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(54) Steel fibre for reinforcement of high-performance concrete

(57) A steel fibre (10) for reinforcement of high-performance concrete or mortar has a length ranging from 3 mm to 30 mm, a thickness ranging from 0.08 mm to 0.30 mm, and a tensile strength greater than 2000 MPa. The steel fibre is provided with anchorages (12, 24) the dimension of which in a direction perpendicular to the longitudinal axis of the steel fibre is maximum 50 % of the thickness. These anchorages provide an effective staying in the high-performance concrete without influencing the mixability of the steel fibres in a negative way.

FIG.1(a)

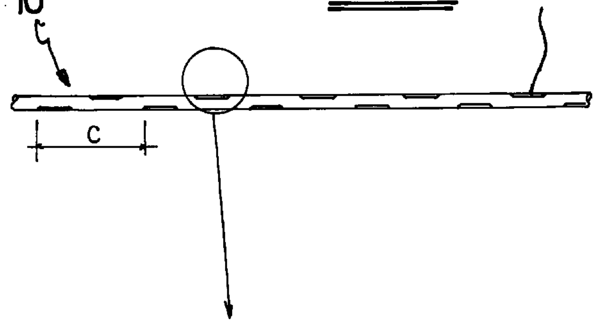
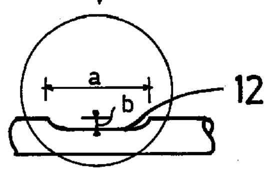


FIG.1(b)



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Description

Field of the invention.

The invention relates to a steel fibre for reinforcement of high-performance concrete or mortar.

Background of the invention.

It is known in the art to reinforce high-performance concretes by means of steel fibres.

BE-A3-1005815 (N.V. BEKAERT S.A.) teaches that for conventional concretes with a compressive strength ranging from 30 MPa to 50 MPa, it makes no sense to increase the tensile strength of a steel fibre above 1300 MPa since an increase in tensile strength does not add any increase in flexural strength to the reinforced concrete. BE 1005815 further teaches, however, that for concretes with an increased compressive strength, the tensile strength of the steel fibres should increase proportionally.

WO-A1-95/01316 (BOUYGUES) adapts the average length of metal fibres to the maximum size of granular elements which are present in high-performance concrete so that metal fibres act as conventional rebars in high-performance concrete. The volume percentage of metal fibres in high-performance concrete is relatively high and ranges between 1.0 % and 4.0 % of the concrete volume after setting.

Summary of the invention.

It is an object of the present invention to further optimize the geometry and the tensile strength of steel fibres to high-performance concrete.
It is also an object of the present invention to reduce mixing problems when reinforcing high-performance concrete with high volume percentages of steel fibres.
It is another object of the present invention to improve the anchorage of steel fibres in the reinforcement of high-performance concrete.

According to the present invention there is provided a steel fibre for reinforcement of high-performance concrete or mortar. The steel fibre has a length ranging from 3 mm to 30 mm, a thickness ranging from 0.08 mm to 0.30 mm and a tensile strength greater than 2000 MPa, e.g. greater than 2500 MPa, or greater than 3000 MPa. The steel fibre is provided with anchorages the dimension of which in a direction perpendicular to the longitudinal axis of the steel fibre is maximum 50 %, e.g. maximum 25 %, e.g. maximum 15 % of the thickness.

The terms 'high-performance concrete or mortar' refer to concrete or mortar the compression strength of which is higher than 75 MPa (1 MPa = 1 Mega-Pascal = 1 Newton/mm^2), e.g. higher than 200 MPa. The compression strength is the strength as measured by ASTM-Standard N° C39-80 on a cube of concrete of 150 mm edge, where the cube is pressed between two parallel surfaces until rupture.
The term 'thickness' of a steel fibre refers to the smallest cross-sectional dimension of a straight steel fibre without the anchorages.
The term 'anchorage' refers to any deviation from a straight steel fibre with a uniform transversal cross-section where the deviation helps to improve the anchorage or staying of the steel fibre in the concrete.
Within the context of the present invention, the term 'anchorage' does not refer to small bendings, i.e. bendings with a high radius of curvature, in the steel fibre which are a result of the steel wire having been wound on a spool before the final drawing and/or cutting. Steel fibres with only such small bendings which are the result of the previous winding of the steel wire, are still considered as 'straight' steel fibres.

The advantage of the present invention may be explained as follows. Concretes have a so-called interfacial zone between the cement paste and aggregates added to the concrete. This interfacial zone can be studied by means of a scanning electronic microscope (SEM). It has been observed that due to an increased presence of water in the neighbourhood of the aggregates, cement hydration is accelerated in the interfacial zone, resulting in the presence of calcium hydroxide intermixed with calcium-silica-hydrates and ettringite in the interfacial zone. The consequence is an interfacial zone with a relatively high degree of porosity. This interfacial zone forms the weakest link of the concrete and determines to a large extent its strength which tends to be smaller than the strength of its cement paste. The thickness of the interfacial zone ranges from about 50 μm (micrometer) to about 100 μm around the aggregates. A similar interfacial zone has been observed around steel fibres added to the concrete.
In comparison with conventional concretes, high-performance concretes are characterized by :

(a) a relatively low water/cement ratio (smaller than 0.45) ;
(b) the addition of superplasticizers which much increase the workability of concrete in spite of the low water/cement ratio ;
(c) the addition of mineral additives such as silica fumes, fly ashes, blast furnace slag, pulverized fuel, micro-fillers and/or pozzolans and/or the addition of chemical additives such as water glass and tensides.

The additives mentioned under (c) result in an increased bond between aggregates and cement and result in an interfacial zone the thickness of which is substantially decreased, if not disappeared. Indeed silica fumes, for example, transform the calcium hydroxides of the interfacial zone into calcium-silica-hydrates.
In order to have an effective anchorage or staying in conventional concretes, steel fibres must have anchorages with dimensions that are a few times the thickness

of the interfacial zone, i.e. a few times 50 μm à 100 μm. Anchorages with smaller dimensions will not work to the same degree, since they would not bridge adequately the interfacial zone.

In contradiction with the interfacial zone of conventional concrete, the interfacial zone of high-performance concretes is either not so weak or not so thick or even not existent. The result is that steel fibres provided with anchorages of a small dimension work effectively.

A supplementary advantage of the smaller dimensions of the anchorage is that the mixing problem of steel fibres in the concrete is reduced since the dimensions of bendings or waves (if any) of the steel fibres can be limited in size.

Another advantage is that, due to the improved anchorage, the volume of steel fibres needed for a required performance of the concrete, may be reduced, which also reduces considerably the degree of mixing problems.

Within the context of the present invention the anchorages are not limited to a particular form or way of manufacturing. The anchorages may take the form of bendings or waves on condition that their dimension in a direction perpendicular to the longitudinal axis of the steel fibre is limited in size. The anchorages may also take the form of micro-roughenings, e.g. obtained by means of a controlled oxidation or by means of a controlled etching operation.

Preferably the steel fibre according to the invention has no bendings or waves. The absence of any bendings or waves increases the mixability of the fibre in the high-performance concrete. This is very important since the volume percentage of steel fibres in high-performance concrete is substantially higher than in conventional concretes, and the higher this volume percentage the greater the risk for mixing problems.

In a first preferable embodiment of the invention the anchorages are indentations which are distributed along the length of a straight steel fibre. The depth of these indentations ranges from 5 % to 25 % of the thickness of the steel fibre without indentations. For example, the depth of these indentations ranges from 0.01 mm to 0.05 mm. The indentations may be provided at regular distances along the length of the steel fibre.

In a second preferable embodiment of the invention the steel fibre is provided with flattenings at both ends of the steel fibre. The thickness of the flattened ends may range from 50 % to 85 % of the thickness of the non-flattened steel fibre. Such a steel fibre has preferably an elongation at fracture which is greater than 4 %.

In order to provide the required tensile strength, a steel fibre according to the present invention preferably has a carbon content above 0.40 %, e.g. above 0.82 %, or above 0.96 %.

Brief description of the drawings.

The invention will now be described into more detail with reference to the accompanying drawings wherein

- FIGURE 1(a) gives a global view of a steel fibre provided with indentations along its length ;
- FIGURE 1(b) gives an enlarged view of an indentation ;
- FIGURE 2 schematically illustrates how a steel fibre with indentations can be manufactured ;
- FIGURE 3(a) gives an side view and FIGURE 3(b) gives an upper view of a steel fibre with flattened ends ;
- FIGURE 4 schematically illustrates how a steel fibre with flattened ends can be manufactured.

Description of the preferred embodiments of the invention.

First preferable embodiment.

FIGURE 1(a) shows a steel fibre 10 which is provided with indentations 12 which are regularly distributed along its length. FIGURE 1(b) illustrates in more detail an indentation 12. For example, the steel fibre 10 has a length of 13 mm, and - apart from the indentations 12 - a round cross-section with a diameter of 0.20 mm. The size a of an indentation 12 in the longitudinal direction is 0.50 mm and the depth b of an indentation 12 is 0.010 mm (= 10 μm). The indentations 12 are provided both at the upper side and at the under side of the steel fibre 10. The distance (pitch) between two indentations at the upper or at the under side is about 1.50 mm.

FIGURE 2 illustrates how a steel fibre 10 with indentations 12 can be manufactured. A steel wire 14 is drawn by means of a winding drum 16 through a (final) reduction die 18. Having reached its final diameter the wire 14 is further guided to two wheels 20 which are both provided at their surface with protrusions 21 in order to bring the indentations 12 in the wire 14. The two wheels 20 give the necessary pulling force to guide the wire 14 from the winding drum 16 to a cutting tool 22 where the steel wire 14 is cut in steel fibres 10 of the same lengths.

Second preferable embodiment.

FIGUREs 3(a) and 3(b) illustrate a straight steel fibre 10 with flattened ends 24. The flattened ends 24 provide the anchorage in the high-performance concrete. Preferably the steel fibre 10 has no burrs since burrs could provoke concentrations of tensions in the concrete and these concentrations could lead to initiation of cracks. The transition in the steel fibre 10 from the round transversal cross-section to the flattened ends 24 should not be abrupt but should be gradually and smooth. As an example the steel fibre 10 has following dimensions : a length of 13 mm, a diameter of a round cross-section of 0.20 mm, a thickness d of the flattened ends 24 of 0.15 mm and a length e of the flattened ends 24 - transition zone included - of 1.0 mm.

FIGURE 4 illustrates how a steel fibre 10 with flattened ends 24 can be manufactured by means of two rolls 26 which give flattenings to a steel wire 14 and simultaneously cut the steel wire into separate steel fibres.

Since a steel fibre 10 according to this second embodiment will be anchored in the high-performance concrete only at the ends 24 (and not along its length as in the first embodiment), it is preferable to increase the potential of plastic energy in the steel fibre by applying a suitable thermal treatment in order to increase the elongation at fracture of the steel fibre 10. Such a thermal treatment is known as such in the art. The thermal treatment can be applied by passing the steel wire 14 through a high-frequency or mid-frequency induction coil of a length that is adapted to the speed of the steel wire and to heat the steel wire 14 to about more than 400 °C. The steel wire will suffer from a certain decrease of its tensile strength (about 10 to 15 %) but at the same time will see its elongation at fracture increase. In this way the plastic elongation can be increased to more than 5% and even to 6%.

The composition of the steel fibre may vary to a large extent. Conventionally it comprises a minimum carbon content of 0.40 % (e.g. at least 0.80 %, e.g. 0.96 %), a manganese content ranging from 0.20 to 0.90 % and a silicon content ranging from 0.10 to 0.90 %. The sulphur and phosphorous contents are each preferably kept below 0.03 %. Additional elements such as chromium (up to 0.2 à 0.4 %), boron, cobalt, nickel, vanadium ... may be added to the composition in order to reduce the degree of reduction required for obtaining a particularly tensile strength.

The steel fibre can be provided with a coating such as a metallic coating. For example it can be provided with a copper alloy coating in order to increase its drawability or it can be provided with a zinc or alluminium alloy coating in order to increase its corrosion resistance.

The steel fibre according to the present invention is not limited to particular tensile strengths of the steel fibre. For steel fibres of 0.20 mm thickness tensile strengths can be obtained ranging from moderate values of 2000 MPa to higher values of 3500 MPa, 4000 MPa and even higher. It is preferable, however, to adapt the tensile strength of the steel fibre both to the compression strength of the high-performance concrete and to the quality of the anchorage in the high-performance concrete. The higher the degree of anchorage in the concrete, the more useful it is to further increase the tensile strength of the steel fibre itself.

The steel fibres according to the invention may be glued together by means of a suitable binder which looses its binding ability when mixing with the other components of the high-performance concrete. The applying of such a binder increases the mixability, as has been explained in US-A-4,224,377. However, in the context of the present invention, this is not strictly necessary.

Claims

1. A steel fibre for reinforcement of high-performance concrete or mortar,
said steel fibre having a length ranging from 3 mm to 30 mm,
a thickness ranging from 0.08 mm to 0.30 mm,
and a tensile strength greater than 2000 MPa,
said steel fibre being provided with anchorages the dimension of which in a direction perpendicular to the longitudinal axis of the steel fibre is maximum 50 % of the thickness.

2. A steel fibre according to claim 1
wherein the dimension of said anchorages in a direction perpendicular to the longitudinal axis of the steel fibre is maximum 25 % of the thickness.

3. A steel fibre according to claim 1 or 2
wherein the dimension of said anchorages in a direction perpendicular to the longitudinal axis of the steel fibre is maximum 15 % of the thickness.

4. A steel fibre according to any one of claims 1 to 3
said steel fibre having no bendings.

5. A steel fibre according to any one claims 1 to 4
wherein said anchorages are indentations distributed along the length of the fibre.

6. A steel fibre according to claim 5
wherein the depth of said indentations ranges from 0.01 mm to 0.05 mm.

7. A steel fibre according to any one of claims 1 to 4
wherein said anchorages result in flattenings at both ends of the fibre.

8. A steel fibre according to claim 7
said steel fibre having a total elongation at fracture greater than 4 %.

9. A steel fibre according to any one of the preceding claims
wherein said steel fibre has a carbon content being greater than 0.40%.

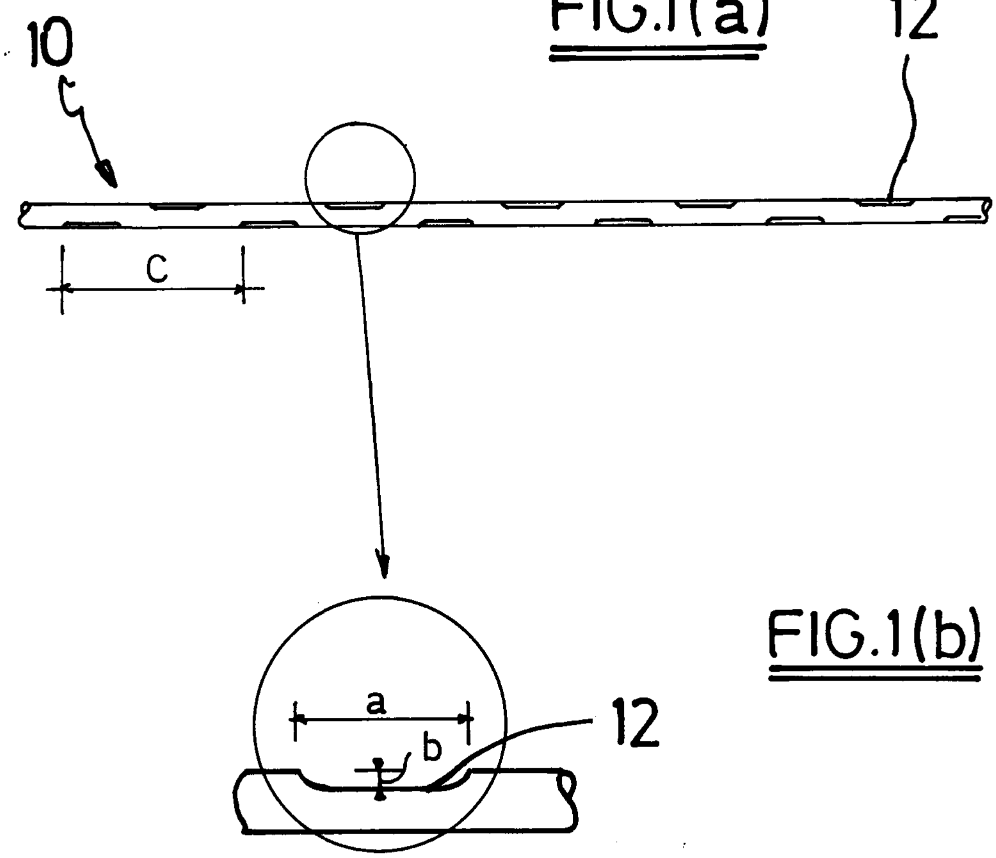

FIG.1(a)

FIG.1(b)

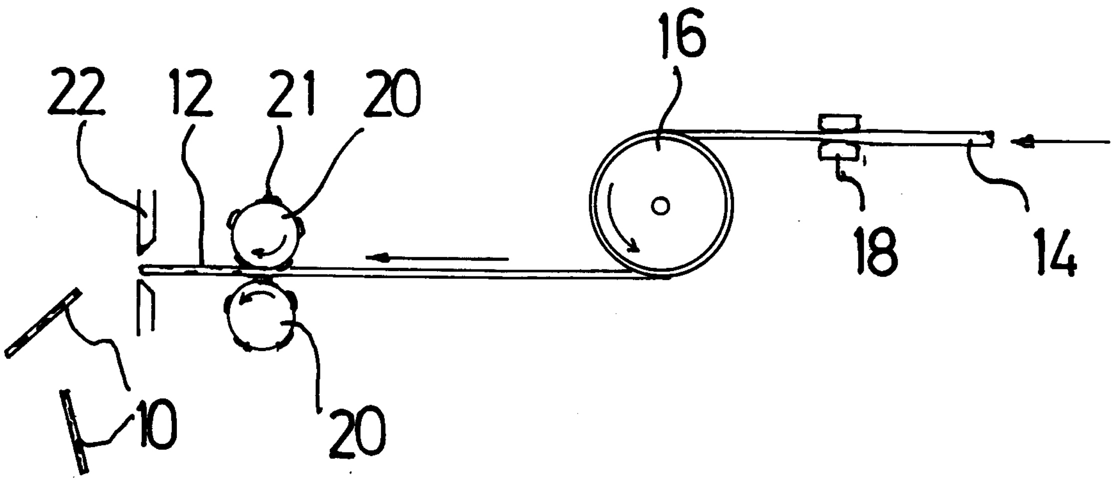

FIG. 2

FIG. 3(a)

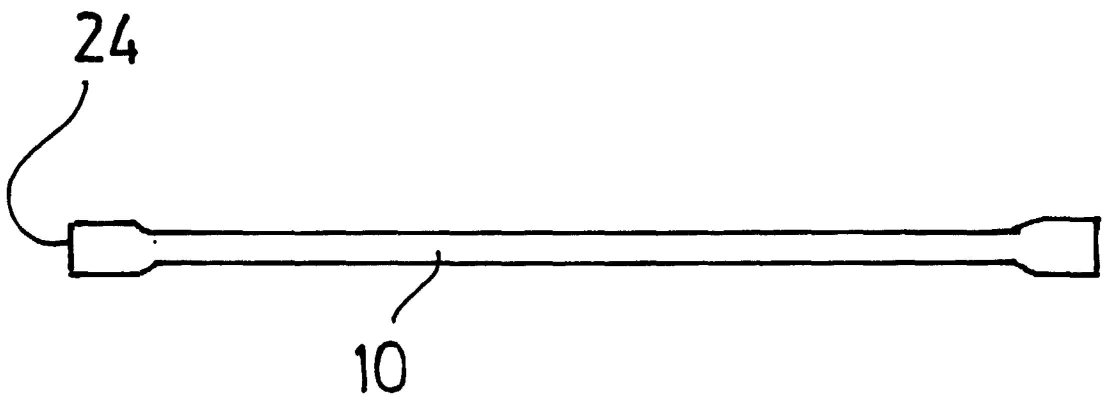

FIG. 3(b)

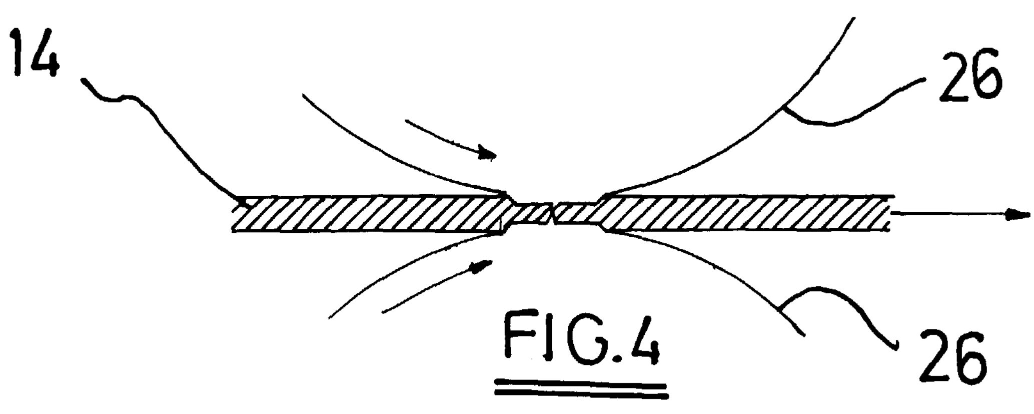

FIG. 4

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EUROPEAN SEARCH REPORT

Application Number
EP 97 20 0582

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int.Cl.6)
X Y	DE 33 47 675 A (LAMPRECHT) * claim 1; example 1 *	1-3 4,5,7	E04C5/01
Y	DE 30 32 162 A (FELIX SCHUH + CO) * claims 1,2 * * page 14, line 28 - page 14, line 31 * * page 15, line 15 - page 15, line 25 * * figures 2,3 *	4	
Y A	DE 42 23 804 A (HERMANN GLOERFELD-METALLWAREN) * column 4, line 37 - column 4, line 44 * * column 7, line 17 - column 7, line 20 * * figures 4,5,10-13 *	5 6	
Y	DE 88 15 120 U (HERMANN GLOERFELD) * the whole document *	4,5	
Y	DE 28 32 495 A (VAN THIEL'S DRAADINDUSTRIE) * page 5, paragraph 1 * * figures 1-5 *	7	TECHNICAL FIELDS SEARCHED (Int.Cl.6)
A	DE 19 41 223 A (HENDRIX) * page 2, paragraph 2 * * claim 2; figure 1 *	1	E04C
A	DE 30 24 648 A (HOLLATZ) * page 8, paragraph 1 - page 8, paragraph 2 * * page 15, paragraph 7 - page 16, paragraph 4 *	1,9	

The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
THE HAGUE	24 July 1997	Hendrickx, X

CATEGORY OF CITED DOCUMENTS

X : particularly relevant if taken alone
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