



(43) International Publication Date
26 June 2014 (26.06.2014)

(10) International Publication Number
WO 2014/094692 A1

- (51) International Patent Classification:
C04B 28/02 (2006.01) *C04B 14/48* (2006.01)
- (21) International Application Number:
PCT/CZ2013/000161
- (22) International Filing Date:
5 December 2013 (05.12.2013)
- (25) Filing Language: English
- (26) Publication Language: English
- (30) Priority Data:
PV 2012-903 17 December 2012 (17.12.2012) CZ
- (71) Applicant: **CZECH TECHNICAL UNIVERSITY IN PRAGUE** [CZ/CZ]; Faculty of Civil Engineering, Thákurova 7, 166 29 Praha 6 (CZ).
- (72) Inventors: **FLÁDR, Josef**; Na Výsluní 82, 334 42 Chlumčany (CZ). **VODIČKA, Jan**; Na Kocínce 8, 160 00 Praha 6 (CZ). **KOHOUTKOVÁ, Alena**; Ověnecká 330/44, 170 00 Praha 7 (CZ). **BROUKALOVÁ, Iva**; Cukrovárnická 13, 160 00 Praha 6 (CZ).
- (74) Agent: **DUŠKOVÁ, Hana**; Czech Technical University in Prague - Patent Centre, Žitná 4, 166 36 Praha 6 (CZ).
- (81) Designated States (*unless otherwise indicated, for every kind of national protection available*): AE, AG, AL, AM, AO, AT, AU, AZ, BA, BB, BG, BH, BN, BR, BW, BY, BZ, CA, CH, CL, CN, CO, CR, CU, CZ, DE, DK, DM,

DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IR, IS, JP, KE, KG, KN, KP, KR, KZ, LA, LC, LK, LR, LS, LT, LU, LY, MA, MD, ME, MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PA, PE, PG, PH, PL, PT, QA, RO, RS, RU, RW, SA, SC, SD, SE, SG, SK, SL, SM, ST, SV, SY, TH, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, ZA, ZM, ZW.

- (84) Designated States (*unless otherwise indicated, for every kind of regional protection available*): ARIPO (BW, GH, GM, KE, LR, LS, MW, MZ, NA, RW, SD, SL, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, RU, TJ, TM), European (AL, AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV, MC, MK, MT, NL, NO, PL, PT, RO, RS, SE, SI, SK, SM, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, KM, ML, MR, NE, SN, TD, TG).

Declarations under Rule 4.17:

— *of inventorship (Rule 4.17(iv))*

Published:

- *with international search report (Art. 21(3))*
- *before the expiration of the time limit for amending the claims and to be republished in the event of receipt of amendments (Rule 48.2(h))*

(54) Title: ULTRA-HIGH STRENGTH STEEL FIBRE REINFORCED CONCRETE

(57) Abstract: Ultra-high strength steel fibre reinforced concrete with cement matrix contains silica cement, basalt aggregate, steel fibres, admixtures and additives. The dosage of admixtures is given by the results of the porosity tests of basalt aggregate and steel fibres mixture. The admixtures are dosed so that the required workability is reached; according to real application. There is 600 to 1000 kg/m³ of silica cement in cement matrix, basalt aggregate has three sieve sizes, namely 0-4, 4-8 and 8-16, the total dose of basalt aggregate is in the range 1500 and 2000 kg/m³. Ratio of sieve sizes is determined by granulometry and mineralogical composition of particular source of basalt aggregate. Water/cement ratio ranges between 0.16 and 0.25. Two types of steel fibres are evenly distributed in the volume of hardened steel fibre reinforced concrete. The first type of fibres has rectangular section with width ranging between 0.2 and 0.5 mm, height between 1.5 and 2.0 mm and length between 25 and 35 mm with strength between 350 and 450 MPa. The second type of steel fibres has circular section with diameter ranging between 0.08 and 0.12 mm, their length ranges between 8 and 15 mm and their strength is higher than 2000 MPa. The total weight of both types of fibres ranges between 100 and 280 kg/m³.



WO 2014/094692 A1

Ultra-high strength steel fibre reinforced concrete

Background of the Invention

5

Submitted design concerning a new composition of steel fibre reinforced concrete with ultra-high strengths refers to composite materials with cement matrix with ultra-high compressive strengths, higher than 120 MPa.

10 Description of Prior Art

Development of steel fibre reinforced composites with cement matrix nowadays aims to concretes called HPC or UHPC, accordingly high performance and ultra-high performance concretes characterized primarily by high average
15 compressive strengths – about 200 MPa. The matter is based on dense structure of composites, achieved by cement dosage of 600 – 1000 kg/m³, by minimal water/cement ratio of (0.16 – 0.25) and by a type of steel fibres of 8 – 12 mm length and dosage of 100-300 kg/m³. The utilisation of special additives and admixtures is inevitable. Aggregate, as essential constituent of the composite, is
20 used in fractions with maximum size of 2 or 4 mm. The main disadvantage of the solution is significant settling of steel fibres to bottom surface of the manufactured element. The effect happens because the fibres cannot be supported by bigger aggregates with size 8 or 16 mm. This leads to pronounced inhomogeneity of material and diminution of steel fibre reinforced concrete properties.

25

Summary of the Invention

The drawbacks listed above are removed by steel fibre reinforced concrete with ultra-high strengths with the cement matrix that contains silica cement, basalt
30 aggregate, steel fibres, admixtures and additives. The amount of admixtures in the volume is given by results of tests of porosity of basalt aggregate and steel fibres.

Admixtures are dosed to reach required workability for practical application. The principle of the new solution is that in cement matrix there is the amount 600 to 1000 kg/m³ of silica cement, basalt aggregate consists of three sieve sizes, namely 0-4, 4-8 and 8-16, water/cement ratio ranges between 0.16 and 0.25 and
5 two types of steel fibres evenly distributed in the volume of hardened steel fibre reinforced concrete. The total dose of basalt aggregate is in the range of 1500 to 2000 kg/m³ and ratio of sieve sizes is determined by granulometry and mineralogical composition of particular source of basalt aggregate. Concerning the steel fibres, the first type of fibres has rectangle cross-section; width of the cross
10 section ranges between 0.2 and 0.5 mm, cross sectional height ranges between 1.5 and 2.0 mm and length of fibres ranges between 25 and 35 mm. Strength of the first type of fibres is 350 – 450 MPa. The second type of steel fibres has circle cross-section with diameter ranging between 0.08 and 0.12 m; their length is between 8 and 15 mm and their strength is higher than 2000 MPa. The weight of
15 both types of fibres together ranges between 100 and 280 kg/m³.

Ratio of the first and second type of fibres is expediential between 0.5/1.5 and 1.5/0.5.

The use of fibres from industrial waste is very advantageous. The first type of fibres is profitably made from waste steel strip and the second type is made
20 from cut cord fibres gained in recycling of tires.

The amount of admixtures varies between 5 and 15% of steel fibre reinforced concrete volume.

New solution consists in design of structure of cement composite, namely steel fibre reinforced concrete, where two different types of steel fibres are utilised.
25 The importance of the new solution significantly increases if the steel fibres are gained entirely from waste. The result of utilisation of dispersed fibre of two different types is both strengthening of the steel fibre reinforced structure and providing of uniform distribution of coarse aggregate. The necessary condition for the design of the steel fibre reinforced concrete composition is utilisation of basalt

aggregate with common grain size distribution 0-4, 4-8, 8-16. Weight ratio of coarse sizes depends on required characteristics of hardened concrete.

5 Detailed Description of the Preferred Embodiments

Design of the steel fibre reinforced concrete composition is performed according to requirements on strength in compression, eventually tensile strength. The dosage of aggregate ranges between 1500 – 2000 kg/m³ depending on used weight batches of steel fibres. Total weight of both types of fibres ranges between 100 – 280 kg/m³. Steel fibres of the first type have rectangular cross-section 0.2-0.5 mm / 1.5-2 mm, length of 25-30 mm and strength of 350-450 MPa; they are made from waste steel ribbons. Steel fibres of the second type have circular cross-section with diameter of 0.08-0.12 mm, length of 8-15 mm and their strength is higher than 2000 MPa. The second type of fibres is advantageously gained during recycling of tires. The weight ratio of listed types of steel fibres is within the limits of 0.5:1.5 and 1.5:0.5; generally 1 : 1; the steel fibres are always evenly distributed in the hardened concrete.

Cement, admixtures and additives are dosed with the aim to reach dense structure of the steel fibre reinforced concrete. The dense structure is the carrier of ultra-high strengths and provides suitable workability of the fresh steel fibre reinforced concrete by common compaction tools. There is 600 to 1000 kg/m³ of silica cement in the cement matrix. Basalt aggregate is composed from three sieve sizes, namely 0-4, 4-8 and 8-16, in the weight dose between 1500 and 2000 kg/m³. The ratio of the sieve sizes is determined according to the demands of compressive strength of hardened steel fibre reinforced concrete. Water / cement ratio ranges between 0.16 and 0.25.

Examples of composition of the steel fibre reinforced concrete, including recorded average strengths in compression and tensile splitting strength are listed in the table bellow.

1. example of high-performance concrete mix proportions:

Label		C1
Units		kg/m ³
Cement		650
Aggregate	0/4	400
	4/8	400
	8/16	800
Fibres	Dramix	140
	Fibrex	140
Microsilica		40
Superplasticizer		30

5

Results of compressive strengths

Specimen	Dimensions (mm)	Weight (kg)	Density (kg/m ³)	Load (kN)	Strength (MPa)
C1.1	98,5	2,885	2929	1440	146,2
	100				
	100				
C1.2	99	2,800	2828	1420	143,4
	100				
	100				
C1.3	100	2,840	2840	1430	143,0
	100				
	100				
C1.4	99,5	2,840	2854	1425	143,2
	100				
	100				
C1.5	99	2,850	2879	1460	147,5
	100				
	100				
C1.6	100	2,835	2835	1420	142,0
	100				
	100				
average		2,84	2862,9		144,0

Results of tensile splitting strength

Specimen	Dimensions (mm)	Weight (kg)	Density (kg/m ³)	Load (kN)	Strength (MPa)
C1.1	149,5	9,312	2768	560	15,9
	150				
	150				
C1.2	149	9,415	2808	560	16,0
	150				
	150				
C1.3	148	9,365	2812	530	15,2
	150				
	150				
average		9,36	2796,3		15,7

5

The resulting compressive strength significantly exceeds the value of 60 MPa, which is the minimal limit for high-strength steel fibre reinforced concrete; that is why this material can be called high-strength one. Both strengths exceed common concrete strengths approximately six times; this implies utilisation of the material in extremely loaded elements such as columns of high-rise buildings, bridge piers and bridge decks.

10

2. example of the mixture composition of the high-performance concrete:

15

Label		P1
Unit		kg/m ³
Cement		800
Aggregate	0/4	420
	4/8	460
	8/16	960
Fibres	Dramix	140
	Fibrex	140
Microsilica		160
Superplasticiser		30

Results of compressive strengths

Specimen	Dimensions (mm)	Weight (kg)	Density (kg/m ³)	Load (kN)	Strength (MPa)
P1.1	100	2,774	2774	1680	168,0
	100				
	100				
P1.2	100,5	2,787	2773	1730	172,1
	100				
	100				
P1.3	102,5	2,836	2767	1910	186,3
	100				
	100				
average		2,80	2771,3		175,5

5

Resulting compressive strength exceeds the value of 150 MPa, which is minimal limit for Ultra-high strength steel fibre reinforced concrete, that's why the material can be called ultra-high-strength. This material is intended due to its properties for utilisation in extremely compressed elements or extremely slender elements, that may be required in designing of the entity. Composition of the material makes it resistant to freeze-and-thaw cycles and climate strains.

For the mix recipe P1 tensile strength was not experimentally verified. During the investigations the assumption was confirmed that the tensile strength is 1/10 of compressive strength. This ratio satisfies also the model mix recipe C1. For the mixture P1 tensile strength between 19.5 MPa and 16 MPa can be assumed.

20 Industrial Applicability

Ultra-high strengths of steel fibre reinforced concrete (SFRC), that is the matter of the solution, predestinate SFRC for utilisation in concrete building

industry. Its application in real structures surely will lead to much thinner structures compared to structures made from common ordinary concretes and high-strength concretes. Utilisation of steel fibre reinforced concrete is assumed especially for the structures that cannot be constructed in present conditions, i.e. extremely
5 structurally demanding and complicated details of concrete structures regarding reinforcing with common rebar reinforcement and prestressing tendons.

The industrial utilisation of steel fibre reinforced concrete is encouraged by the way of its manufacturing, which can be performed by common machine
10 equipment of concrete plants. Small strains due to shrinkage and creep that result from the structure of concrete with dispersed steel fibres that stiffen the structure of manufactured steel fibre reinforced concrete are also very important.

PATENT CLAIMS

1. Ultra-high strength steel fibre reinforced concrete with cement matrix, containing silica cement, basalt aggregate, steel fibres, admixtures and additives, where the dosage of admixtures in batch is given by the results of porosity tests of the mixture of basalt aggregate and steel fibres and admixtures are dosed so that required workability was reached according to real application **characterized by the fact** that the cement matrix contains 600 to 1000 kg/m³ of silica cement, basalt aggregate is compounded of three sieve sizes, namely aggregate sieve sizes 0-4, 4-8 and 8-16, whose total weight dose is between 1500 and 2000 kg/m³ and ratio of sieve grain sizes is given on the basis of granulometry and mineralogical composition of particular source of basalt aggregate, water/cement ratio ranges between 0.16 and 0.25 and steel fibres consist of two types of evenly distributed in volume of hardened concrete, where the first type of fibres has rectangular section with the width between 0.2 and 0.5 mm, height between 25 and 35 mm and strength 350 and 450 MPa and the second type of steel fibres has circular section with diameter ranging between 0.08 and 0.12 mm and their length is between 8 and 15 mm and their strength is higher than 2000 MPa and total weight ranges between 100 and 280 kg/m³.
2. Ultra-high strength steel fibre reinforced concrete according to the first claim **characterised by** the ratio of the first type and second type of fibres ranging between 0.5:1.5 and 1.5:0.5.
3. Ultra-high strength steel fibre reinforced concrete according to the first and second claim **characterised by** manufacturing of the first type of steel fibres from waste steel ribbon and the second type of steel fibres is from cut cord wires gained in recycling of tyres.
4. Steel fibre reinforced concrete according to any of claims 1, 2 and 3 **characterised by** the fact that the dosage of additives ranges between 5 and 15% of volume of manufactured steel fibre reinforced concrete.

INTERNATIONAL SEARCH REPORT

International application No
PCT/CZ2013/000161

A. CLASSIFICATION OF SUBJECT MATTER
INV. C04B28/02 C04B14/48
ADD.

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
C04B

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

EPO-Internal, COMPENDEX, INSPEC, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	HORSZCZARUK ET AL: "Hydro-abrasive erosion of high performance fiber-reinforced concrete", WEAR, ELSEVIER SEQUOIA, LAUSANNE, CH, vol. 267, no. 1-4, 15 June 2009 (2009-06-15), pages 110-115, XP026133248, ISSN: 0043-1648, DOI: 10.1016/J.WEAR.2008.11.010 [retrieved on 2009-05-23] chapters 2-5; tables 1,2 ----- -/--	1-4



Further documents are listed in the continuation of Box C.



See patent family annex.

* Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier application or patent but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search

29 April 2014

Date of mailing of the international search report

13/05/2014

Name and mailing address of the ISA/

European Patent Office, P.B. 5818 Patentlaan 2
NL - 2280 HV Rijswijk
Tel. (+31-70) 340-2040,
Fax: (+31-70) 340-3016

Authorized officer

Büscher, Olaf

INTERNATIONAL SEARCH REPORT

International application No
PCT/CZ2013/000161

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT		
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	DATABASE WPI Week 200909 Thomson Scientific, London, GB; AN 2009-B34068 XP002723734, & CN 101 318 801 A (UNIV SOUTHEAST) 10 December 2008 (2008-12-10) abstract -----	1-4
A	DATABASE WPI Week 201155 Thomson Scientific, London, GB; AN 2011-J07712 XP002723735, & CN 102 092 996 A (UNIV NANJING SCI&TECHNOLOGY) 15 June 2011 (2011-06-15) abstract -----	1-4
A	EP 2 492 254 A1 (UNIV CATALUNYA POLITECNICA [ES]) 29 August 2012 (2012-08-29) paragraphs [0005] - [0008], [0010] - [0020]; claims 1-9 -----	1-4

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No

PCT/CZ2013/000161

Patent document cited in search report		Publication date	Patent family member(s)	Publication date
CN 101318801	A	10-12-2008	NONE	

CN 102092996	A	15-06-2011	NONE	

EP 2492254	A1	29-08-2012	EP 2492254 A1	29-08-2012
			ES 2360003 A1	31-05-2011
			MA 33686 B1	01-10-2012
			WO 2011067431 A1	09-06-2011
