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(54) **STEEL FIBRE FOR REINFORCING CONCRETE OR MORTAR PROVIDED WITH FLATTENED SECTIONS**

STAHLFASER ZUR VERSTÄRKUNG VON BETON ODER MÖRTEL MIT ABGEFLACHTEN
ABSCHNITTEN

FIBRE D'ACIER COMPRENANT DES SEGMENTS APLATIS, DESTINÉE AU RENFORCEMENT DU
BÉTON OU DU MORTIER

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Description**Technical Field**

5 **[0001]** The invention relates to steel fibres for reinforcing concrete or mortar having a middle portion and at least one anchorage end whereby the middle portion is provided with at least one flattened section. The steel fibres according to the present invention show a good performance at service-ability limit state (SLS) and at ultimate limit state (ULS) when embedded in concrete or mortar.

The invention further relates to concrete or mortar structures comprising such steel fibres.

Background Art

15 **[0002]** Concrete is a brittle material having low tensile strength and low strain capacity. To improve properties of concrete like tensile strength and strain capacity, fibre reinforced concrete and more particularly metallic fibre reinforced concrete has been developed.

It is known in the art that the properties of the fibres like fibre concentration, fibre geometry and fibre aspect ratio greatly influences the performance of the reinforced concrete.

[0003] With respect to fibre geometry it is known that fibres having a shape different from a straight shape provide better anchorage of the fibre in the concrete or mortar.

20 It is furthermore known that fibres not showing the tendency to form balls when added to or mixed with concrete or mortar are preferred. Numerous examples of different fibre geometries are known in the art. DE 9202767U1 discloses a steel fibre according to the preamble of claim 1. There are for example fibres that are provided with undulations, either over the whole length or over part of their length. Examples of steel fibres undulated over their whole length are described in WO84/02732. Also fibres having hook-shaped ends are known in the art. Such fibres are for example described in

25 US 3,942,955. Similarly, there are fibres of which the cross-section profile changes over the length, such as fibres provided with thickened and/or with flattened sections.

An example of a steel fibre provided with thickened sections is a steel fibre with thickenings in the form of a nail head at each of the extremities as described in US 4,883,713.

30 Japanese patent 6-294017 describes the flattening of a steel fibre over its entire length. German Utility Model G9207598 describes the flattening of only the middle portion of a steel fibre with hook-shaped ends. US 4,233,364 describes straight steel fibres provided with ends that are flattened and are provided with a flange in a plane essentially perpendicular to the flattened ends.

Steel fibres with flattened hook shaped ends are known from EP 851957 and EP 1282751.

35 **[0004]** Currently known prior art fibres for concrete reinforcement function very well in the known application fields like industrial flooring, sprayed concrete, pavement, ...

However, the disadvantage of currently known prior art fibres is the relatively low performance at ultimate limit state (ULS) when low or moderate dosages of fibres are used. For more demanding structural applications, like beams and elevated slabs high dosages, typically from 0.5 vol% (40 kg/m³) onwards and not exceptionally up to 1.5 vol % (120 kg/m³) are used to provide the necessary performance at ULS. These high dosages do not facilitate the mixing and

40 placing of the steel fibre reinforced concrete. Some prior art fibres do not perform at ULS as they break at crack mouth opening displacements (CMODs) lower than what is required for ULS. Other fibres, like fibres with hook shaped ends do not perform well at ULS as they are designed to be pulled out.

Disclosure of Invention

[0005] It is an object of the present invention to provide steel fibres for the reinforcement of concrete or mortar avoiding the drawbacks of the prior art.

50 **[0006]** It is another object to provide steel fibres which are capable of bridging the crack mouth opening displacements greater than 0.5 mm, 1 mm, 1.5 mm, 2 mm, 2.5 mm or even greater than 3 mm during the three point bending test according to the European Standard EN 14651 (June 2005).

[0007] It is a further object of the present invention to provide steel fibres showing good anchorage in concrete or mortar.

55 **[0008]** It is a further object to provide steel fibres not showing the tendency to form balls when mixed in the concrete or mortar.

[0009] Furthermore it is an object of the present invention to provide steel fibres which may advantageously be used for structural applications whereby the steel fibres are used in low or moderate dosages, typically 1 vol% of steel fibres or 0.5 vol% of steel fibres.

[0010] Additionally it is another object to provide steel fibres that allow to reduce or to avoid the creep behaviour of cracked concrete reinforced with those fibres in the tension zone.

[0011] According to a first aspect of the present invention, there is provided a steel fibre for reinforcing concrete or mortar. The steel fibre comprises a middle portion, a first anchorage end at one end of the middle portion and a second anchorage end at the other end of the middle portion. The middle portion has a length L . The middle portion comprises a first flattened section, a second flattened section and a central section. The first flattened section has a length l_{f1} . The second flattened section has a length l_{f2} . The central section of the middle portion has a length l' . The central section is located between the first flattened section and the second flattened section and extends from the first flattened section to the second flattened section. The first flattened section is located close to but not immediately adjacent to the first anchorage end and the second flattened section is located close to but not immediately adjacent to the second anchorage end. The central section has the same cross-section over the entire length l' of the central section. The ratio of the length of the central section l' divided by the length of the middle portion L (ratio l'/L) is higher than 0.50. The central section has a tensile strength R_m of at least 1000 MPa and an elongation at maximum load A_{g+e} of at least 2.5 %.

[0012] The central section of the middle portion, i.e. the section of the middle portion between the first flattened section and the second flattened section, comprises the major part of the middle portion. Preferably, the ratio length of the central section divided (l') divided by the length of the middle portion (L) (=ratio l'/L) is larger than 0.55, larger than 0.60, larger than 0.65, larger than 0.70 or even larger than 0.75. The length l' ranges preferably between 10 and 40 mm, more preferably between 25 and 40 mm.

[0013] With "close to but not immediately adjacent to an anchorage end" is meant that the distance between an anchorage end and a flattened section is small but not zero. Preferably, the distance between the first anchorage end and the first flattened section and/or the distance between the second anchorage end and the second flattened section is ranging between 0.5 and 20 mm, for example ranging between 1 and 5 mm, as for example 2 or 3 mm.

[0014] As the first flattened section is located close to but not immediately adjacent to the first anchorage end, the middle portion has a section located between the first anchorage end and the first flattened section. Similarly, as the second flattened section is located close to but not immediately adjacent to the second flattened section, the middle portion has a section located between the second flattened section and the second anchorage end.

[0015] The middle portion of a steel fibre according to the present invention comprises thus consecutively :

- a section between the first anchorage end and the first flattened section;
- a first flattened section;
- a central section;
- a second flattened section;
- a section between the second flattened section and the second anchorage end.

[0016] The middle portion is preferably straight or rectilinear. For a straight middle portion the section between the first anchorage end and the first flattened section, the first flattened section, the central section, the second flattened section and the section between the second flattened section and the second anchorage end are all positioned on one straight line.

[0017] The central section of the middle portion is straight or rectilinear.

[0018] The length of the middle portion L is defined as the total length of the middle portion and corresponds thus with the sum of the length of the section between the first anchorage end, the first flattened section, the length of the first flattened section l_{f1} , the length of the central section l' , the length of the second flattened section l_{f2} and the length of the section between the second flattened section and the second anchorage end.

[0019] Essential for the invention is that the middle portion of the steel fibre according to the present invention is provided with two flattened sections of limited length with a central section (preferably a non-flattened section) of substantial length l' between the two flattened sections.

The central section has a tensile strength R_m of at least 1000 MPa and an elongation at maximum load A_{g+e} of at least 2.5 %.

The steel fibres according to the present invention show an excellent performance both at service-ability limit state (SLS) of a concrete or mortar structure or at ultimate limit state (ULS).

[0020] It is known in the art that providing a steel fibre with flattened sections is improving the anchoring of the steel fibre in concrete or mortar.

Different ways of providing steel fibres with flattened sections are described in the prior art :

- Japanese patent 6-294017 describes the flattening of a steel fibre over its entire length;
- German Utility Model 9207598 describes the flattening of only the middle portion of a steel fibre with hook-shaped

ends;

- US 4,233,364 describes straight steel fibres provided with ends that are flattened and are provided with a flange in a plane essentially perpendicular to the flattened ends;
- German Utility Model 9202767 describes a steel fibre with a middle portion having a number of flattened sections;
- EP 851957 and EP 1282751 describe steel fibres with flattened hook shaped ends.

[0021] The steel fibres according to the present invention are distinguished from the prior art fibres as the middle portion of the steel fibres according to the present invention is provided with two flattened sections of a limited length, close to the anchorage end.

Surprisingly, it has been found that a steel fibre provided with two flattened sections of limited length close to but not immediately adjacent to the anchorage end shows improved anchorage in concrete or mortar.

[0022] The steel fibres according to the present invention perform particularly well both at service-ability limit state (SLS) of a concrete or mortar structure and at ultimate limit state (ULS) when used at moderate or low dosage, i.e. at a dosage of less than 1 vol% or less than 0.5 vol%, for example 0.25 vol%.

It is known in the art that increasing the amount of fibres in concrete positively influences the performance of fibre reinforced concrete.

A big advantage of the present invention is that good performance at SLS and ULS is obtained with moderate or low dosage of steel fibres.

[0023] For this invention the material properties used for evaluating the performance in ULS and SLS of steel fibre reinforce concrete is the residual flexural tensile strength $f_{R,i}$. The residual flexural tensile strength is derived from the load at a predetermined crack mouth opening displacement (CMOD) of midspan deflection δ_R .

The residual flexural tensile strengths are determined by means of a three point bending test according to European Standard EN 14651 (described further in this application).

The residual flexural tensile strength $f_{R,1}$ is determined at $CMOD_1 = 0.5$ mm ($\delta_{R,1} = 0.46$ mm), the residual flexural tensile strength $f_{R,2}$ is determined at $CMOD_2 = 1.5$ mm ($\delta_{R,2} = 1.32$ mm), the residual flexural tensile strength $f_{R,3}$ is determined at $CMOD_3 = 2.5$ mm ($\delta_{R,3} = 2.17$ mm) and the residual flexural tensile strength $f_{R,4}$ is determined at $CMOD_4 = 3.5$ mm ($\delta_{R,4} = 3.02$ mm).

The residual flexural tensile strength $f_{R,1}$ is the key requirement for SLS design.

The residual flexural tensile strength $f_{R,3}$ is the key requirement for ULS design.

[0024] For steel fibres according to the present invention - contrary to the steel fibres known in the art - the ratio between the residual flexural strength $f_{R,3}$ and the residual flexural strength $f_{R,1}$ ($f_{R,3}/f_{R,1}$) is high even when low or moderate dosages of steel fibres are used as for example dosages lower than 1 vol% or dosages lower 0.5 vol%, for example 0.25 vol%.

For fibres according to the present invention the ratio $f_{R,3}/f_{R,1}$ is preferably higher than 1, more preferably higher than 1.15, for example 1.2 or 1.3 when dosages lower than 1 vol% or dosages lower than 0.5 vol%, for example 0.25 vol% are used.

[0025] For concrete reinforced with steel fibres according to the present invention with a dosage of 0.5 vol%, the residual flexural tensile strength $f_{R,3}$ using a C35/45 concrete is higher than 3.5 MPa, preferably higher than 5 MPa, more preferably higher than 6 MPa as for example 7 MPa.

[0026] Fibres known in the art as for example steel fibres having conically shaped ends (nail heads) made of low carbon steel wire function well for limiting the width or growth of up to about 0.5 mm (SLS). However, these fibres have a low performance at ULS. This type of steel fibres breaks at crack mouth opening displacements lower than required for ULS.

The ratio $f_{R,3}/f_{R,1}$ is lower than 1 for moderate dosages in a normal strength concrete, for example C35/45 concrete.

Other fibres known in the art are fibres with hook shaped ends as for example known from EP 851957 are designed to pull out.

Also for this type of fibres the ratio $f_{R,3}/f_{R,1}$ is lower than 1 for moderate dosages in a normal strength concrete.

[0027] The first flattened section has a length l_{f1} ; the second flattened section has a length l_{f2} . The length of the first flattened section l_{f1} and the length of the second flattened section l_{f2} are preferably ranging between 0.5 mm and 10 mm, more preferably between 1 mm and 3 mm as for example 2 mm or 2.5 mm. The length of the first flattened section l_{f1} and the length of the second flattened section l_{f2} can be the same or can be different. Preferably, the length of the first flattened section l_{f1} and the length of the second flattened section l_{f2} are the same.

[0028] Compared to the length of the middle portion L , the length of the first flattened section l_{f1} and the length of the second flattened section are small. The ratio l_{f1}/L and the ratio l_{f2}/L are preferably lower than 0.15. More preferably, the ratio l_{f1}/L and the ratio l_{f2}/L are lower than 0.10 or lower than 0.07.

[0029] Also the total length of the first and the second flattened section is small compared to the length of the middle portion L . The total length of the first and the second flattened sections corresponds with the sum of the length of the first flattened section l_{f1} and the length of the second flattened section l_{f2} .

The ratio $(l_{f1}+l_{f2})/L$ is preferably lower than 0.30. More preferably the ratio $(l_{f1}+l_{f2})/L$ is lower than 0.20 or lower than 0.14.

[0030] The first flattened section and the second flattened section have preferably a rectangular or a substantially rectangular cross-section. In alternative embodiments the first and the second flattened sections have an oval or a substantially oval cross-section.

[0031] The central section may have any type of cross-section although a circular cross-section is preferred. The central section has the same cross-section over the entire length l' of the central section. For some embodiments it is essential that the central section has the same cross-section over the entire length of l' of the central section.

The central section may be flattened such as rectangular, substantially rectangular, oval or substantially oval. However if the parts of the middle portion other than the flattened section or sections are flattened (for example the central section), they are flattened to a lower degree than the flattened section or flattened sections.

[0032] Similarly, the section between the first anchorage end and the first flattened section and the section between the second anchorage end and the second flattened section may have any type of cross-section although a circular cross-section is preferred. Preferably, the section between the first anchorage end and the first flattened section and the section between the second anchorage end and the second flattened section have the same cross-section over the entire length of these sections. For some embodiments it is essential that the section between the first anchorage end and the first flattened section and the section between the second anchorage end and the second flattened section have the same cross-section over the entire length of these section.

The section between the first anchorage end and the first flattened section and the section between the second anchorage end and the second flattened section may be flattened such as rectangular, substantially rectangular, oval or substantially oval. However if these section are flattened, they are flattened to a lower degree than the flattened section or flattened sections.

[0033] Preferably, the section between the first anchorage end and the first flattened section and the section between the second anchorage end and the second flattened section has the same cross-section as the central section of the middle portion.

[0034] Compared to the thickness of the central section, the thickness of the first flattened section and of the second flattened section is preferably reduced with 10 till 40 %, for example between 15 and 30 %, such as 20 or 25 %. A higher reduction in thickness has a positive influence on the anchorage force of the steel fibre in concrete or mortar and on the performance of the steel fibre in concrete or mortar. However, a reduction in thickness higher than 40 % is not desired as such a reduction in thickness weakens the strength of the middle portion to a high degree.

[0035] In some embodiments of the present invention, the steel fibre is provided with flattened sections having one flattened side. In other embodiments of the invention, the steel fibre is provided with flattened sections having two flattened sides.

[0036] In a preferred embodiment, the flattened sections comprise sections flattened in a plane which is substantially parallel with the plane of the steel fibre.

In an alternative embodiment, the flattened sections comprise sections flattened in a plane which is substantially perpendicular to the plane of the steel fibre.

MAXIMUM LOAD CAPACITY F_m - TENSILE STRENGTH R_m

[0037] A steel fibre according to the present invention, more particularly the central section of the middle portion of a steel fibre according to the present invention preferably has a high maximum load capacity F_m . The maximum load capacity F_m is the greatest load that the steel fibre withstands during a tensile test.

The maximum load capacity F_m of the central section portion is directly related to the tensile strength R_m of the central section as the tensile strength R_m is the maximum load capacity F_m divided by the original cross-section area of the steel fibre.

For a steel fibre according to the present invention, the tensile strength of the central section of the steel fibre is preferably above 1000 MPa and more particularly above 1400 MPa, e.g. above 1500 MPa, e.g. above 1750 MPa, e.g. above 2000 MPa, e.g. above 2500 MPa.

The high tensile strength of steel fibres according to the present invention allows the steel fibres to withstand high loads. A higher tensile strength is thus directly reflected in a lower dosage of the fibres, if the steel fibres used provide good anchorage.

ELONGATION AT MAXIMUM LOAD

[0038] According to a preferred embodiment the steel fibre according to the present invention, more particularly the

central section of the middle portion of a steel fibre according to the present invention has an elongation at maximum load A_{g+e} of at least 2.5 %.

According to particular embodiments of the present invention, the central section of the middle portion of the steel fibre has an elongation at maximum load A_{g+e} higher than 2.75 %, higher than 3.0 %, higher than 3.25 %, higher than 3.5 %, higher than 3.75 %, higher than 4.0 %, higher than 4.25 %, higher than 4.5 %, higher than 4.75 %, higher than 5.0 %, higher than 5.25 %, higher than 5.5 %, higher than 5.75 % or even higher than 6.0%.

[0039] Within the context of the present invention, the elongation at maximum load A_{g+e} and not the elongation at fraction A_t is used to characterise the elongation of a steel fibre, more particularly of the central section of the middle portion of a steel fibre.

The reason is that once the maximum load has been reached, constriction of the available surface of the steel fibre starts and higher loads are not taken up.

The elongation at maximum load A_{g+e} is the sum of the plastic elongation at maximum load A_g and the elastic elongation.

[0040] The high degree of elongation at maximum load A_{g+e} may be obtained by applying a particular stress-relieving treatment such as a thermal treatment to the steel wires where the steel fibres will be made of. In this case at least the central section of the middle portion of the steel fibre is in a stress-relieved state.

[0041] Steel fibres having a high ductility or a high elongation at maximum load A_{g+e} are preferred, these fibres will not break at CMOD's above 1.5 mm, above 2.5 mm or above 3.5 mm in the three point bending test according to EN 14651.

ANCHORAGE FORCE

[0042] Preferably, the steel fibre according to the present invention has a high degree of anchorage in concrete or mortar.

By providing the middle portion of the steel fibres with flattened sections according to the present invention the anchorage of the steel fibre in concrete or mortar is considerably improved.

It is known in the art that the type of anchorage end directly influences the anchorage of the steel fibre in the concrete or mortar.

The anchorage ends may comprise thickened or enlarged anchorage ends, nail heads, flattened anchorage ends, hook-shaped anchorage ends, bent or undulated anchorage ends or any combination thereof. According to the present invention, surprisingly it was found that for most types of anchorage ends the anchorage of the steel fibre in concrete or mortar is improved by providing the middle portion of the steel fibre with a flattened section close to but not immediately adjacent to the anchorage end.

A high degree of anchorage will avoid pull-out of the fibres.

A high degree of anchorage combined with a high elongation at maximum strength will avoid pull-out of the fibres, will avoid fibre failure and will avoid brittle failure of concrete in tension.

A high degree of anchorage combined with a high tensile strength allows that better use is made of the tensile strength after the occurrence of cracks.

[0043] Steel fibres according to the present invention, more particularly the central section of the middle portion of the steel fibres, have for example a tensile strength R_m higher than 1000 MPa and an elongation at maximum load A_{g+e} of at least 2.5 %, a tensile strength R_m of at least 1000 MPa and an elongation at maximum load A_{g+e} of at least 4 %.

In a preferred embodiment the steel fibres, more particularly the central section of the middle portion of the steel fibres, have a tensile strength R_m of at least 1500 MPa and an elongation at maximum load A_{g+e} of at least 2.5 %, a tensile strength R_m of at least 1500 MPa and an elongation at maximum load A_{g+e} of at least 4 %.

In further preferred embodiments the steel fibres, more particularly the central section of the middle portion of the steel fibres, have a tensile strength R_m of at least 2000 MPa and an elongation at maximum load A_{g+e} of at least 2.5 %, a tensile strength R_m of at least 2000 MPa and an elongation at maximum load A_{g+e} of at least 4 %.

Fibres having a high tensile strength R_m may withstand high loads. Fibres characterised by a high elongation at maximum load A_{g+e} will not break at CMODs above 0.5 mm, above 1.5 mm, above 2.5 mm or above 3 mm in the three point bending test according to EN 14651.

[0044] The steel fibres, more particularly the central section of the middle portion of the steel fibres typically have a diameter D ranging between 0.10 mm to 1.20 mm, for example ranging between 0.5 mm and 1 mm, more particularly 0.7 mm or 0.9 mm. In case the cross-section of the steel fibre and more particularly of the central section of the middle portion of the steel fibre is not round, the diameter is equal to the diameter of a circle with the same surface area as the cross-section of the central section of the middle portion of the steel fibre.

The steel fibres typically have a ratio length of the steel fibre divided by the diameter of the steel fibre (=ratio length of the steel fibre/ D) ranging from 40 to 100.

The length of the steel fibres is for example 60 mm, 65 mm or 70 mm. With length of a steel fibre is meant the total length of the steel fibre i.e. the sum of the length of middle portion and the length of the anchorage end or anchorage ends.

[0045] The steel fibre according to the present invention can be provided with any type of anchorage ends such as

thickened or enlarged anchorage ends, nail heads, flattened anchorage ends, hook-shaped anchorage ends, bent or undulated anchorage ends or any combination thereof.

[0046] A particular type of anchorage ends comprises anchorage ends that are deflecting from the main axis of the middle portion of the steel fibre.

With 'deflecting' is meant turning aside from a straight line, i.e. turning aside from the main axis of the middle portion of the steel fibre.

A first example of a steel fibre having an anchorage end that is deflecting comprises a middle portion and an anchorage end at one or both ends of the middle portion. The middle portion has a main axis. The anchorage end is deflecting from the main axis in a first bent section. The first bent section has a first radius of curvature. Possibly the anchorage end comprises further bent sections such as a second bent section having a second radius of curvature and a third bent section having a third radius of curvature. Two consecutive bent sections can be connected directly to each other. Alternatively, two bent sections are connected by means of a straight section.

"Consecutive bent sections" means bent sections that are following one after the other.

Preferably, when this steel fibre being in a stable position on a horizontal surface is vertically projected on this horizontal surface, the vertical projections in this horizontal surface of at least two consecutive bent sections are located at one side of the vertical projection in this horizontal surface of the main axis of the middle portion.

With "stable position" is meant the position in which a steel fibre remains when laid down on a horizontal surface.

[0047] A further example of a steel fibre provided with anchorage ends comprises a steel fibre having a middle portion and an anchorage ends at one or both ends of the middle portion. The middle portion has a main axis. The anchorage end or anchorage ends comprise(s) at least a first, a second and a third straight section. Each of the first, second and third straight section has a main axis.

The first straight section is connected to the middle portion by a first bent section; the second straight section is connected to the first straight section by a second bent section; the third straight section is connected to the second straight section by a third bent section.

Each of the first, second and third straight section have a main axis, i.e. the main axis of the first straight section, the main axis of the second straight section and the main axis of the third straight section. The included angle between the main axis of the middle portion and the main axis of the first straight section is ranging between 100 and 160 degrees. The second straight section has a main axis being substantially parallel with the main axis of the middle portion.

[0048] A steel fibre according to the present invention may be provided with one anchorage end at one end of the middle portion. Preferably, a steel fibre is provided with an anchorage end according to the present invention at both ends of the steel fibre.

In case the steel fibre is provided with an anchorage end at both ends of the middle portion the two anchorage ends can be the same or can be different.

[0049] For a steel fibre having an anchorage end at both ends of the middle portion, both anchorage ends may be bending away in the same direction from the main axis of the middle portion of the steel fibre (symmetric fibres).

Alternatively, one anchorage end may be bending away in one direction from the main axis of the middle portion of the steel fibre while the other anchorage end is bending away in the opposite direction from the main axis of the middle portion of the steel fibre (asymmetric fibres).

[0050] According to a second aspect a reinforced concrete structure comprising a concrete structure reinforced with steel fibres according to the present invention is provided. The reinforced concrete structure may or may not be reinforced with traditional reinforcement (for example pre-stressed or post-tensioned reinforcement) in addition to the steel fibres according to the present invention.

[0051] For a reinforced concrete structure reinforced with steel fibres according to the present invention the ratio residual flexural tensile strength $f_{R,3}$ divided by the residual flexural tensile strength $f_{R,1}$ (ratio $f_{R,3}/f_{R,1}$) is preferably higher than 1 and more preferably higher than 1.15 or higher than 1.2, for example 1.3. This ratio is reached when low dosages of steel fibres are used, for example a dosage lower than 1 vol% or a dosage lower than 0.5 vol %, or even with a dosage of 0.25 vol%.

[0052] The residual flexural tensile strength $f_{R,3}$ of a reinforced concrete structure using steel fibres according to the present invention is preferably higher than 3.5, more preferably the residual flexural tensile strength $f_{R,3}$ is higher than 5 or even higher than 6 MPa.

[0053] The concrete structure reinforced with fibres according to the present invention has an average post crack residual strength at ULS exceeding 3 MPa, e.g. more than 4 MPa, e.g. more than 5 MPa, 6 MPa, 7 MPa, 7.5 MPa. By using steel fibres according to the present invention, concrete structures having an average post crack residual strength at ULS exceeding 3 MPa can be reached using C35/45 concrete and using dosages of less than 1 vol% or even less than 0.5 vol%.

According to the present invention preferred reinforced concrete structures have an average post crack residual strength at ULS exceeding 5 MPa using C35/45 concrete and using dosages of less than 1 vol% or even less than 0.5 vol%.

[0054] It is important to notice that reinforced concrete structures having an average post crack residual strength at

ULS exceeding 3 MPa or 5 MPa are existing. However, these reinforced concrete structure known in the art use high dosages of steel fibres (above 0.5 vol % or above 1 vol %) in normal strength concrete or high strength concrete or use moderate dosages of high strength fibres in high strength concrete.

[0055] According to a third aspect the use of steel fibres according to the present invention for load carrying structures of concrete is provided.

Brief Description of Figures in the Drawings

[0056] The invention will now be described into more detail with reference to the accompanying drawings where

- Figure 1 illustrates a tensile test (load-strain test) of a steel fibre;
- Figure 2 illustrates a three point bending test (load-crack mouth opening displacement curve or a load-deflection curve);
- Figure 3 illustrates a load-crack mouth opening displacement curve;
- Figure 4 and Figure 5 show embodiments of steel fibres that do not meet the requirements of the present invention;
- Figure 6 and Figure 7 show embodiments of steel fibres according to the present invention.

Mode(s) for Carrying Out the Invention

[0057] The present invention will be described with respect to particular embodiments and with reference to certain drawings but the invention is not limited thereto but only by the claims. The drawings described are only schematic and are non-limiting. In the drawings, the size of some of the elements may be exaggerated and not drawn on scale for illustrative purposes. The dimensions and the relative dimensions do not correspond to actual reductions to practice of the invention.

[0058] The following terms are provided solely to aid in the understanding of the inventions.

- Maximum load capacity (F_m) : the greatest load which the steel fibre withstands during a tensile test;
- Elongation a maximum load (%) : increase in the gauge length of the steel fibre at maximum force, expressed as a percentage of the original gauge length;
- Elongation at fracture (%) : increase in the gauge length at the moment of fracture expressed as a percentage of the original gauge length;
- Tensile strength (R_m): stress corresponding to the maximum load (F_m);
- Stress : force divided by the original cross-sectional area of the steel fibre;
- Dosage : quantity of fibres added to a volume of concrete (expressed in kg/m^3 or in vol% (1 vol % corresponds with 78,50 kg/m^3));
- Normal strength concrete : concrete having a strength less than or equal to the strength of concrete of the C50/60 strength classes as defined in EN206;
- High strength concrete : concrete having a strength higher than the strength of concrete of the C50/60 strength classes as defined in EN 206.

[0059] To illustrate the invention a number of different steel fibres, both prior art steel fibres and steel fibres according to the present invention are subjected to two different tests :

- a tensile test (load-strain test); and
- a three point bending test (load-crack mouth opening displacement curve or a load-deflection curve).

[0060] The tensile test is applied on the steel fibre, more particularly on the middle portion or on the central section of the steel fibre. Alternatively, the tensile test is applied on the wire used to make the steel fibre.

The tensile test is used to determine the maximum load capacity F_m of the steel fibre and to determine the elongation at maximum load A_{g+e} .

The three point bending test is applied on a notched reinforced beam as specified in EN 14651.

The test is used to determine the residual tensile strengths.

The tests are illustrated in Figure 1 and Figure 2 respectively.

[0061] Figure 1 shows a test set up 60 of a tensile test (load-strain test) of a steel fibre). With the help of the test set up 60 steel fibres are tested as to maximum load capacity F_m (breaking load), tensile strength R_m and total elongation at maximum load A_{g+e} .

The anchorage ends (for example the enlarged or hook shaped ends) of the steel fibre to be tested are cut first. The remaining middle portion 14 (or the remaining central section) of the steel fibre is fixed between two pairs of clamps 62, 63. Through the clamps 62, 63 an increasing tensile force F is exercised on the middle portion 14 of the steel fibre. The displacement or elongation as a result of this increasing tensile force F is measured by measuring the displacement of the grips 64, 65 of the extensometer. L_1 is the length of the middle portion 14 (or of the remaining central section) and is e.g. 50 mm, 60 mm or 70 mm. L_2 is the distance between the clamps and is e.g. 20 mm or 25 mm. L_3 is the extensometer gauge length and is minimum 10 mm, e.g. 12 mm, e.g. 15 mm. For an improved grip of the extensometer to the middle portion 14 of the steel fibre, the middle portion of the steel fibre (or the central section) can be coated or can be covered with a thin tape to avoid slippery of the extensometer over the steel fibre. By this test a load-elongation curve is recorded.

The percentage total elongation at maximum load is calculated by the following formula :

$$A_{g+e} = \frac{\text{extension at maximum load}}{\text{extensometer gauge length } L_3} \times 100$$

[0062] With the help of setup 60 of Figure 1, a number of different wires are tested as to maximum load capacity F_m (breaking load), tensile strength R_m and total elongation at maximum load A_{g+e} .

Five tests per specimen are done. Table 1 gives an overview of the wires that are tested.

Table 1

Wire type	Carbon content	Diameter (mm)	F_m (N)	R_m (MPa)	A_{g+e} (%)
1	Low	1.0	911	1160	1.86
2	Low	0.9	751	1181	2.16
3	High	0.89	1442	2318	5.06
4	Medium	0.75	533	1206	2.20
5	Medium	0.90	944	1423	1.84

[0063] Low carbon steel is defined as steel having a carbon content of maximum 0.15 %, for example 0.12%; medium carbon steel is defined as steel having a carbon content ranging between 0.15 % and 0.44 %, for example 0.18 % and high carbon steel is defined as steel having a carbon content higher than 0.44 %, for example 0.5 % or 0.6 %.

[0064] Figure 2 shows the experimental set up 200 of a three point bending test. The three point bending test was performed at 28 days according to European Standard EN 14651 using a 150 x 150 x 600 mm prismatic specimen 210. In the mid-span of the specimen 210 a single notch 212 with a depth of 25 mm was sawn with a diamond blade to localize the crack. The test set up comprises two supporting rollers 214, 216 and one loading roller 218. The setup is capable of operating in a controlled manner, i.e. producing a constant rate of displacement (CMOD or deflection). The tests were carried out with a displacement rate as specified in EN 14651. A load-crack mouth opening displacement curve or a load-deflection curve is recorded.

An example of a load-crack mouth opening displacement curve 302 is given in Figure 3.

[0065] The residual flexural strength $f_{R,i}$ ($i=1, 2, 3, 4$) are assessed according to EN 14651. The residual flexural tensile strengths $f_{R,1}$, $f_{R,3}$ respectively are defined at the following crack mouth opening displacements (CMOD _{i}) or mid span deflection ($\delta_{R,i}$) :

$$\begin{aligned} \text{CMOD}_1 &= 0.5 \text{ mm} & \delta_{R,1} &= 0.46 \text{ mm} \\ \text{CMOD}_3 &= 2.5 \text{ mm} & \delta_{R,3} &= 2.17 \text{ mm} \end{aligned}$$

[0066] The residual flexural tensile strengths $f_{R,i}$ ($i=1, 2, 3$ or 4) are assessed according to EN 14651 and can be calculated by the following expression :

$$f_{R,i} = \frac{3F_{R,i}L}{2bh_{sp}^2} \quad (\text{N/mm}^2)$$

with :

F_i = the load corresponding with $\text{CMOD}=\text{CMOD}_i$ or $\delta=\delta_i$

($i=1,2,3,4$);

b = width of the specimen (mm);

h_{sp} = distance between tip of the notch and the top of the specimen (mm);

L = span length of the specimen (mm).

[0067] With the help of setup 200 of Figure 2, the performance of a number of different steel fibres is tested as to determine the anchorage force and the failure mechanism. For the test the steel fibres are embedded in C35/45 concrete. The curing time was 14 days or 28 days.

An overview of the steel fibres that are tested are given in Table 2. The test results are given in Table 3.

The steel fibres are specified by the length of the steel fibre, the wire type used to make the steel fibre, the diameter of the steel fibre (more particularly the diameter of the middle portion or of the central section of the steel fibre) and the details of the anchorage ends.

All steel fibres described in Table 2 have two anchorage ends, a first anchorage end at one end and a second anchorage end at the other end. In case the middle portions of the steel fibres are provided with flattened sections, the middle portion is provided with a flattened section for each of the anchorage ends : a first flattened section close to but not immediately adjacent to the first anchorage end and a second flattened section close to but not immediately adjacent to the second anchorage end.

FIB 2 (Figure 5) is a fibre having at both ends a nail head as anchorage end. FIB 1, FIB3 and FIB4 have anchorage ends having a first straight section, a second straight section and possibly a third straight section. Between the middle portion and the first straight section of an anchorage end there is a first bent section; between the second straight section of an anchorage end and the first straight section of an anchorage end there is a second bent section, between the third straight section of an anchorage end and the second straight section of an anchorage end there is a third bent section. Table 3 specifies the details of the anchorage ends such as the number of straight sections of the anchorage end, the included angle between the main axis of the middle portion and the main axis of the first straight section, the orientation of the second straight section towards the middle portion, the included angle between the main axis of the second straight section and the main axis of the third straight section, the orientation of the fourth straight section towards the middle portion. The geometry of the different fibres is shown in Figure 4, Figure 5, Figure 6 and Figure 7.

FIB1 (Figure 4) and FIB2 (Figure 5) are prior art fibres. FIB1 (Figure 4) is a low carbon fibre having anchorage ends with two straight sections. FIB3 (Figure 6) and FIB4 (Figure7) are fibres according to the present invention.

[0068] Two straight sections with a common vertex define two angles. The sum of these two angle is equal to 360 degrees. For the purpose of this invention the smallest of the two angles defined by two straight sections with a common vertex is called the "included angle".

This means that the included angle between the main axis of the middle portion and the main axis of the first straight section is the smallest angle defined by the main axis of the middle portion and the main axis of the first straight section. Similarly, the included angle between the main axis of the second straight section and the main axis of the third straight section is the smallest angle defined by the main axis of the second straight section and the main axis of the third straight section.

[0069] Prior art steel fibre FIB1 is shown in Figure 4. The steel fibre 400 comprises a middle portion 404 and an anchorage end 402 at both ends of the middle portion 404. The middle portion 404 has a main axis 403. Each of the anchorage ends comprises a first bent section 405, a first straight section 406, a second bent section 407 and a second

straight section 408. The included angle between the main axis 403 of the middle portion 404 and the main axis of the first straight section 406 is indicated by α .

The second straight section 408 is parallel or substantially parallel with the main axis of the middle portion 403.

[0070] Prior art steel fibre FIB2 is shown in Figure 5. Steel fibre 500 comprises a middle portion 504 provided at both ends of the middle portion 504 with anchorage ends 502. The anchorage ends comprise nail heads.

[0071] The steel fibre 600 shown in Figure 6 (FIB3) is a steel fibre according to the present invention. Figure 6a is a view in the plane of the steel fibre;

Figure 6b is a top view.

The steel fibre 600 has a middle portion 604 provided with anchorage ends 602 at both ends. The middle portion 604 has a main axis 603. The middle portion 604 of the steel fibre 600 is provided with two flattened sections 601: a first flattened section close to but not immediately adjacent to the first anchorage end and a second flattened section close to but not immediately adjacent to the second anchorage end. The first flattened section 601 has a length l_{f1} ; the second flattened section 601 has a length l_{f2} . The distance between the first flattened sections and the first anchorage end is for example 2 mm or 3 mm. Similarly, the distance between the second flattened section and the second anchorage end is for example 2 mm or 3mm.

The middle portion 604 has a central section 610 that is located between the first flattened section and the second flattened section. The central section 610 has a length l'

The total length of the middle portion is indicated by L and corresponds with the sum of the length of the section between the first anchorage end and the first flattened section, the length of the first flattened section l_{f1} , the length of the central section l' , the length of the second flattened section l_{f2} and the length of the section between the second flattened section and the second anchorage end.

[0072] Each of the anchorage ends 602 comprises a first bent section 605, a first straight section 606, a second bent section 607 and a second straight section 608. Both anchorage ends are bending away in the same direction from the main axis 603 of the middle portion 604.

The included angle between the main axis 603 of the middle portion 604 and the main axis of the first straight section 606 is indicated by α .

The second straight section 608 is parallel or substantially parallel with the main axis 603 of the middle portion 604.

[0073] Figure 7 shows a further embodiment of a steel fibre 700 according to the present invention (FIB4).

Figure 7a is a view in the plane of the steel fibre; Figure 7b is a top view. The steel fibre 700 has a middle portion 704 provided with anchorage ends 702 at both ends. The middle portion 704 has a main axis 703. The middle portion 704 of the steel fibre 700 is provided with two flattened sections 701: a first flattened section close to but not immediately adjacent to the first anchorage end and a second flattened section close to but not immediately adjacent to the second anchorage end.

The first flattened section 701 has a length l_{f1} ; the second flattened section 701 has a length l_{f2} . The distance between the first flattened sections and the first anchorage end is for example 2 mm or 3 mm. Similarly, the distance between the second flattened section and the second anchorage end is for example 2 mm or 3mm.

The middle portion 704 has a central section 710 that is located between the first flattened section and the second flattened section. The central section 710 has a length l'

The total length of the middle portion is indicated by L and corresponds with the sum of the length of the section between the first anchorage end and the first flattened section, the length of the first flattened section l_{f1} , the length of the central section l' , the length of the second flattened section l_{f2} and the length of the section between the second flattened section and the second anchorage end.

[0074] Each of the anchorage ends 702 comprises a first bent section 705, a first straight section 706, a second bent section 707 and a second straight section 708, a third bent section 709 and a third straight section 712. Both anchorage ends are bending away in the opposite directions from the main axis 703 of the middle portion 704.

The included angle between the main axis 703 of the middle portion 704 and the main axis of the first straight section 706 is indicated by α .

The included angle between the main axis of the second straight section 706 and the main axis of the third straight section 708 is indicated by β . The second straight section 708 is parallel or substantially parallel with the main axis 703 of the middle portion 704.

Table 2

Fibre type	Length (mm)	Wire type	Diameter (mm)	Flattened sections (yes/no)	Number of straight sections	α (degrees)	2 nd straight section parallel with main axis middle portion (yes/no)	β (degrees)	Fig.
FIB1	60	2	0.90	No	2	140	Yes	/	Fig. 4
FIB2	54	1	1.00	No	/	/	/	/	Fig. 5
FIB3	60	3	0.89	Yes	2	140	Yes	/	Fig. 6
FIB4	60	3	0.89	Yes	3	140	Yes	140	Fig. 7
α Included angle between the main axis of the middle portion and the main axis of the 1 st straight section β Included angle between the main axis of the 2 nd straight section and the main axis of the 3 rd straight section									

Table 3

Fiber type	Dosage (kg/m ³)	Curing time (days)	f_L	$f_{R,1}$	$f_{R,2}$	$f_{R,3}$	$f_{R,3}/f_{R,1}$
FIB1	40	28	5.48	3.75	3.85	3.68	0.98
FIB2	40	28	5.80	4.11	4.31	2.83	0.69
FIB3	40	28	5.80	4.88	6.21	6.47	1.33
FIB3	20	28	5.68	3.06	3.83	4.23	1.38
FIB4	40	14	5.11	4.80	6.14	6.48	1.35

[0075] From Table 3 it can be concluded that the ratio $f_{R,3}/f_{R,1}$ of the prior art fibres (FIB1 and FIB2) is below 1. Also the residual flexural tensile strengths $f_{R,1}$, $f_{R,2}$ and $f_{R,3}$ of the prior art fibres (FIB1 and FIB2) are low, i.e. considerably lower than the residual flexural tensile strengths $f_{R,1}$, $f_{R,2}$ and $f_{R,3}$ of FIB3. The residual flexural tensile strengths $f_{R,1}$, $f_{R,2}$ and $f_{R,3}$ of steel fibres FIB1, FIB2 and FIB3 cannot be directly compared with the residual flexural tensile strengths $f_{R,1}$, $f_{R,2}$ and $f_{R,3}$ of FIB4 as the curing time of steel fibres FIB1, FIB2 and FIB3 is 28 days whereas the curing time of steel fibre FIB4 is only 14 days.

For the steel fibres according to the present invention (FIB3 and FIB4) the ratio $f_{R,3}/f_{R,1}$ is above 1.

[0076] Steel fibre FIB3 is tested in two different dosages : 20 kg/m³ and 40 kg/m³. Even when a fibre dosage of 20 kg/m³ is used the ratio $f_{R,3}/f_{R,1}$ is exceeding 1. This indicates that such steel fibres behave like traditional reinforcing steel (stress-strain based instead of stress-crack opening based).

[0077] When the steel fibres of Table 2 are subjected to a pull out test to determine the anchorage force, the anchorage force of steel fibres FIB3 and FIB4 in concrete is higher than the anchorage force of steel fibres FIB1 and FIB2.

[0078] When steel fibres FIB3 and FIB4 provided with flattened sections are compared with steel fibres having the same geometry and steel composition as steel fibres FIB3 and FIB4 but without flattened sections, steel fibres FIB3 and FIB4 provided with flattened sections have a higher anchorage force in concrete than the steel fibres without flattened sections.

[0079] As a matter of example, steel fibres according to the invention may be made as follows.

Starting material is a wire rod with a diameter of e.g. 5.5 mm or 6.5 mm and a steel composition having a minimum carbon content of for example 0.50 per cent by weight (wt %), e.g. equal to or more than 0.60 wt %, a manganese content ranging from 0.20 wt % to 0.80 wt %, a silicon content ranging from 0.10 wt % to 0.40 wt %. The sulphur content is maximum 0.04 wt % and the phosphorous content is maximum 0.04 wt %.

A typical steel composition comprises 0.725 % carbon, 0.550 % manganese, 0.250 % silicon, 0.015 % sulphur and 0.015 % phosphorus. An alternative steel composition comprises 0.825 % carbon, 0.520 % manganese, 0.230 % silicon, 0.008

% sulphur and 0.010 % phosphorus. The wire rod is cold drawn in a number of drawing steps until its final diameter ranging from 0.20 mm to 1.20 mm.

If a high elongation at fracture and/or at maximum load is required it can be preferred to subject the drawn wire to a stress-relieving treatment, e.g. by passing the wire through a high-frequency or mid-frequency induction coil of a length that is adapted to the speed of the passing wire. It has been observed that a thermal treatment at a temperature of about 300 °C for a certain period of time results in a reduction of the tensile strength of about 10% without increasing the elongation at fracture and the elongation at maximum load. By slightly increasing the temperature, however, to more than 400 °C, a further decrease of the tensile strength is observed and at the same time an increase in the elongation at fracture and an increase in the elongation at maximum load.

[0080] The wires may or may not be coated with a corrosion resistant coating such as a zinc or a zinc alloy coating, more particularly a zinc aluminium coating or a zinc aluminium magnesium coating. Prior to drawing or during drawing the wires may also be coated with a copper or copper alloy coating in order to facilitate the drawing operation.

[0081] The stress-relieved wires are then cut to the appropriate lengths of the steel fibres and the ends of the steel fibres are given the appropriate anchorage or thickening. Cutting and hook-shaping can also be done in one and the same operation step by means of appropriate rolls.

[0082] The thus obtained steel fibres may or may not be glued together according to US-A-4284667.

[0083] In addition or alternatively, the obtained steel fibres may be put in a chain package according to EP-B1-1383634 or in a belt like package such as disclosed in European patent application with application number 09150267.4 of Applicant.

Claims

1. A steel fibre (600, 700) for reinforcing concrete or mortar, said steel fibre (600, 700) comprising a middle portion (604, 704) having a length L, a first anchorage end (602, 702) at one end of said middle portion (604, 704) and a second anchorage end (602, 702) at the other end of said middle portion (604, 704), said middle portion (604, 704) comprising a first flattened section (601, 701), a second flattened section (601, 701) and a central section (610, 710), said central section (610, 710) being located between said first and said second flattened section (601, 701) and extending from said first flattened section (601, 701) to said second flattened section (601, 701), said first flattened section (601, 701) being located close to but not immediately adjacent to said first anchorage end (602, 702) and said second flattened section (601, 701) being located close to but not immediately adjacent to said second anchorage end (602, 702), said central section (610, 710) having a length l', said steel fibre being **characterised in that** said central section (610, 710) has the same cross-section over the entire length l' of said central section (610, 710), the ratio of the length of said central section l' divided by the length of the middle portion L (ratio l'/L) is higher than 0.50, said central section (610, 710) has a tensile strength R_m of at least 1000 MPa and an elongation at maximum load A_{g+e} of at least 2.5 %
2. A steel fibre (600, 700) according to claim 1, whereby said middle portion (604, 704) of said steel fibre (600, 700) has a tensile strength R_m of at least 1500 MPa.
3. A steel fibre (600, 700) according to claim 1 or claim 2, whereby said middle portion (604, 704) of said steel fibre (600, 700) has an elongation at maximum load A_{g+e} of at least 4 %.
4. A steel fibre (600, 700) according to any one of the preceding claims, whereby the distance between the first anchorage end (602, 702) and the first flattened section (601, 701) and/or the distance between the second anchorage end (602, 702) and the second flattened section (601, 701) ranges between 0.5 and 20 mm.
5. A steel fibre (600, 700) according to any one of the preceding claims, whereby said first flattened section (601, 701) has a length l_{f1} and said second flattened section (601, 701) has a length l_{f2} , said length l_{f1} and said length l_{f2} are ranging between 0.5 and 10 mm.
6. A steel fibre (600, 700) according to any one of the preceding claims, whereby said flattened sections (601, 701) are flattened in a plane which is substantially parallel with the plane of the steel fibre (600, 700).
7. A steel fibre (600, 700) according to any one of the preceding claims, whereby said flattened sections (601, 701) are flattened in a plane which is substantially perpendicular to the plane of the steel fibre (600, 700).
8. A steel fibre (600, 700) according to any one of the preceding claims, whereby said steel fibre (600, 700) has a

diameter D ranging between 0.1 mm and 1.20 mm.

9. A steel fibre (600, 700) according to any one of the preceding claims, whereby said ratio length of the steel fibre (600, 700) divided by the diameter of the steel fibre (600, 700) (=ratio length steel fibre/D) is ranging between 40 and 100.
10. A steel fibre (600, 700) according to any one of the preceding claims, whereby said steel fibre (600, 700) is in a stress-relieved state.
11. A concrete structure reinforced with steel fibres (600, 700) according to one or more of claims 1 to 10.
12. A concrete structure according to claim 11, whereby the ratio residual flexural tensile strength $f_{R,3}$ divided by residual flexural tensile strength $f_{R,1}$ (=ratio $f_{R,3}/f_{R,1}$) is higher than 1 with a dosage of said steel fibres (600, 700) of less than 1 vol %.
13. A concrete structure according to claim 11 or 12, whereby the residual flexural tensile strength $f_{R,3}$ is higher than 5MPa with a dosage of said steel fibres (600, 700) of less than 1 vol %.
14. Use of steel fibres (600, 700) as defined in any one of claims 1 to 10 for load carrying structures of concrete.

Patentansprüche

1. Stahlfaser (600, 700) zum Verstärken von Beton oder Mörtel, wobei die Stahlfaser (600, 700) umfasst: einen mittleren Abschnitt (604, 704) mit einer Länge L, ein erstes Verankerungsende (602, 702) an einem Ende des mittleren Abschnitts (604, 704) und ein zweites Verankerungsende (602, 702) am anderen Ende des mittleren Abschnitts (604, 704), wobei der mittlere Abschnitt (604, 704) einen ersten abgeflachten Abschnitt (601, 701), einen zweiten abgeflachten Abschnitt (601, 701) und einen zentralen Abschnitt (610, 710) umfasst, wobei der zentrale Abschnitt (610, 710) zwischen dem ersten und dem zweiten abgeflachten Abschnitt (601, 701) angeordnet ist und sich von dem ersten abgeflachten Abschnitt (601, 701) zum zweiten abgeflachten Abschnitt (601, 701) erstreckt, wobei der erste abgeflachte Abschnitt (601, 701) in der Nähe, aber nicht unmittelbar neben dem ersten Verankerungsende (602, 702) angeordnet ist und wobei der zweite abgeflachte Abschnitt (601, 701) in der Nähe, aber nicht unmittelbar neben dem zweiten Verankerungsende (602, 702) angeordnet ist, wobei der zentrale Abschnitt (610, 710) eine Länge l' aufweist, wobei das Stahlkabel **dadurch gekennzeichnet ist, dass** der zentrale Abschnitt (610, 710) den gleichen Querschnitt über die gesamte Länge l' des zentralen Abschnitts (610, 710) aufweist, wobei das Verhältnis zwischen der Länge des zentralen Abschnitts l' geteilt durch die Länge des mittleren Abschnitts L (Verhältnis l'/L) größer als 0,50 ist, wobei der zentrale Abschnitt (610, 710) eine Zugfestigkeit R_m von mindestens 1000 MPa und eine Dehnung bei maximaler Belastung A_{g+e} von mindestens 2,5 % besitzt.
2. Stahlfaser (600, 700) nach Anspruch 1, wobei der mittlere Abschnitt (604, 704) der Stahlfaser (600, 700) eine Zugfestigkeit R_m von mindestens 1500 MPa besitzt.
3. Stahlfaser (600, 700) nach Anspruch 1 oder Anspruch 2, wobei der mittlere Abschnitt (604, 704) der Stahlfaser (600, 700) eine Dehnung bei maximaler Belastung A_{g+e} von mindestens 4 % besitzt.
4. Stahlfaser (600, 700) nach einem der vorhergehenden Ansprüche, wobei der Abstand zwischen dem ersten Verankerungsende (602, 702) und dem ersten abgeflachten Abschnitt (601, 701) und/oder der Abstand zwischen dem zweiten Verankerungsende (602, 702) und dem zweiten abgeflachten Abschnitt (601, 701) im Bereich zwischen 0,5 und 20 mm liegt.
5. Stahlfaser (600, 700) nach einem der vorhergehenden Ansprüche, wobei der erste abgeflachte Abschnitt (601, 701) eine Länge l_{f1} und der zweite abgeflachte Abschnitt (601, 701) eine Länge l_{f2} besitzt, wobei die Länge l_{f1} und die Länge l_{f2} in dem Bereich zwischen 0,5 und 10 mm liegen.
6. Stahlfaser (600, 700) nach einem der vorhergehenden Ansprüche, wobei die abgeflachten Abschnitte (601, 701) in einer Ebene abgeflacht sind, die im Wesentlichen parallel zu der Ebene der Stahlfaser (600, 700) verläuft.
7. Stahlfaser (600, 700) nach einem der vorhergehenden Ansprüche, wobei die abgeflachten Abschnitte (601, 701)

in einer Ebene abgeflacht sind, die im Wesentlichen senkrecht zu der Ebene der Stahlfaser (600, 700) verläuft.

8. Stahlfaser (600, 700) nach einem der vorherigen Ansprüche, wobei die Stahlfaser (600, 700) einen Durchmesser D in dem Bereich zwischen 0,1 mm und 1,20 mm aufweist.

9. Stahlfaser (600, 700) nach einem der vorhergehenden Ansprüche, wobei das Verhältnis der Länge der Stahlfaser (600, 700) geteilt durch den Durchmesser der Stahlfaser (600, 700) (= Verhältnis Länge Stahlfaser/D) in dem Bereich zwischen 40 und 100 liegt.

10. Stahlfaser (600, 700) nach einem der vorherigen Ansprüche, wobei sich die Stahlfaser (600, 700) in einem spannungsentlasteten Zustand befindet.

11. Mit Stahlfasern (600, 700) verstärkte Betonstruktur nach einem oder mehreren der Ansprüche 1 bis 10.

12. Betonstruktur nach Anspruch 11, wobei das Verhältnis der restlichen Biegezugfestigkeit $f_{R,3}$ geteilt durch die restliche Biegezugfestigkeit $f_{R,1}$ (= Verhältnis $f_{R,3}/f_{R,1}$) bei einer Dosierung der Stahlfasern (600, 700) von weniger als 1 Vol.-% größer als 1 ist.

13. Betonstruktur nach Anspruch 11 oder 12, wobei die restliche Biegezugfestigkeit $f_{R,3}$ bei einer Dosierung der Stahlfasern (600, 700) von weniger als 1 Vol.-% größer als 5 MPa ist.

14. Verwendung von Stahlfasern (600, 700) nach einem der Ansprüche 1 bis 10 für lasttragende Betonstrukturen.

Revendications

1. Fibre d'acier (600, 700) pour renforcer du béton ou du mortier, ladite fibre d'acier (600, 700) comprenant une partie intermédiaire (604, 704) présentant une longueur L, une première extrémité d'ancrage (602, 702) à une extrémité de ladite partie intermédiaire (604, 704), et une deuxième extrémité d'ancrage (602, 702) à l'autre extrémité de ladite partie intermédiaire (604, 704), ladite partie intermédiaire (604, 704) comprenant une première section aplatie (601, 701), une deuxième section aplatie (601, 701) et une section centrale (610, 710), ladite section centrale (610, 710) étant située entre lesdites première et deuxième sections aplaties (601, 701) et s'étendant à partir de ladite première section aplatie (601, 701) jusqu'à ladite deuxième section aplatie (601, 701), ladite première section aplatie (601, 701) étant située à proximité de mais pas immédiatement adjacente à ladite première extrémité d'ancrage (602, 702), et ladite deuxième section aplatie (601, 701) étant située à proximité de mais pas immédiatement adjacente à ladite deuxième extrémité d'ancrage (602, 702), ladite section centrale (610, 710) présentant une longueur l', ladite fibre d'acier étant **caractérisée en ce que** ladite section centrale (610, 710) présente la même section transversale sur la totalité de la longueur l' de ladite section centrale (610, 710), le rapport de la longueur l' de ladite section centrale divisée par la longueur L de la partie intermédiaire (rapport l'/L) est supérieur à 0,50, ladite section centrale (610, 710) présente une résistance à la traction R_m d'au moins 1000 MPa et un allongement sous une charge maximum A_{g+e} d'au moins 2,5 %.

2. Fibre d'acier (600, 700) selon la revendication 1, dans laquelle ladite partie intermédiaire (604, 704) de ladite fibre d'acier (600, 700) présente une résistance à la traction R_m d'au moins 1500 MPa.

3. Fibre d'acier (600, 700) selon la revendication 1 ou la revendication 2, dans laquelle ladite partie intermédiaire (604, 704) de ladite fibre d'acier (600, 700) présente un allongement sous une charge maximum A_{g+e} d'au moins 4 %.

4. Fibre d'acier (600, 700) selon l'une quelconque des revendications précédentes, dans laquelle la distance entre la première extrémité d'ancrage (602, 702) et la première section aplatie (601, 701) et/ou la distance entre la deuxième extrémité d'ancrage (602, 702) et la deuxième section aplatie (601, 701) est comprise dans la gamme entre 0,5 mm et 20 mm.

5. Fibre d'acier (600, 700) selon l'une quelconque des revendications précédentes, dans laquelle ladite première section aplatie (601, 701) présente une longueur l_{f1} et ladite deuxième section aplatie (601, 701) présente une longueur l_{f2} , ladite longueur l_{f1} et ladite longueur l_{f2} étant comprise dans la gamme entre 0,5 mm et 10 mm.

6. Fibre d'acier (600, 700) selon l'une quelconque des revendications précédentes, dans laquelle lesdites sections

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aplaties (601, 701) sont aplaties dans un plan qui est sensiblement parallèle au plan de la fibre d'acier (600, 700).

5 7. Fibre d'acier (600, 700) selon l'une quelconque des revendications précédentes, dans laquelle lesdites sections aplaties (601, 701) sont aplaties dans un plan qui est sensiblement perpendiculaire au plan de la fibre d'acier (600, 700).

8. Fibre d'acier (600, 700) selon l'une quelconque des revendications précédentes, dans laquelle ladite fibre d'acier (600, 700) présente un diamètre D qui est compris dans la gamme entre 0,1 mm et 1,20 mm.

10 9. Fibre d'acier (600, 700) selon l'une quelconque des revendications précédentes, dans laquelle ledit rapport de la longueur de la fibre d'acier (600, 700) divisée par le diamètre de la fibre d'acier (600, 700) (= le rapport de la longueur de la fibre d'acier/D) est compris dans la gamme entre 40 et 100.

15 10. Fibre d'acier (600, 700) selon l'une quelconque des revendications précédentes, dans laquelle ladite fibre d'acier (600, 700) se trouve dans un état exempt de contraintes.

11. Structure de béton renforcée avec des fibres d'acier (600, 700) selon une ou plusieurs des revendications 1 à 10.

20 12. Structure de béton selon la revendication 11, dans laquelle le rapport de la résistance résiduelle à la traction par flexion $f_{R,3}$ divisée par la résistance résiduelle à la traction par flexion $f_{R,1}$ (= le rapport $f_{R,3}/f_{R,1}$) est supérieur à 1 avec un dosage desdites fibres d'acier (600, 700) inférieur à 1 % en volume.

25 13. Structure de béton selon la revendication 11 ou 12, dans laquelle la résistance résiduelle à la traction par flexion $f_{R,3}$ est supérieure à 5 MPa avec un dosage desdites fibres d'acier (600, 700) inférieur à 1 % en volume.

30 14. Utilisation de fibres d'acier (600, 700) selon l'une quelconque des revendications 1 à 10 pour des structures de béton de support de charges.

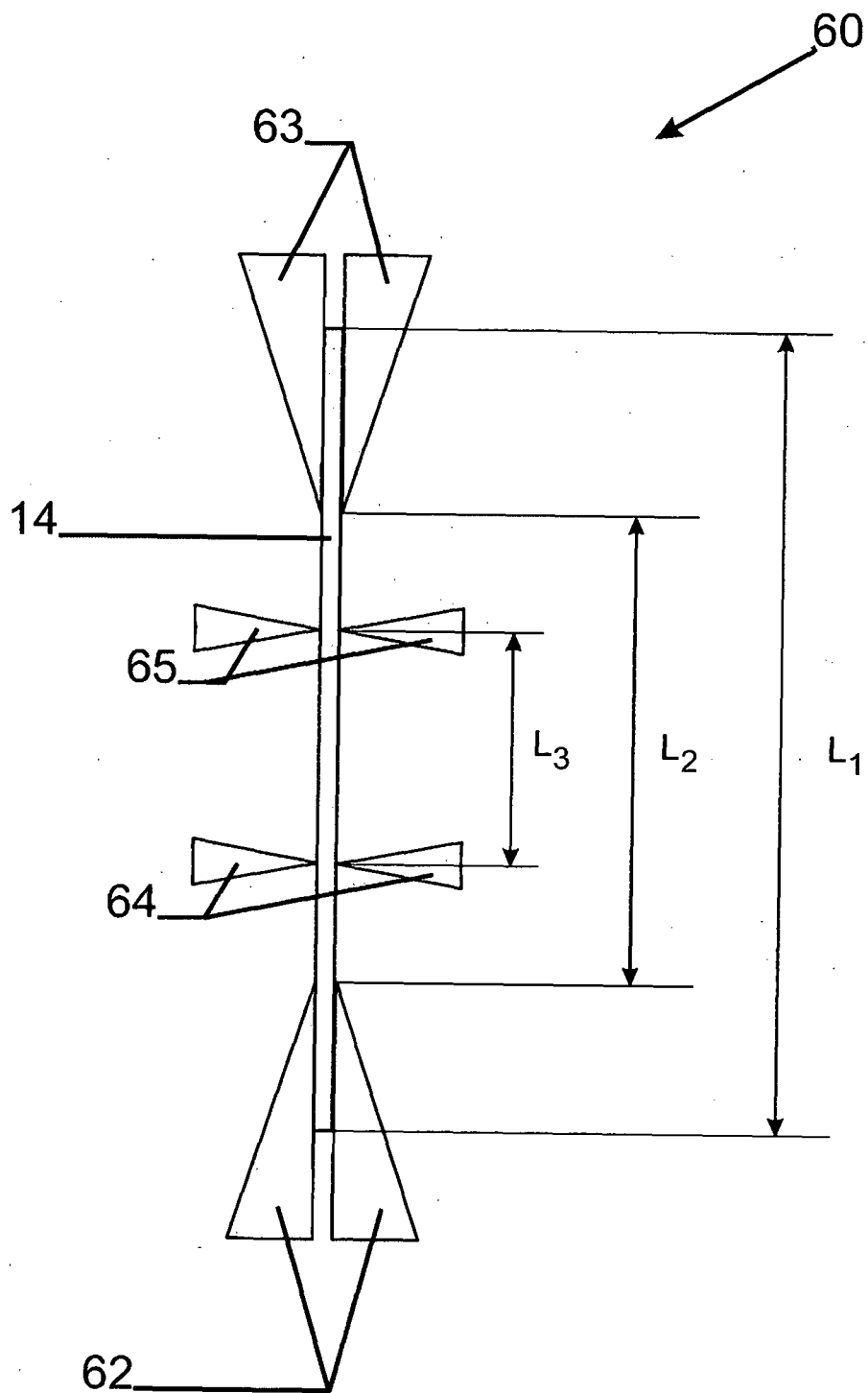
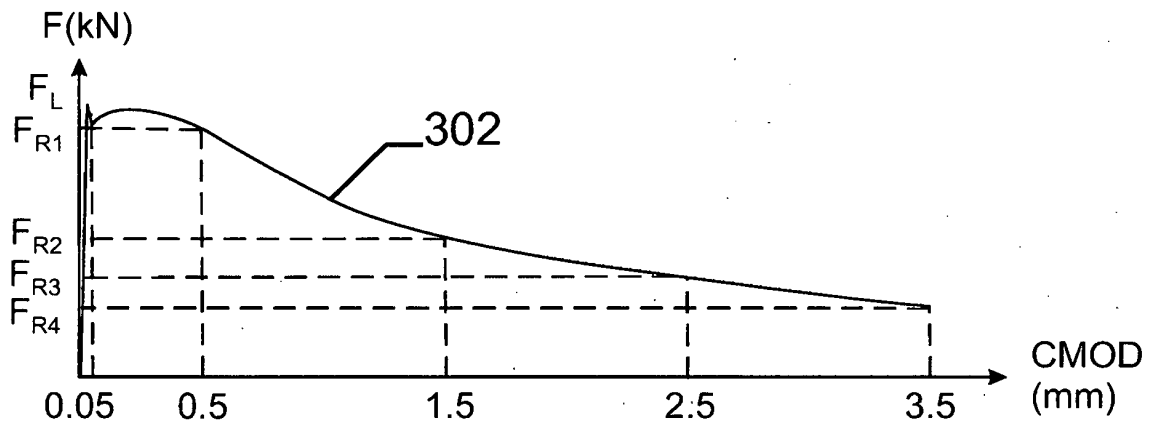
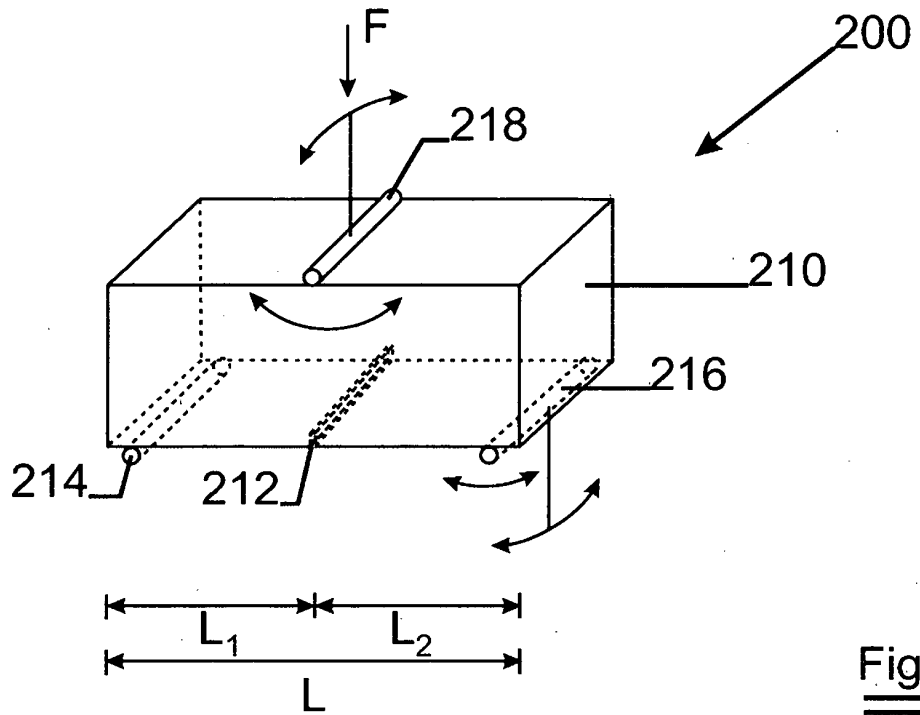


Fig. 1



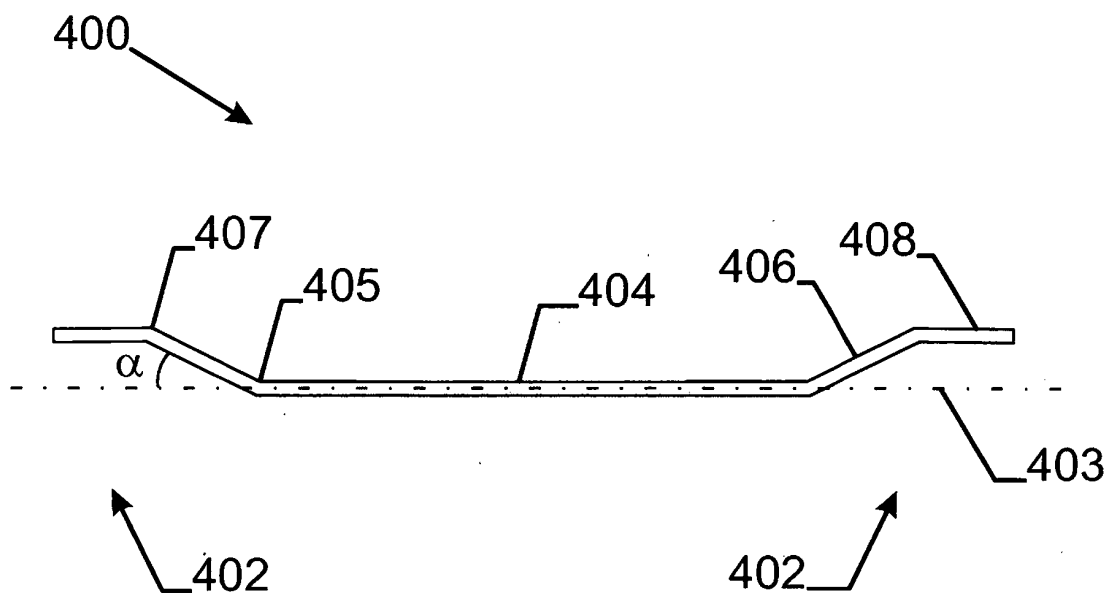


Fig. 4

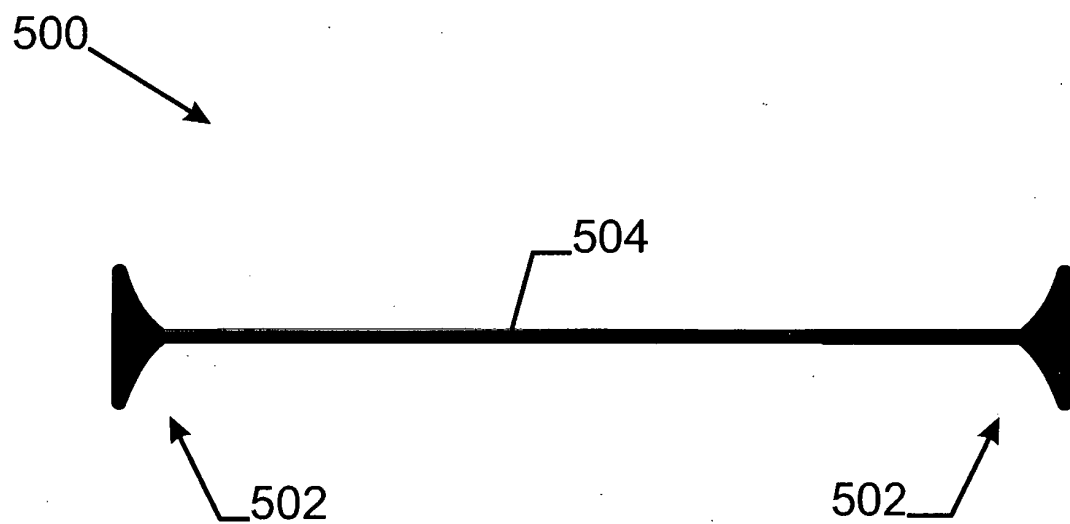


Fig. 5

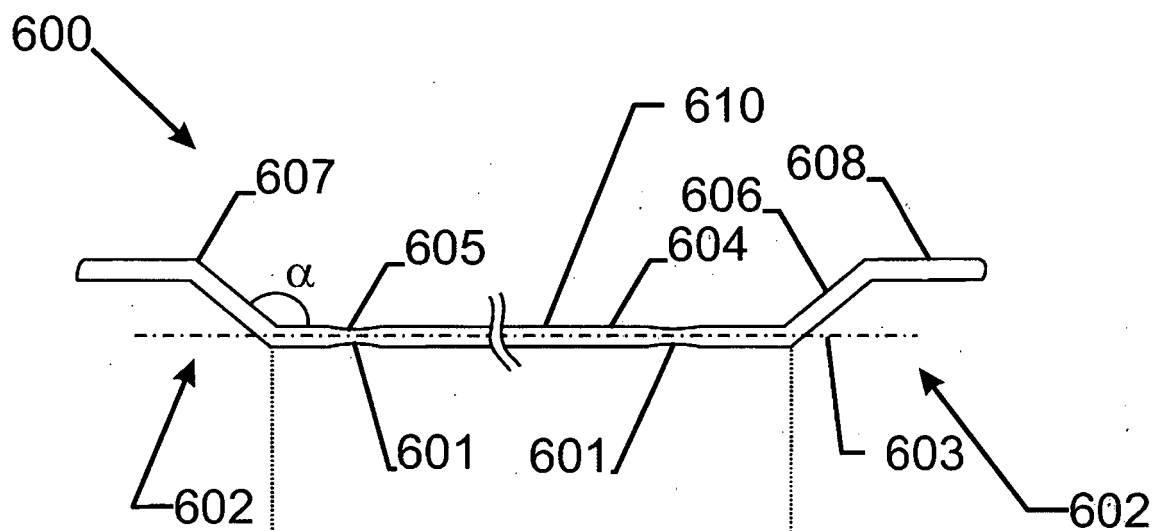


Fig. 6a

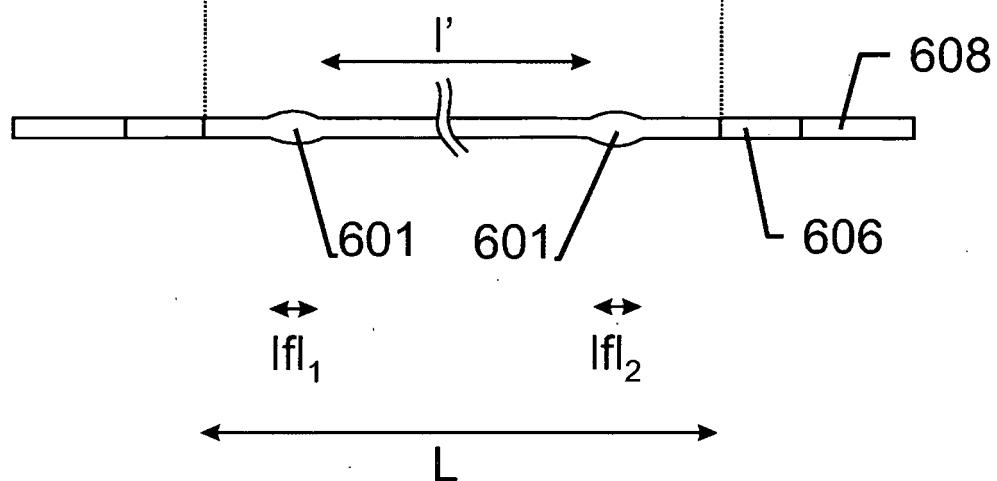


Fig. 6b

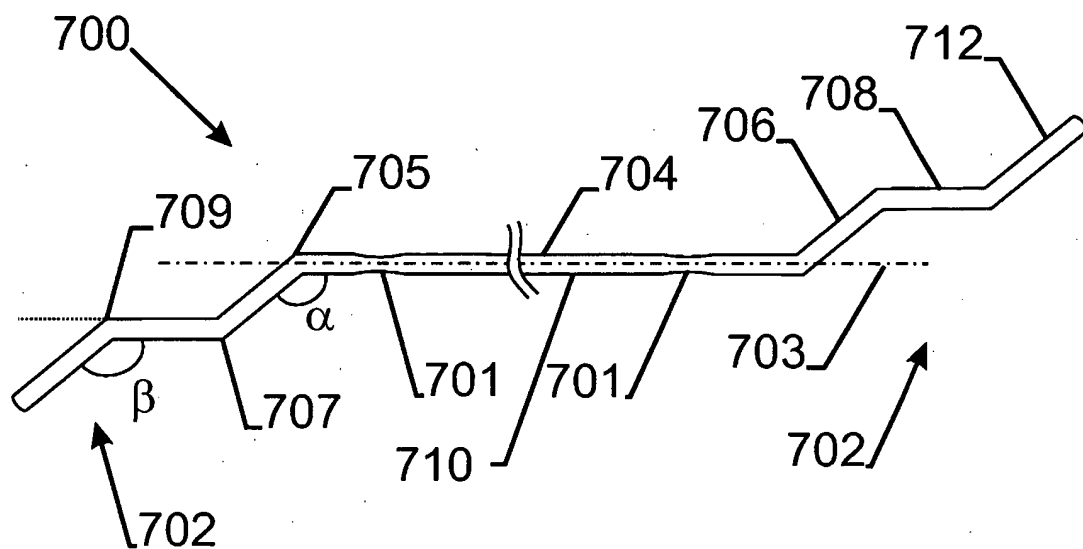


Fig. 7a

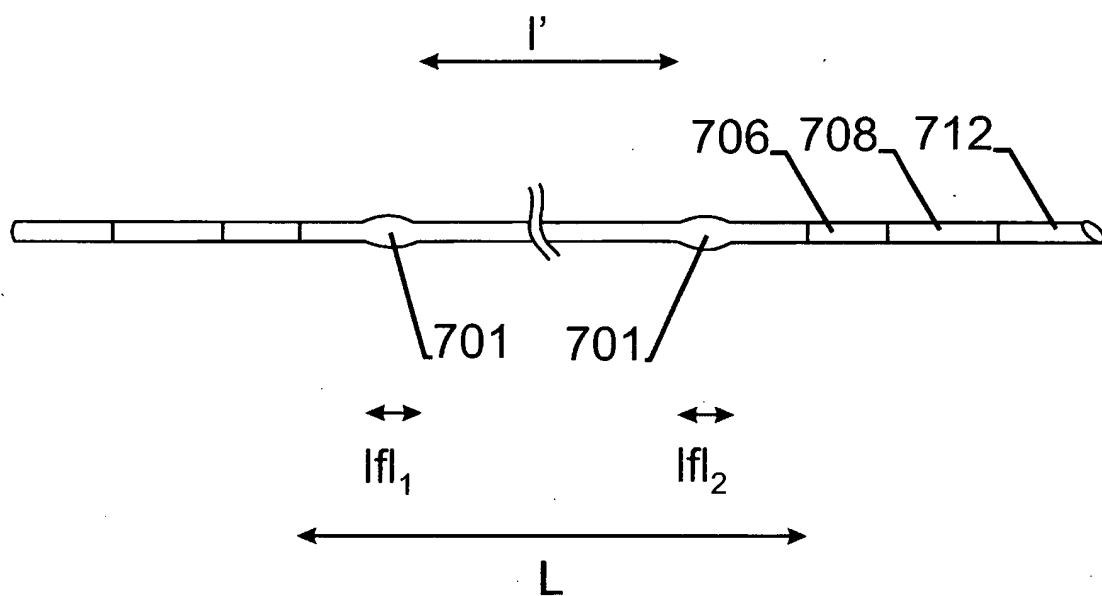


Fig. 7b

REFERENCES CITED IN THE DESCRIPTION

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