtained and features of structure formation. Using composite binder and fine aggregate with active surface accelerates the synthesis of new formations, based on shortening the period of structure formation by binding calcium hydroxide formed during alite hydration and formation of dense composite microstructure as evidenced by X-ray pattern study, which allowed comparison between cement stone of fine-grained fiber-reinforced concrete based on composite binder and fine aggregate with microdispersed admixture and superplasticizer GLENIUM115.

ACKNOWLEDGMENTS

This work was supported by grants of the President of the SP-5949.2013.1 and the grant of President of the Russian Federation MK-2715.2012.8 on "Development of scientific and practical bases of efficiency of fine fiber-reinforced concrete on the basis of man-made sand and a composite binder for industrial and civil construction."

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