Universitatea Tehnică de Construcții București

SPECIAL FEATURES OF PREPARATION AND APPLICATION OF DISPERSED REINFORCED CONCRETE

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CONTENT

Disperse reinforced concrete

- Disperse reinforced concrete with metal fibers is defined as "material obtained by mixing cement, aggregates, metal fibers, additives, mineral additions and water during preparation, in predetermined proportions, whose properties develop through the hydration and hardening of the cement and the interaction between the metal fibers and the matrix.
- Metal fibers were created to improve the durability and tensile strength of concrete. Metal fibers provide three-dimensional reinforcement of concrete, like other microsystems.
- Fiber-reinforced concrete cannot completely replace conventional reinforced concrete. However, there are areas of use in which fiber-reinforced concrete can be used as an alternative or in addition to conventional reinforced concrete, offering constructive and economic advantages.
- It has been found that fibers, of any nature, improve the properties of plain concrete.

Disperse reinforced concrete

- Dispersed reinforced concrete results from the incorporation of a variable amount of discontinuous fibers into the concrete mass.
- Most applications of dispersed fiber reinforced concrete are based on the principle of improving the mechanical properties and characteristics (strength) of the material. However, the role of fiber reinforcement of simple or classically reinforced concrete should not be reduced only to this principle of improving strength, but especially to controlling the cracking process and thereby improving strength, energy absorption properties and resistance to impact, shock, temperature variations, temperature gradient, fire resistance.

I. History of steel fiber reinforced concrete

- **The first patent referring to a dispersed steel fiber reinforced concrete element dates back to 1874 and was patented in the USA (California) by A. Bernard who proved the improvement of concrete strength by adding uneven steel scraps.**

- **In 1927, also in California, G.C. Martin patented the production of steel fiber reinforced concrete pipes..**

- **Meischke – Smith in 1920 and Etheridge in 1933 highlighted the correlation between fiber shape and increased adhesion..**

II. MATERIALS

1. Cement

Cement is a powdered material, basic in nature, hydrophilic, chemically unstable. Mixed with water, it forms thixotropic pastes, which set and harden over time, forming the “cement stone”. Portland cement is obtained by finely grinding Portland clinker with an addition of gypsum (2÷7%) strictly necessary to regulate the setting time and with possible additions.

The most important properties of the mineralogical components and respectively of the cement, which are of interest to builders are:

- hydration speed and therefore the amount of chemically bound water
- hydration heat and the rate of its release
- the value of mechanical resistances, respectively their evolution over time
- resistance to the action of chemical aggression
- shrinkage upon drying.

2. Aggregates

Aggregates are natural or artificial granulated materials used in the preparation of cement mortars and concretes, respectively in other construction works.

Obtaining aggregates from natural rocks can be done:

→ by direct sampling from river and lake beds, respectively by sorting operations (ballast, sand, gravel) – ballast aggregate;

→ by industrial processes of crushing (hard) rocks – crushing aggregate.

Being a much cheaper material than cement (whose manufacture consumes a lot of energy), it is advantageous for the aggregate to occupy as large a proportion in the mass of the mixture as possible, it also having the role of stabilizing the volume of concrete, respectively of giving it high durability. Occupying a weight of at least 75% in the mass of the mixture, the aggregate must be of quality, this aspect being capital for achieving the designed characteristics of resistance and durability of concrete..

The properties of aggregates depend entirely on those of the source rock, such as :

chemical and mineralogical composition, petrographic characteristics, specific gravity, durability, mechanical strength, physical and chemical stability, pore structure, etc.

On the other hand, the aggregate can also acquire some properties different from those of the base rock, such as:

particle shape and size, texture, absorption, etc.

<u>Classification of aggregates</u>

The main classifications of aggregates are:

a) By nature.

b) By origin.

c) By bulk density in loose and dry state.

d) By the shape of the granules: rounded, lamellar (flat), ovoid, acicular.

e) By the size of the granules.

f) By the degree of roundness and the degree of wear.

g) By the granularity (granulometric composition)

h) From a mineralogical point of view.

i) By processing technology.

3. Concrete additives

Additives are inert chemical substances that, when introduced into the composition of concrete, ensure some of its properties, either in the fresh or hardened state, or in both states.

As a rule, additives do not exceed a dosage of 5% of the cement mass established in the concrete recipe and can be manufactured in solid (powder) or liquid state. When additives are presented in the form of a solution, the amount corresponding to the optimal proportion is added to the mixing water, and if they are in the form of powders, they are mixed beforehand until homogenized, with a quantity of cement.

The functions of additives and the degree of their manifestation are directly influenced by the following factors:

→ additive dosage and dosage of the concrete composition;
→ characteristics of the cement in the composition;
→ conditions for preparing the mixtures and observing them;
→ conditions for transporting and placing the concrete;
→ subsequent treatment of the concrete.

In general, additives have a main function (which gives the desired effect in the concrete composition), but in some cases they can also manifest themselves with some secondary functions. There can also be additives with two important (mixed) functions.

1. Plasticizing additives
2. Fluidizing additives
3. Superfluidizing additives
4. Air-entraining additives
5. Accelerating additives for setting and hardening
6. Retarding additives
7. Antifreeze additives
8. Water-repellent additives (waterproofing)

4. Concrete Admixtures

Admixtures are chemically inert substances that are added to the preparation of concrete, in order to improve (improve) some properties at the fresh and hardened mix level.

Types of admixtures used in the preparation of precast concrete

- wet-ground blast furnace slag (granulate) currently used in the preparation of hydrotechnical concrete;
- alkaline, sulfate or mixed activated blast furnace slag granulate, is used in a mixture with sand and local ballast for industrial floor substrates and road foundations, saving aggregates and cement;
- de-ironed steel slag resulting from the extraction of metal waste from metallurgical plant slags. These can be used as heavy aggregates, after a 6-month rest in dumps, in the composition of simple concrete, based on preliminary tests;

5.Fibers

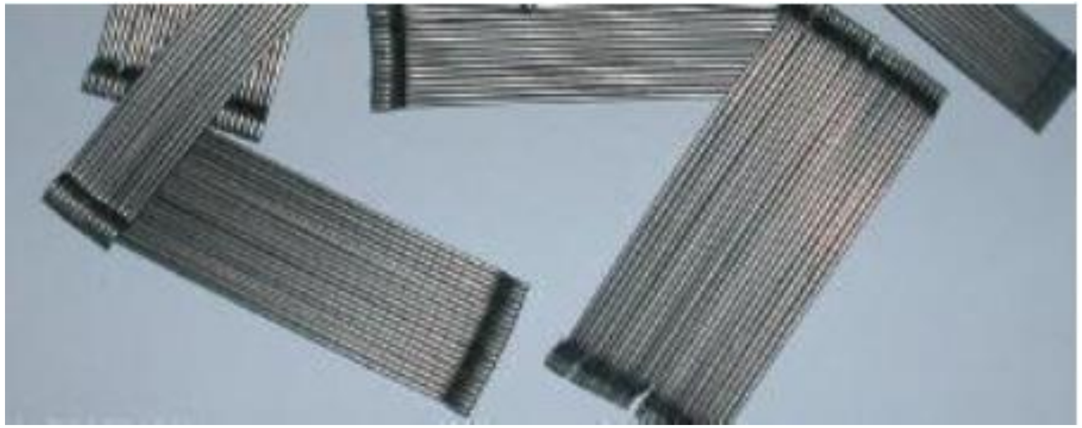
- Natural and artificial fibers for concrete
- Fibers can be used in the composition of concrete with mineral binders, for the purpose of dispersed or preferential reinforcement (in one direction) and having the effect of improving the behavior of concrete under different stresses.
- Classification of fibers:
  - a. Natural fibers:

    → organic - soy, sisal, flax, jute, coconut, cotton, animal hair, wood and vegetable cellulose, etc;

    → minerals - asbestos (currently obsolete).
  - b. Artificial fibers:

    → organic - nitrocellulose or viscose, cellulose acetate, nylon, polyesters or acrylics, modified polypropylene, polyethylene, etc.
- The basic requirements of the fibers, when it is necessary to improve the mechanical strength and delay the cracking process, are: high elongation strength and appropriate modulus of elasticity, increased adhesion to the matrix, chemical stability; from dispersed fiber reinforced concrete are based on the idea of improving the strength properties. The fibers were produced by cutting steel wires with a round and uniform cross-section.
- To increase productivity in manufacturing, steel fibers can be grouped into bundles, cut with guillotine knives or other special devices..

- Smooth surface fibers have low pull-out resistance due to poor adhesion to concrete. In order to improve the pull-out resistance characteristic, fiber types with deformed surfaces have been approved and used. Corrugated fibers, with a continuous shape along the entire length, have improved pull-out resistance.
- The manufacture of fibers joined together using a special, water-soluble bonding solution facilitates the use of fibers of greater lengths than if they were separated, thus eliminating the problems that arise due to the formation of balls (fiber clumps).
- Improving the properties of steel fibers influences the increases in tensile strength of concrete reinforced with such fibers.
- In practice, it is observed that the bending strength of the steel fiber reinforced concrete element increases due to the fact that the distribution of stresses in the stretched area is almost constant.

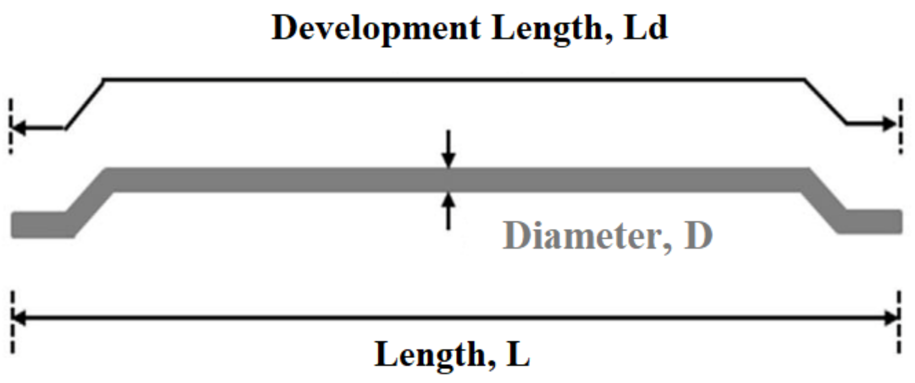


Fibers bonded into strips

5. 1 Metal fibers

Fibers are characterized by both material properties and geometric parameters, length, equivalent diameter, geometric ratio and shape (straight fibers, with beaks at the ends, etc.)

5.2 Geometric characteristics



Fiber Length

The fiber length L is the distance between the outer ends of the fiber.
The developed fiber length Ld is the length of the fiber axis line.
The fiber length should be measured according to specific reference codes.

Aspect ratio, Ld/D

The aspect ratio (geometric ratio) is defined as the ratio of the length, **Ld**, to the equivalent fiber diameter, **D**

5.3 Types of Fibers

Metal fibers can be classified based on production process, shape, and material.

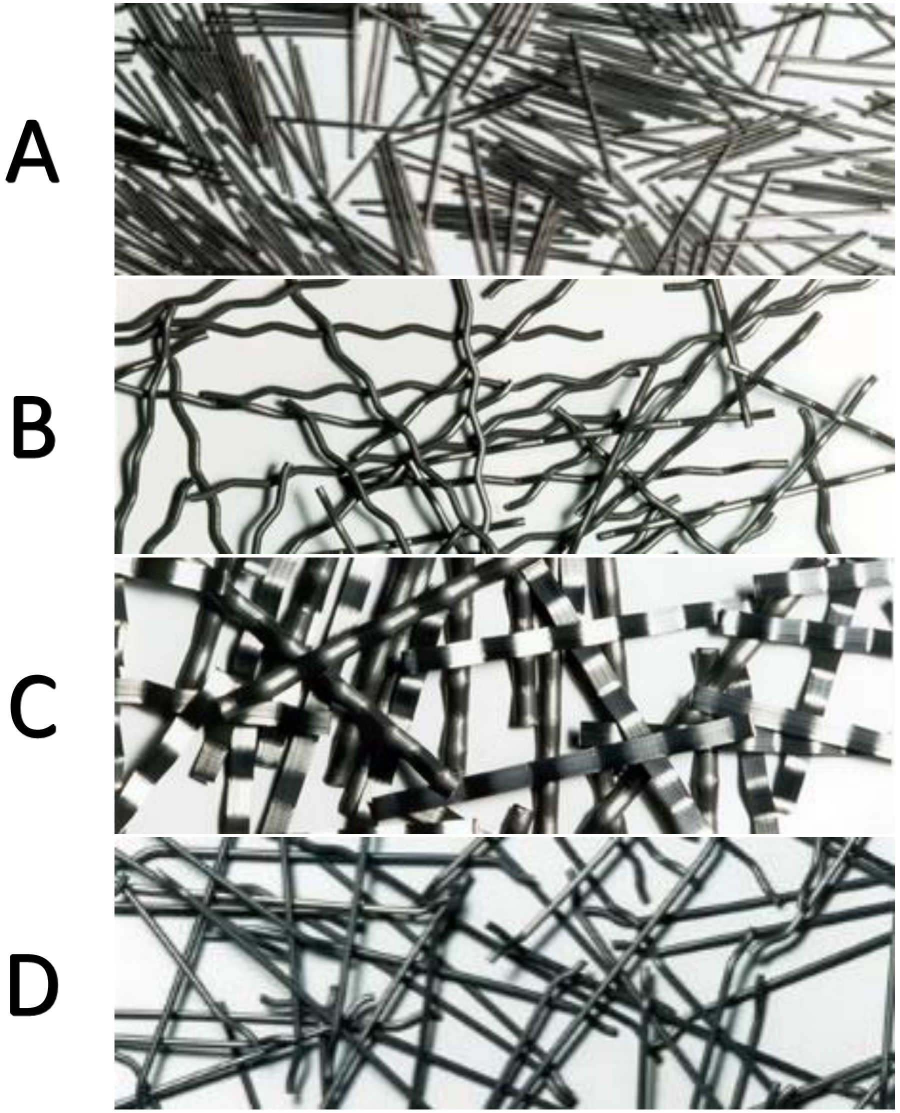
1. Production process:
   - cold drawn wire;
   - cut sheet;
   - other processes.
2. Shape:

   A- flat / straight

   B- corrugated

   C- milled

   D- with beaks at the ends



Material:

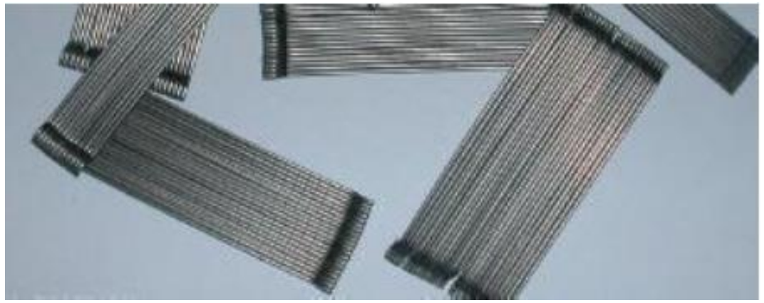
- low carbon steel (C ≤ 0,20%, type 1);
- high carbon steel (C> 0,20%, type 2);
- stainless steel (type 3).

Cold drawn wire

Cold drawn milled wire

Extracted by melting

Fibers bonded into strips



5.4 Packaging and marking

Packaging

The fibers are packed in bags or cardboard boxes, placed on wooden pallets (according to IPPC standards) of approx. 1 MT, protected with plastic film, and securely fastened with metal straps. The fibers must be stored in a way that prevents their damage or the penetration of moisture or other substances that affect them or high temperatures, and be well packaged

CE MARKING (European Conformity).

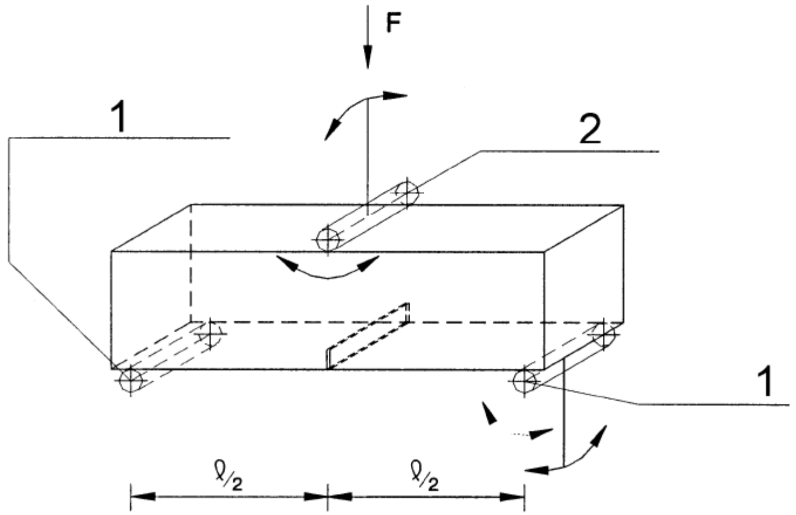
Metal fibers can be used in concrete in Europe only if they comply with the requirements of EN 14889 and are CE marked (European Conformity).

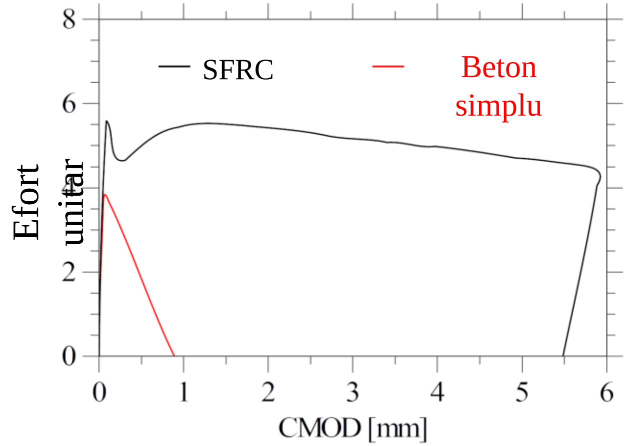
Compliance with this standard indicates the suitability of the fibers for a specific use in concrete.

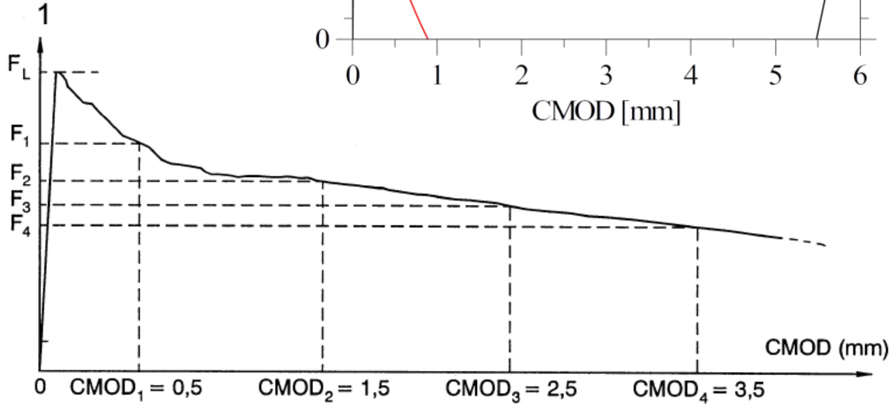
Currently, the CE marking is mandatory in all EU countries. The basic information provided in the CE marking is as follows:

- Fiber type
- CE certification;
- Type and size;
- Tensile strength;
- Young's modulus (modulus of elasticity);
- Length;
- Cross-sectional shape;
- Diameter or cross-sectional dimensions;
- Surface and anchoring (e.g. with embossed end caps);
- Tolerances on length, diameter (and aspect ratio for metal fibers);
- Safety aspects

CE	CE conformity marking, consisting of the "CE"-symbol given in Directive 93/68/EEC
01234	Identification number of the certification body (where relevant)
AnyCo Ltd, PO Box 21, B-1060	Name or Identifying mark and registered address of the producer
08	Last two digits of the year in which the marking was affixed
01234-CPD-00234	Certificate number (where relevant)
EN 14889-1	No. of European Standard
Steel fibre for structural use in concrete mortar and grout Group I Length: 50 mm Diameter: 1.00 mm Shape: deformed Tensile strength: 1200 N/mm²	Description of product
Consistence with 30 kg/m³ fibres: Vebe time: 25 s Effect on strength of concrete: 30kg/m³ to obtain 1,5N/mm² at CMOD=0,5mm and 1N/mm² at CMOD=3,5mm.	Information on regulated characteristics







III. Fresh properties of fibre concrete

1. Rheological properties

(1) The rheological properties of fiber-reinforced concrete depend on the consistency of the matrix, the nature and geometry of the fiber and its dosage.

(2) The typical fiber content for structural applications leads to a reduction in the workability of the mixture, especially for fibers with a complex shape and high aspect ratio

2. Omogenitatea amestecului

(1) Distribuția fibrelor în amestec trebuie să fie uniformă. Pentru a atinge această condiție, trebuie acordată o atenție deosebită pentru a evita aglomerarea de fibre (efect de aglomerare ‘balling’). Chiar dacă cantitatea acestor « aglomerări » este redusa , prezența ei poate provoca unele obstrucții și poate face dificilă pomparea (se infunda furtunul de pompare).

(2) Omogenitatea amestecului poate fi măsurată prin verificarea conținutului de fibre din unele probe prelevate în timpul operației de turnare în conformitate cu EN 14721.

(3) Cu cât zonele cu distribuții eterogene de fibre sunt mai numeroase, cu atât proprietățile betonului armat cu fibre sunt mai diferite fata de cele nominale.

(4) O atenție deosebită trebuie acordată fenomenului de carbonatare, în special atunci când se utilizează o matrice compusă din mortar și fibre metalice.

3. Plastic shrinkage and plastic cracking

It is recognised that plastic shrinkage and cracking are related to bleeding and/or autogenous/chemical shrinkage.

4. Consistence

The addition of fibres to concrete may reduce the slump and/or increase the cohesiveness of the mix. This has to be compensated for by either the use of plasticisers or by adjusting the mix proportions. However, the cohesive appearance of some fibre concretes can be misleading and it may not be necessary to compensate for this apparent low consistence. If fibres are added at the plant under the responsibility of the concrete producer, the end-consistence (at site) requested by the contractor must be provided by the producer. If fibres are added at the job-site by the concrete producer a loss of consistence is likely, and the producer must allow for this in mix design and in batching. In both situations the producer is responsible for the concrete properties and is required to show conformity of the concrete on delivery.

5. Pumpability

Pumping fibre concrete does not require special equipment. However, it is useful to have a vibrator on the grid of the pump.

Concrete containing short fibres of any type will not cause problems. However, longer steel or macro-polymer fibres with an aspect ratio of more than about 60 may require careful attention to mix design, particularly at high dosages (typically, more than 25 kg/m³ of steel fibres, or more than 10 kg/m³ of macro-polymer fibres). This is very much dependent on the type of fibre being used and the fibre supplier should be able to advise on these aspects. It is recommended that the diameter of the pump pipeline should not be less than one and a half times the length of the fibres used for steel fibres but can be smaller for macro-polymer fibres as they exhibit some flexibility in the pipeline.

6. Conținutul de aer

Adăugarea fibrelor poate influența conținutul de aer al oricărui beton. Standardele europene nu menționează acest lucru. Utilizarea fibrelor împreună cu a plastifianților, poate crește conținutul de aer al betonului.

7. Separarea apei

Adăugarea fibrelor are un efect redus asupra vitezei de separare a apei, dar adaugarea fibrelor poate reduce semnificativ atât rata, cât și volumul sângerării.

8. Contracția plastică și fisurarea plastica

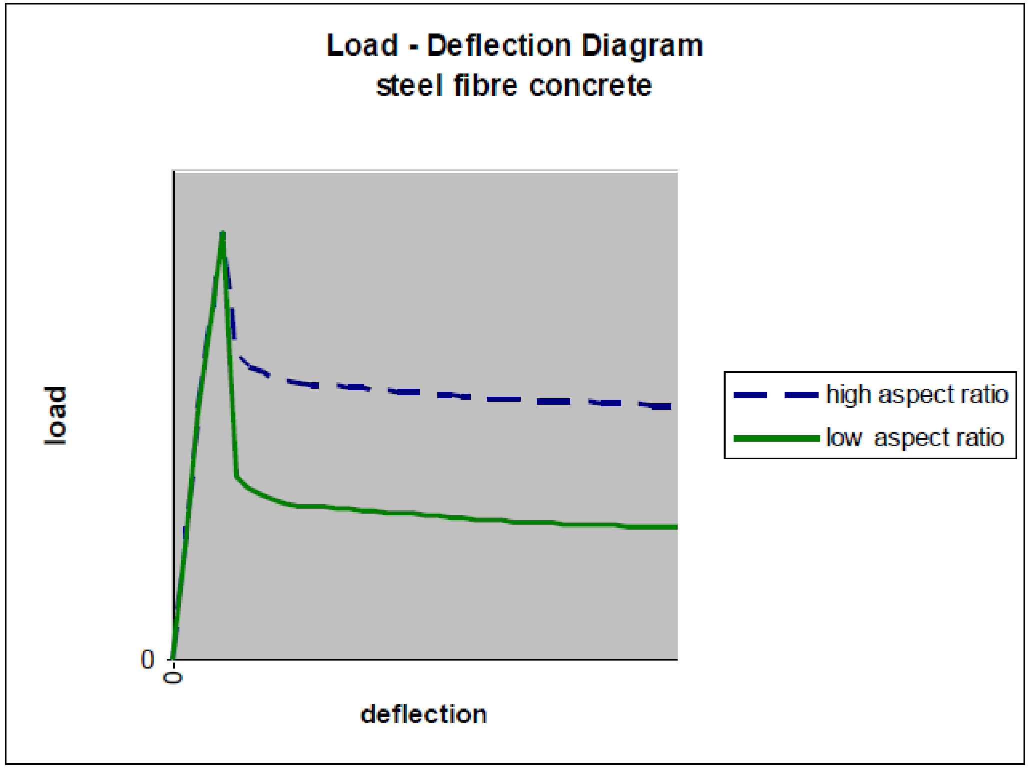
Se recunoaște că contracția și fisurarea plastica sunt legate de separarea apei și / sau contracție autogenă / chimică. Prin urmare, fibrele metalice si cele macropolimerice in general au o influență mică.

IV. Hardened properties of fibre concrete

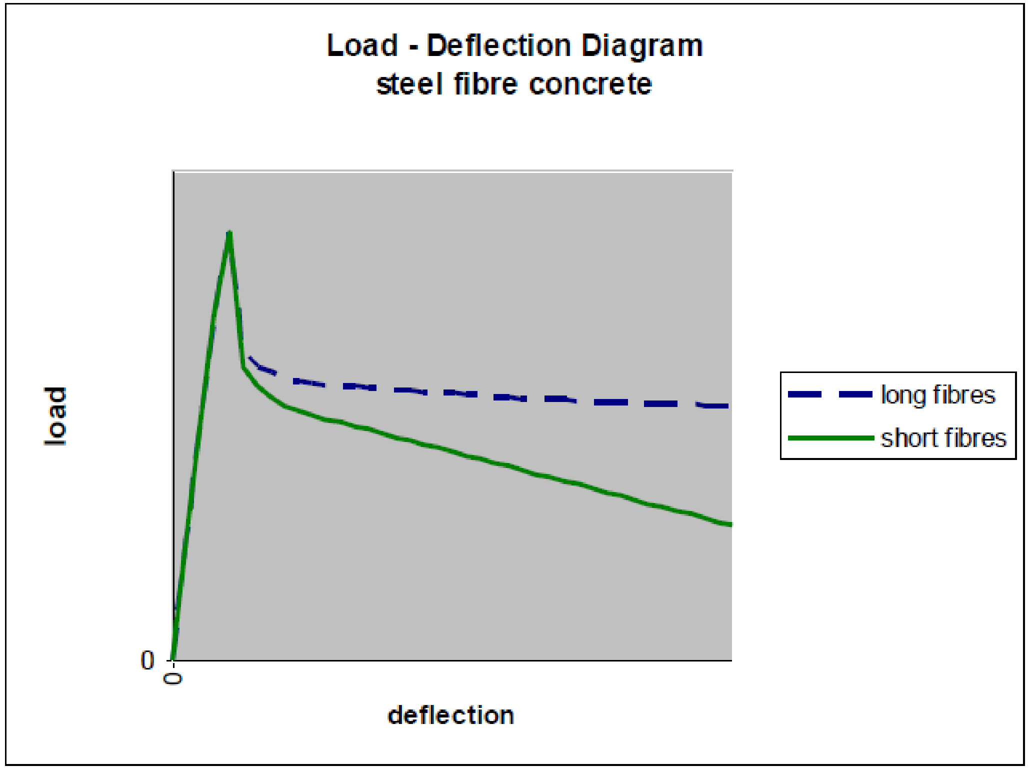
1. General

Fibres are mainly added to influence the hardened concrete properties. Many of the hardened properties which are affected are rarely specified, and are unlikely to be familiar to ready-mixed concrete producers. **Steel and macro-Polymer fibres** significantly affect hardened properties in the following ways:

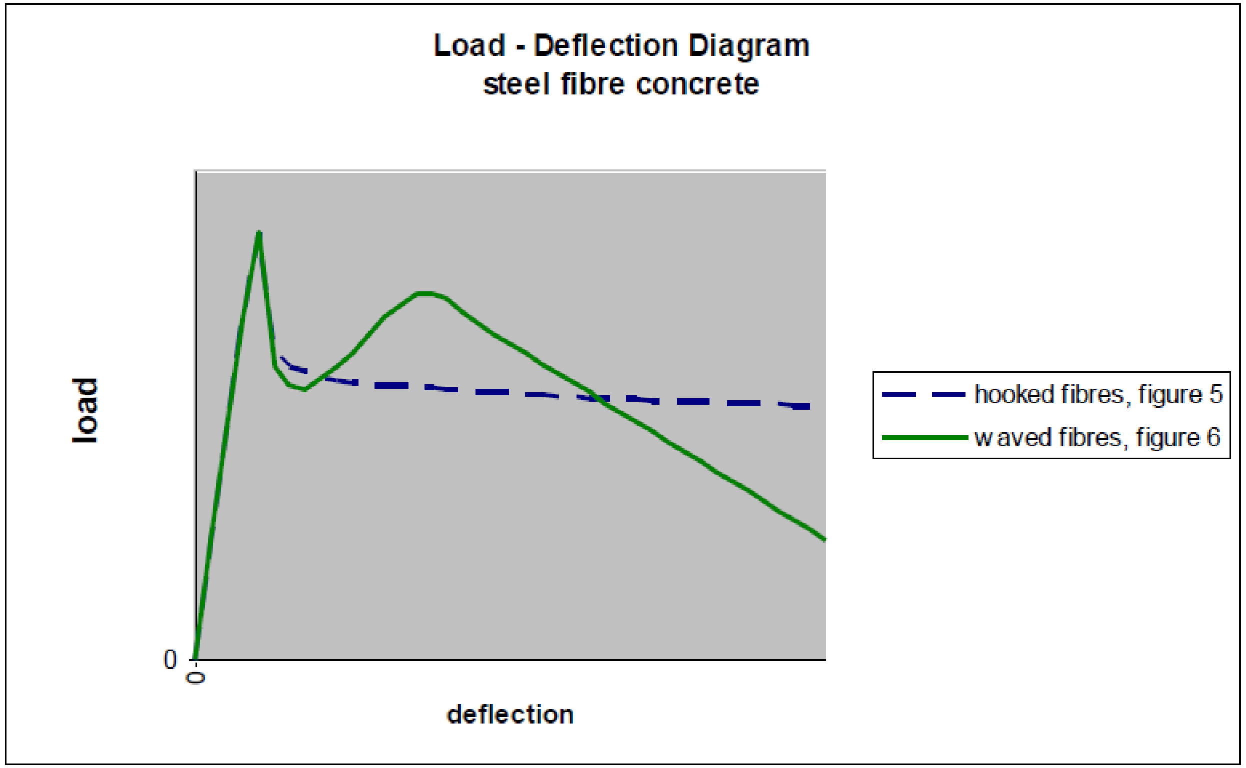
- increased post-crack flexural tensile strength;
- increased shear strength;
- increased impact resistance;
- reduced crack widths (Design in Serviceability Limit State);
- increased fatigue resistance.



Post-crack flexural tensile strength of concrete with fibres of different aspect ratios, the same length and the same fibre content (kg/m³).



Post-crack flexural tensile strength of concrete with fibres of different length, the same aspect ratio and the same fibre content.



Post-crack flexural tensile strength of concrete with fibres of different designs and same fibre content.

Compressive strength

The addition of fibers does not usually affect the compressive strength, unless the air content is increased.Fibers generally reduce the brittleness of the matrix, but have no significant effect on the compressive strength. In practice, the constitutive law of fiber-reinforced concrete can be considered similar to that of ordinary concrete.

Post-crack axial tensile strength

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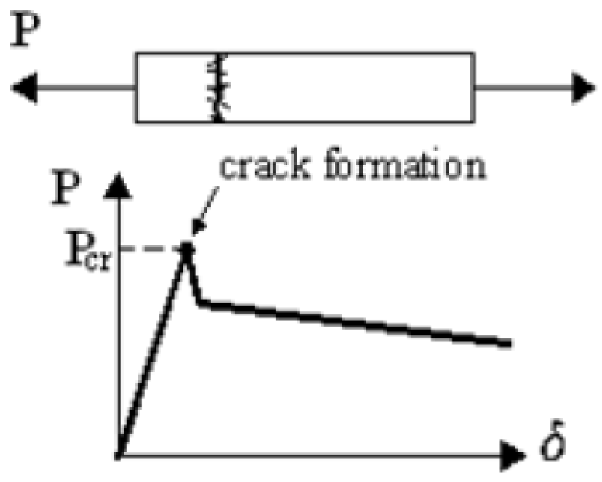


As a uniaxial tensile test is difficult to perform, tensile strength is usually tested indirectly by bending, and axial tensile strength can be calculated from the post-cracking flexural tensile strength by applying conversion factors.

Fire resistance

The fire resistance of concrete structures is generally considered not to be influenced by the addition of steel fibres, though the fibres may reduce the degree of spalling somewhat by bridging areas of spalled concrete.

Specimens after testing for fire resistance according to on the left a specimen with micro-fibres, on the right a specimen without fibres.

Impact resistance

Impact resistance, ductility and toughness are generally increased by the addition of any fibres. When impact resistance is required, design is usually determined by testing and then the concrete is specified by type and fibre content.

Shear resistance

The addition of steel fibres to concrete will enhance the shear resistance of structural elements. A ductile failure mode is induced, in the same way as by the use of reinforcement stirrups. A number of standards and guidelines contain an equation describing the effect of steel fibres as equivalent shear reinforcement.

Durability

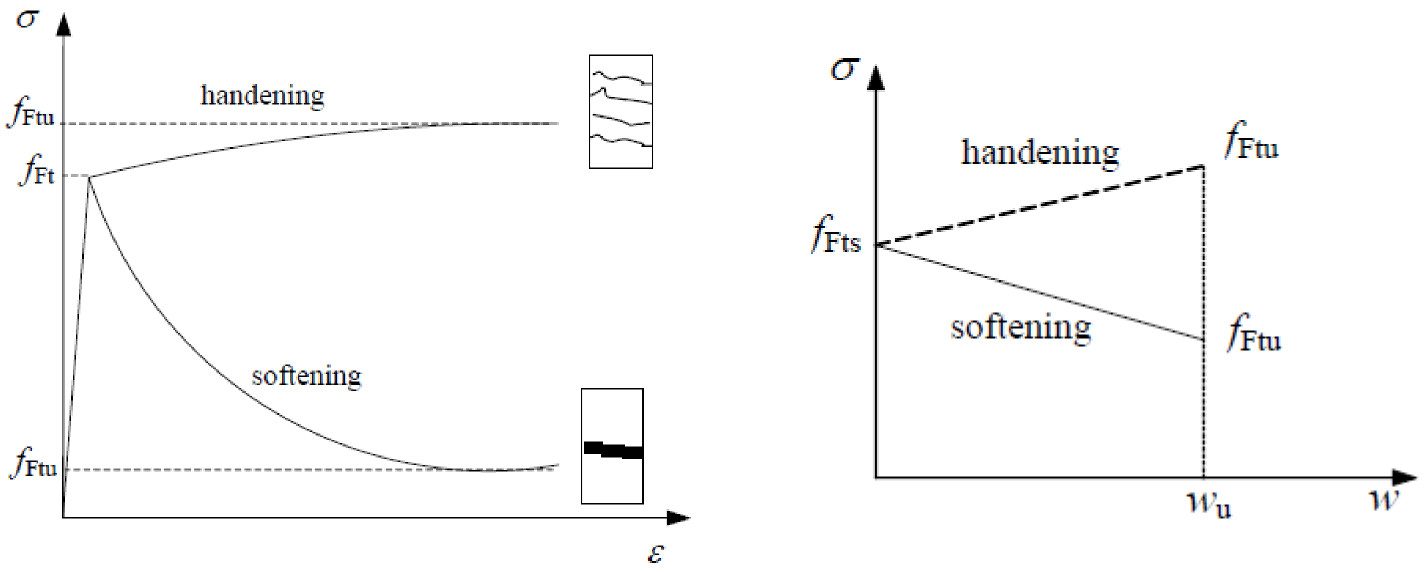
While steel fibres may reduce the risk of spalling due to corrosion of reinforcement, they do not reduce the rate of corrosion or the rate of loss of cross section.

Corrosion of steel fibres themselves at the surface does not cause any spalling. Designers should consider the use of steel fibres in potentially corrosive conditions if the fibres near to the surface contribute to structural performance.

2. Mechanical properties hardening state

Tensile behaviour

(1) Fibers improve the tensile behaviour of the cracked matrix.

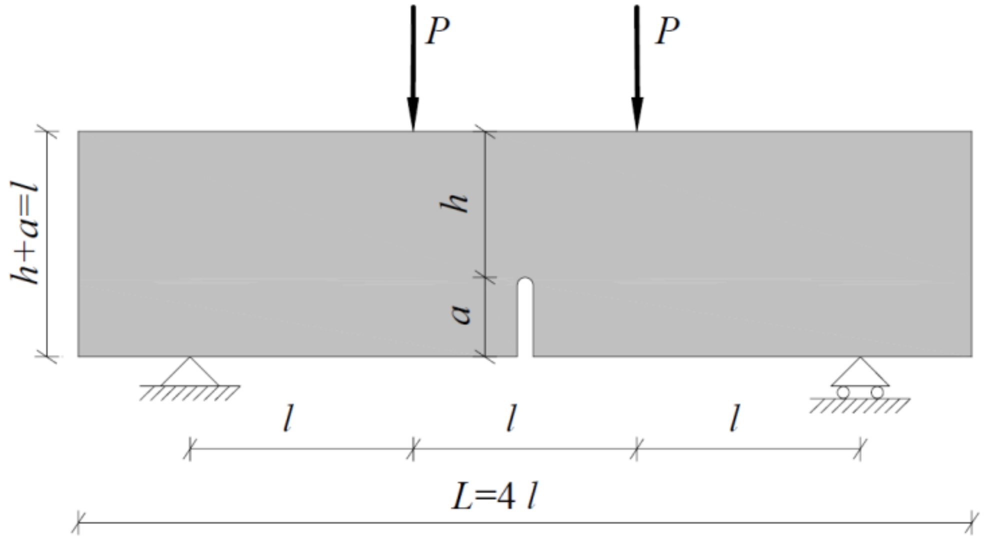


(2) For low fiber content (with volume fractions approx. lower than 2%), the behaviour is softening.
(3) For large fiber content (with volume fractions higher than 2%), the strength can be higher than the matrix one, since a hardening behaviour connected to multi-cracking phenomenon may Occur
(4) The uniaxial first crack tensile strength of fiber reinforced concrete, fFt, may be assumed equal to that of the matrix, $f$ct. For softening behaviour material, the strength, fFt, may be assumed equal to the maximum stress(.

(5) It is possible, through a performance approach, to experimentally identify the characteristic stress-strain curve by appropriate tests on reinforced concrete specimens.

The nominal stress-crack opening variation, σ_N-w, can be determined by uniaxial tension or bending tests.

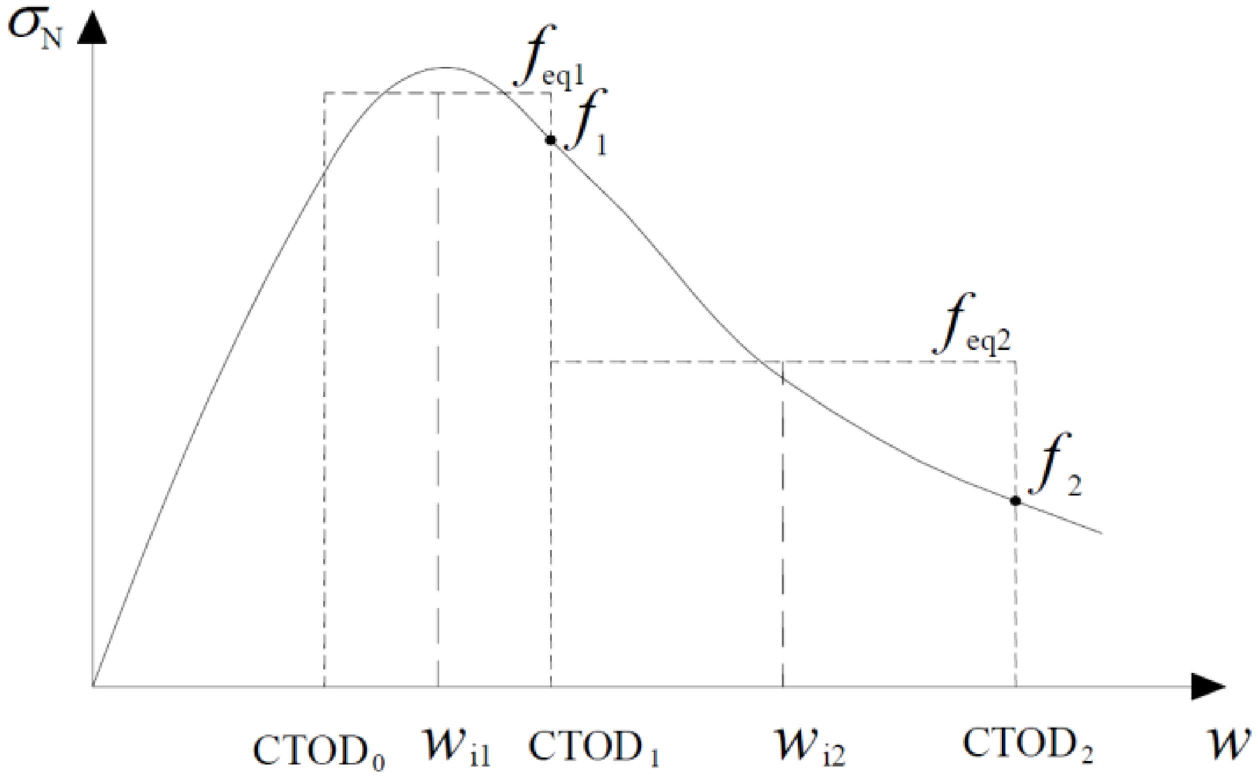
The uniaxial tension test directly provides the σ-w law and can be performed in accordance with specific regulations.



(6) The σ-w law, deduced from a bending test and carried out using the procedures, may be directly used to analyse structural elements subjected to bending.

For elements subjected to simple tension, the strength must be reduced through a coefficient equal to 0.7. When a notched specimen has a hardening behaviour resulting from a bending test, the test must be repeated on an un-notched specimen in order to verify the real ductility.

(7) The post-cracking strength may be defined on the basis of point values, *f*i, corresponding to specified nominal value of crack opening, or on mean values, *f*eqi, calculated for assigned intervals of crack opening. When a notched specimen is considered, the crack opening may be conventionally assumed equal to the displacement between two points at the notch tip, CTOD.



CMOD (mm)	**δ** (mm)
0,05	0,08
0,1	0,13
0,2	0,21
0,5	0,47
1,5	1,32
2,5	2,17
3,5	3,02
4,0	3,44

Relationship between *CMOD* and δ

V. PRODUCTION AND TRANSPORT OF FIBRE CONCRETE

Storage of fibres in concrete plant

The majority of fibre products supplied to the ready mixed concrete industry are pre-packed by the manufacturer. The fibres should be stored as specified by the manufacturer, and in a manner that prevents degradation of the packaging and the storage bags. It should be noted that some storage bags are water-soluble.

The instructions regarding packaging should be followed. Some manufacturers pack fibres in double bags, where the outer bag protects an inner water-soluble bag.

Batching of fibre concrete

Fibres can be added at the concrete plant or on site; different practices may be necessary in these two circumstances. The chosen procedure for adding the fibres influences the quality and performance of the concrete.

There are three primary objectives when batching fibre concrete:

- that the correct type and quantity of fibres are added;
- that the fibres are evenly distributed throughout the concrete: in particular, ‘balling’ of the fibres must be prevented;
- that the addition of fibres does not compromise other aspects of the specification of the concrete.

Addition of fibres at the plant

Addition of fibres at the plant under the responsibility of the concrete producer is the best way to ensure concrete quality. Fibres can be added directly into the truck mixer, or, to optimise dispersion, into the plant mixer. Many producers will have established their own batching procedures, but generally, the following advice is offered:

Where concrete is batched through a dry batch plant (i.e. truck mixing), for each bag of fibres, approximately 35 litres of water per m3 should be added to the truck mixer prior to the addition of the coarse aggregates and fibres. Mixing fibres with water only leads to balling. Ideally, one hundred revolutions of the mixer is required to ensure good fibre distribution, but in practice it is difficult to monitor this. More practically, therefore, a minimum mixing time of five minutes (or one minute per m^3) at the maximum speed of the drum is required.

For reasons of safety, many ready-mixed concrete suppliers do not permit operatives to access the platform at the back of the truck. In such cases it is necessary that a proper system for adding the fibres to the truck mixer be used. One possible solution is to add bags of fibres by means of a lance. Different automated or semi-automated systems exist.

Addition of fibres on job site

For a number of reasons e.g. health and safety or to ensure proper mixing and for general quality control considerations, many ready-mixed suppliers are unwilling to allow fibres to be added on the job site. (This is also prohibited by some national regulations e.g. in Germany). However, it is recognised that fibres *are* sometimes added to the concrete truck mixer at the construction site.

If fibres are added under the responsibility of the contractor (at the plant or on site) the responsibility for the concrete after adding the fibres has to be clearly declared in a written form.

Factory Production Control

Documented procedures should be available stating:

- storage systems for different types of fibres;
- identification of stored material;
- methods that are used to batch/dispense fibres;
- safety requirements for handling/ batching fibres;
- systems used to identify the requirements for the concrete;
- modifications to the concrete composition to enable the optimum properties of the fibre concrete to be achieved;
- systems that are in operation to ensure the correct type and dosage/mass of fibres are batched;
- methods used to ensure fibre are dispersed homogeneously within the mixed concrete;
- testing that is to be undertaken on fresh concrete;
- testing that is to be undertaken on the hardened concrete;
- test methods to be used;
- frequency of testing;
- system that is to be used to evaluate the conformity of the fibre concrete with the specification;
- records that should be maintained of production of fibre concrete.

VI. SPECIFIC PROBLEMS IN THE APPLICATION OF METAL FIBER REINFORCED CONCRETE

EFFECT OF METAL FIBERS ON THE WORKABILITY OF FRESH CONCRETE

1. Workability and rheology of concrete

2. Fiber blocking

3. Segregation

4. Fill capacity of the core

5. Other characteristics of fresh concrete that influence the workability of concrete

1. Workability and rheology of concrete

The workability of metal fiber reinforced concrete is characterized by the consistency of the concrete.

The consistency of concrete is used as a measure of the workability of concrete for conventional pouring. Metal fiber reinforced concrete is more difficult to vibrate, a higher consistency class is recommended than would normally be specified for conventional pouring concrete.

The rheology of self-compacting concrete is characterized by a low yield stress and a moderate plastic viscosity.

The rheology of self-compacting concrete reinforced with metal fibers is characterized in the same way as self-compacting concrete.

2. Fiber Blocking

Blocking occurs if the steel fibres are not able to pass the reinforcement. Blocking can result in honeycombing, poor distribution of fibres and poor surface quality. Based on experiments, a general rule of thumb is that the clear spacing perpendicular to the flow direction should be 2x higher than the length of the fibre. However, in some cases a lower ratio may be applied

3. Segregation

Segregation occurs when the liquid phase of the concrete is not able to transport the fibers and aggregate particles, it occurs in freshly poured concrete and is characterized by the separation of the mortar from larger aggregates in the mixture, by the separation of water or by the separation of aggregates and fibers.

Formwork filling capacity

The formwork filling capacity of self-compacting concrete reinforced with metal fibers depends mainly on the yield stress.

Other characteristics of fresh concrete that influence the placement of concrete:

Plastic viscosity regulates the flow and adhesion of concrete. A high plastic viscosity makes the concrete flow slowly and become adherent.

The yield stress expresses how far the concrete is able to flow. The yield stress is inversely proportional to the flow of concrete, a high yield stress leads to slower flow and vice versa.

4. Measurement methods

To measure the yield stress and plastic viscosity of self-compacting concrete reinforced with metal fibers, it is recommended to use a specific equipment, rheometer, for example the 4C-Rheomete.

The 4C-Rheomete

It is a system for the automatic determination of the yield stress and plastic viscosity of self-compacting concrete.

The system is equipped with a calculator (PC) that automatically tests the flow of the concrete, where the flow curve (spread vs. time) is determined using the digital analysis that appears on the screen.

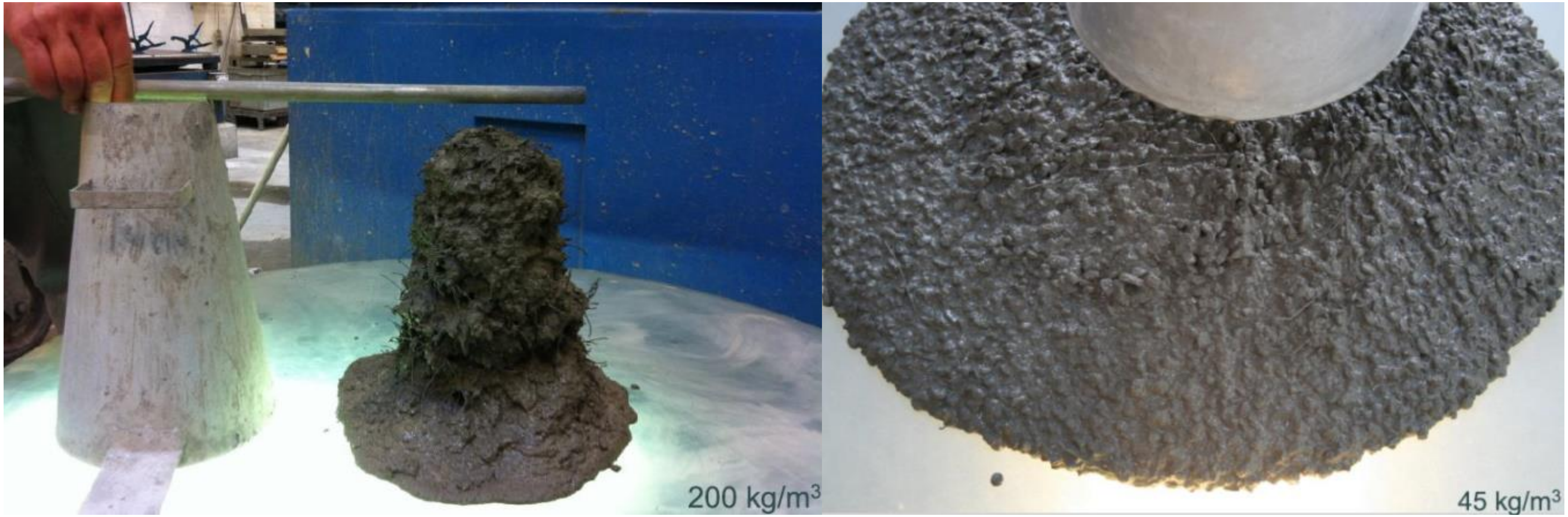
The 4C-Rheomete

5. Workability

Regarding self-compacting concrete, it is recommended to use the L-BOX device to measure the workability of self-compacting concrete reinforced with metal fibers. It is not recommended to use the V-funnel testing device because there is a risk of blockage.

It is recommended to evaluate the blockage by a sample of the concrete used for pouring.

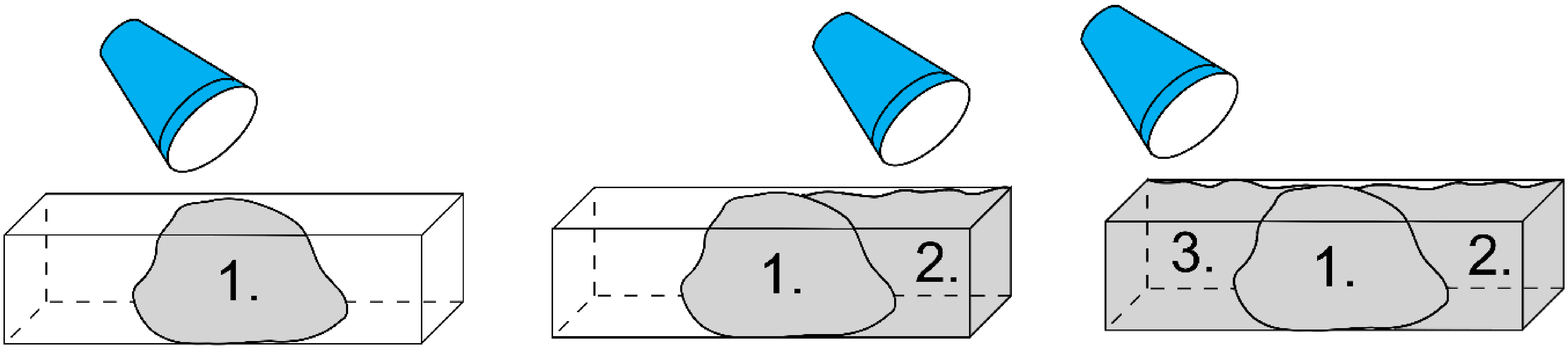
The L-box concrete testing apparatus is used to determine the fluidity, blockage and segregation of concrete, and consists of a funnel tube and frame.



The difference in workability is observed depending on the fiber dosage.

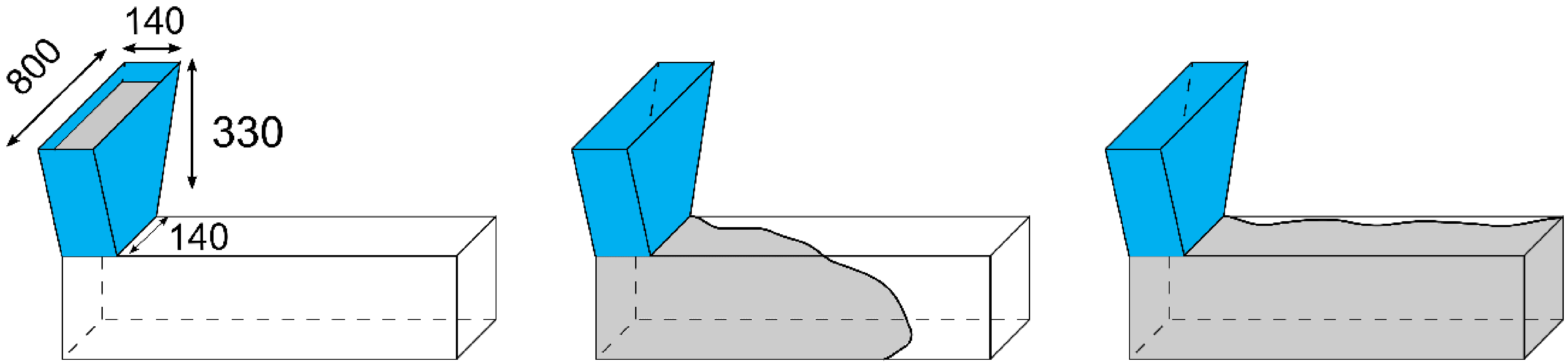
Specific determinations for fresh concrete reinforced with metal fibers
Fiber orientation

Standard prisms are beams that are used to determine the performance classes of metal fiber reinforced concrete and have dimensions (550 x 150 x 150 mm.).



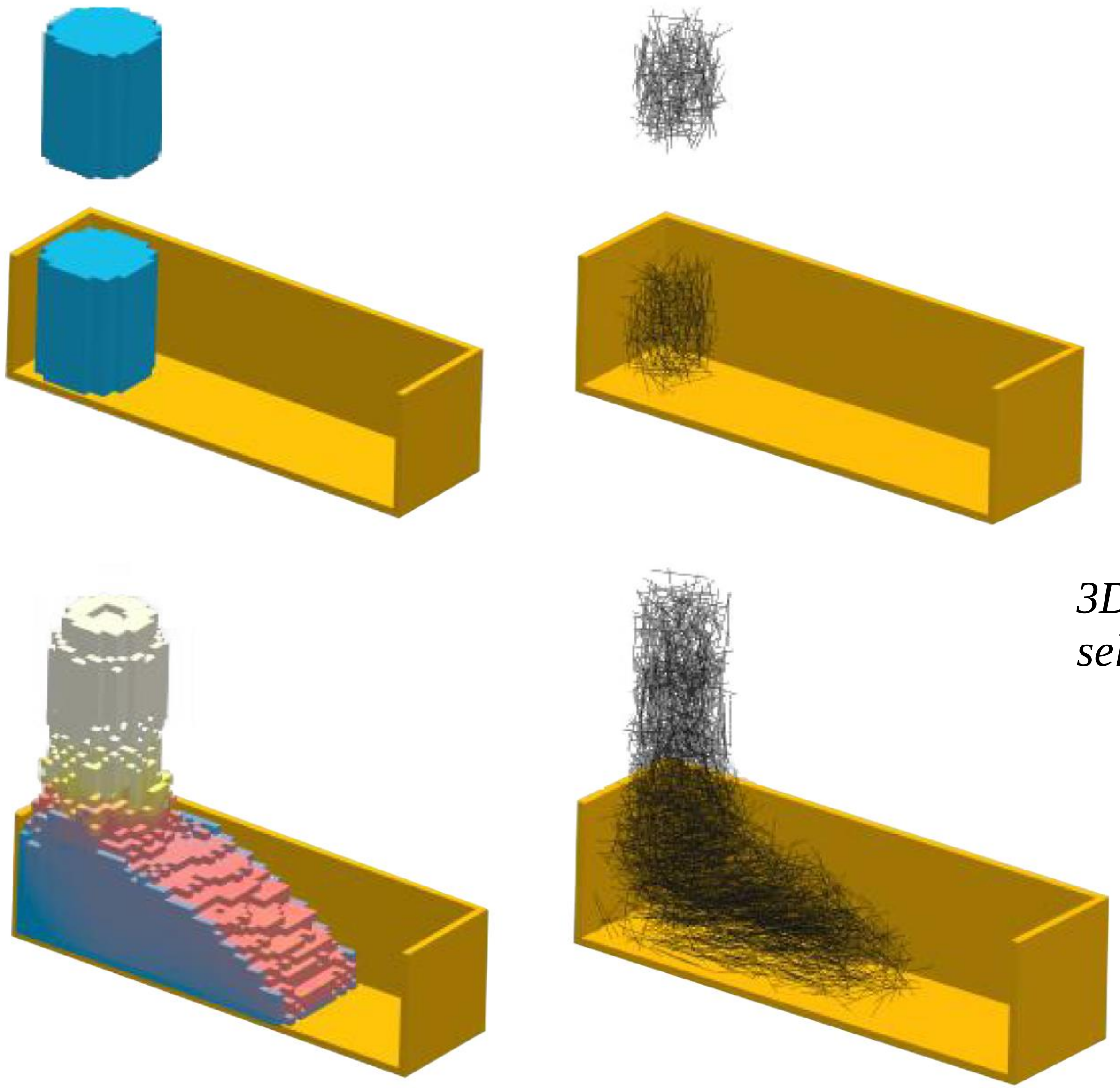
Betonul autocompactant aramt cu fibre metalice

Betonul autocompactant curege singur ,prin urmare, nu există niciun motiv pentru a turna betonul în trei poziții diferite sau nu necesită vibrare.







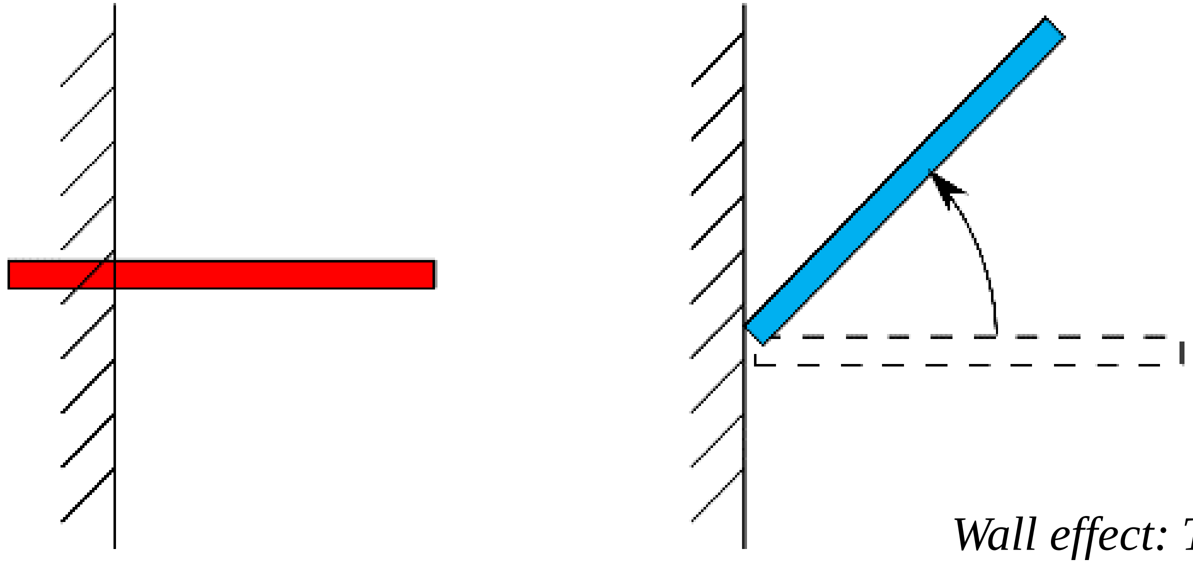


3D views of the initial and intermediate stages of self-compacting concrete reinforced with metal fibers

VII. Fiber Orientation

The orientation of metal fibers in metal fiber reinforced concrete comes from a combination of several basic phenomena, the most important of which is called the wall effect.

The wall effect is caused by the interaction between the immersed metal fibers and the surrounding rigid obstacles (the formwork).



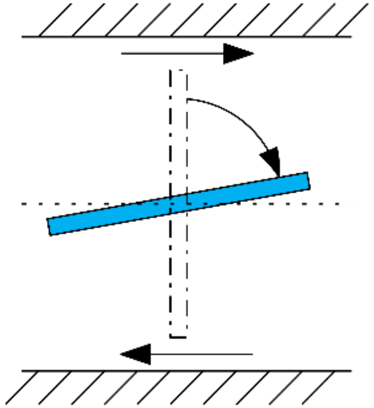
Wall effect: The blue and red bars represent the possible and impossible orientation of the rigid fiber.

Shear-induced orientation

Fibers orient themselves nearly parallel to the direction of shear flow, then remain in this position.

FIBER ORIENTATION CHARACTERIZATION

The most complete information about fiber orientation and distribution is obtained when tracking the position and orientation of each fiber.



Fibre orientation factor**(α_0)**

The results showed that the mechanical response of metal fiber reinforced concrete is mainly influenced by the number of fibers in the crack plane, $\mathbf{N_f}$.

Fibre orientation factor $\boldsymbol{\alpha_0}$ is defined as $\boldsymbol{\alpha_0} = \mathbf{N_f\ A_f / (V_f\ A_c)}$ where $\mathbf{A_f}$ = fiber cross-sectional area, $\mathbf{V_f}$ = the ratio between fiber dosage and density and $\mathbf{A_c}$ is the area of the concrete.

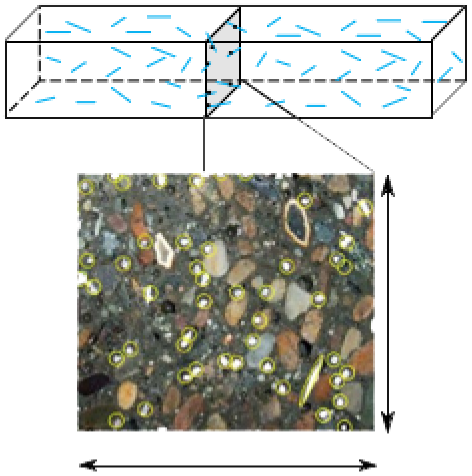
The fiber orientation factor represents the fiber orientation in the direction perpendicular to the specific plane.

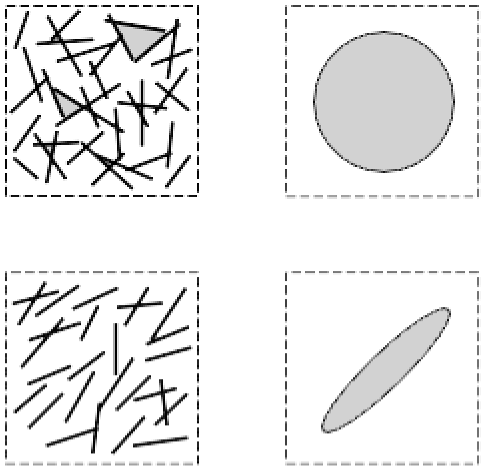
FIBER ORIENTATION SCALING FACTOR K_f^f

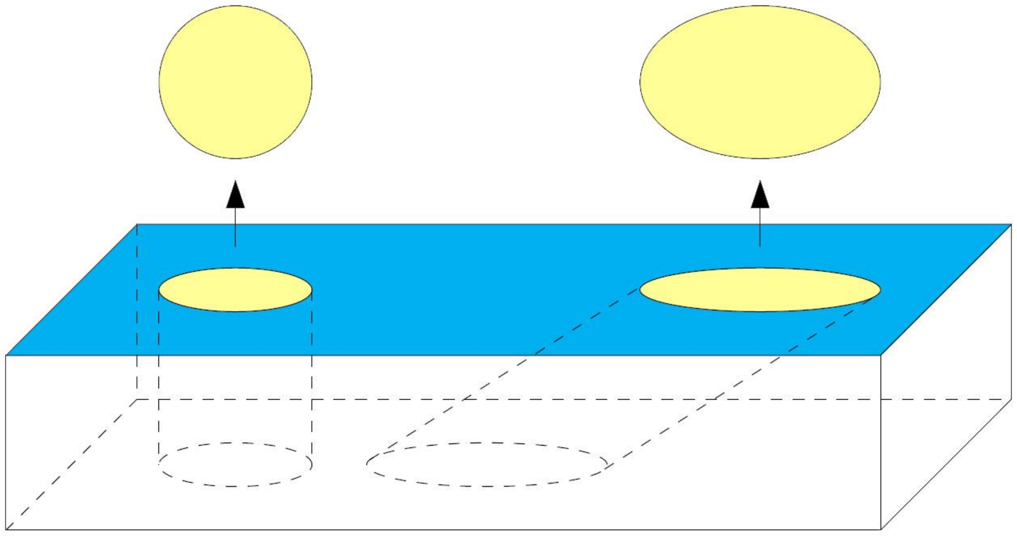
Fiber orientation scaling factor K_f^f used to modify the residual tensile strength from standard beam testing.

if $K_f^f = 1$, the fiber orientation in the element is the same as the fiber orientation in standard beams.

If the orientation factor α_0 is greater than the fiber orientation in standard beams, then $K_f^f > 1$ and vice versa.







Exemplu:

- number of fibres (N_f) = 180
- concrete area(A_c) = 1 50*1 50 = 22500 mm2
- fibre length(L_f) = 60 mm
- fibre aspect ratio(Ψ) = 80
- fibre density(ρ_f) = 7800 kg/m3
- fibre dosage(M_f) = 40 kg/m3
- fibre volume fraction(V_f) = Mf / ρf ≈ 0. 5%
- fibre radius (r_f) = L_f / Ψ / 2 = 0. 375 mm
- fibre area(A_f) = πr_f^2 = 0. 44 mm^2

Fibre orientation factor $\alpha_0 = N_f A_f / (V_f A_c)$ = **<u>0.70</u>**

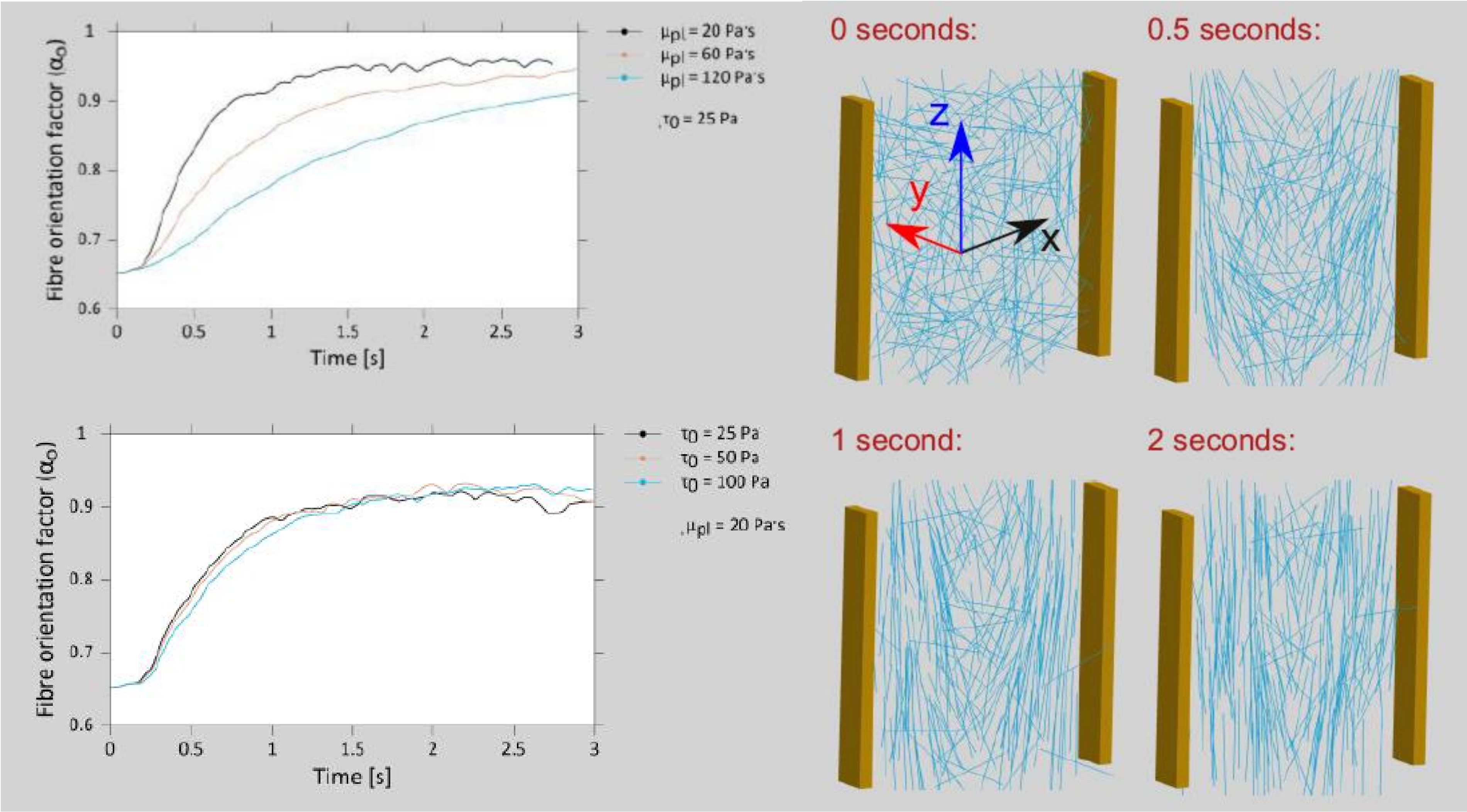
Fibre orientation factor $K_f^f = \alpha_0 / 0.60$ = **1.17** (The value of the reference fiber orientation factor was considered to be 0.60)

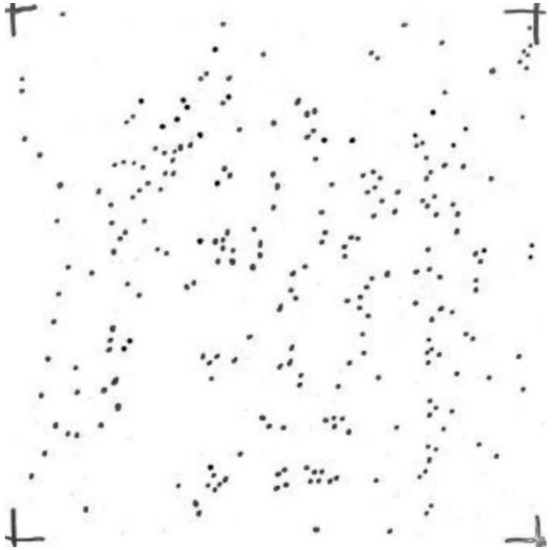
FACTORS THAT INFLUENCE FIBER ORIENTATION

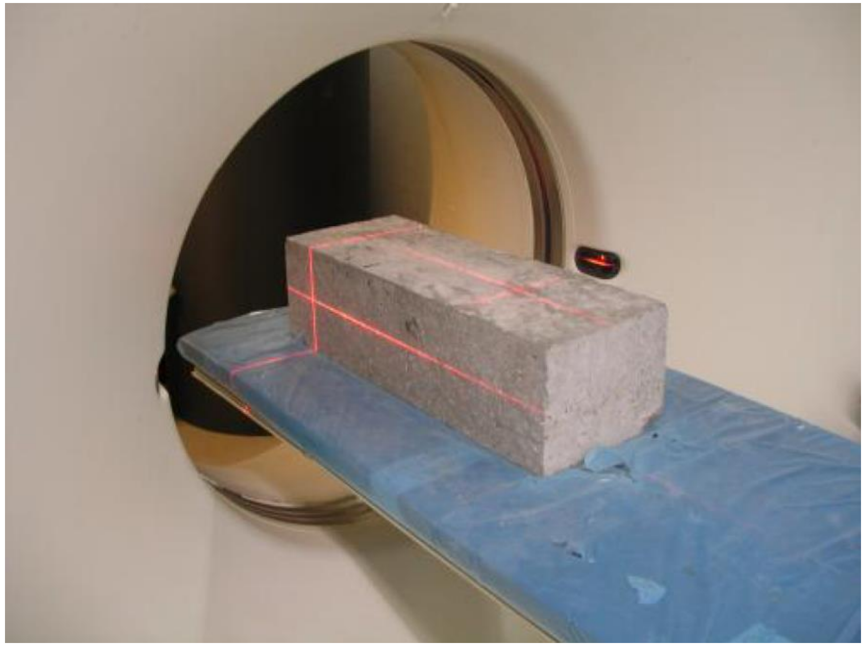
- Formwork geometry and surface
- Reinforcement orientation
- Casting process
- Rheology
- Fiber type and dosage
- Formwork surface
- Variations in plastic viscosity in the range of 25 – 100 kg/m.s (Pa.s) do not have a profound impact on the resulting fiber orientation.
- Yield stress variations in the range of 20 – 100 Pa do not have a profound impact on the resulting fiber orientation.

This corresponds to a workability of approximately 520- 720 mm.

Fiber orientation factor α_0 in the Z direction as a function of time for given values of plastic viscosity (μpl) and yield stress (τ_0)



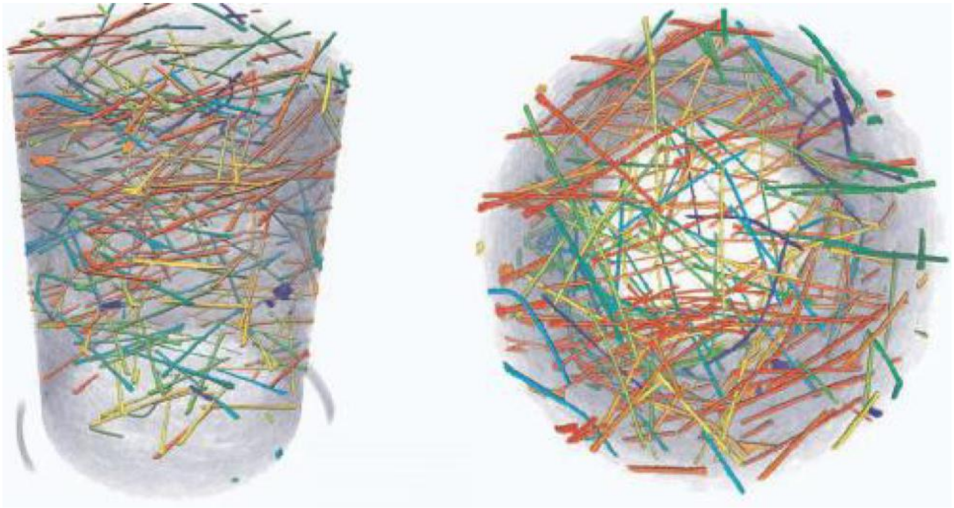




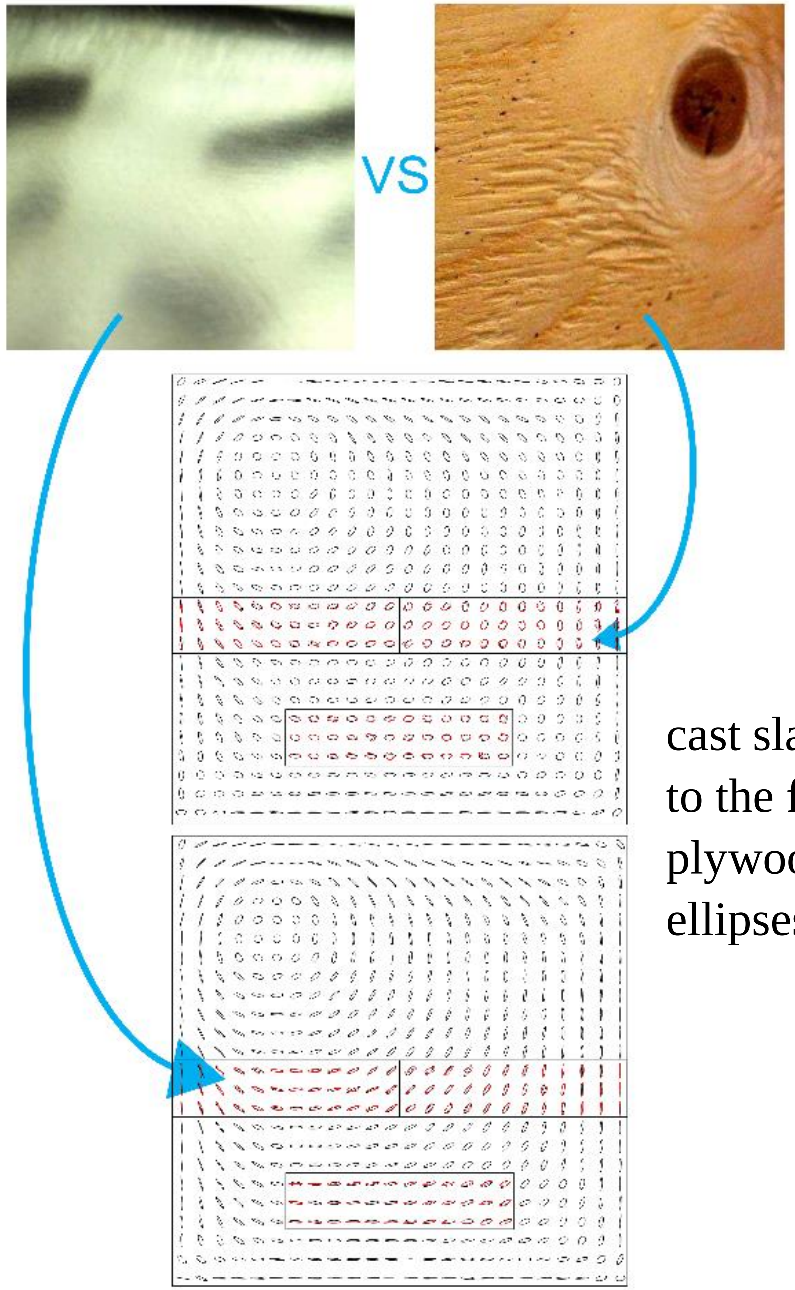
Scanarea CT a unei probe tăiate.

Manual counting process..

a) Cut sample.
b) Manual counting.
c) Scanned result.



Concrete core sample scanned by computed tomography and analyzed by image analysis



cast slabs - effect of the formwork surface on the fiber orientation close to the formwork (left: glued-laminated plywood, right: regular plywood). Bottom: top view of the slabs - the respective orientation ellipses (black = simulation, red = experiment).

Recommendations for fiber orientation

Casting self-compacting concrete reinforced with metal fibers can lead to significant fiber orientation, which can lead to significant variations in mechanical properties.

GENERAL RECOMMENDATIONS

It is recommended that fiber orientation factors be chosen carefully with regard to:

- Be suitable for the structural design (according to the project) and the safety level
- level of documentation and quality
- level of control of the casting process
- series control level
- the level of training and experience in the design and execution of self-compacting concrete reinforced with metal fibers.

Planning the casting process

The fiber orientation factors depend largely on the casting process.

It is recommended to prepare a casting plan that includes a clear description of the casting positions and casting rates. It is important to carry out the casting according to the casting plan.

Documentation

It is recommended to document the casting process, e.g. by means of sketches, videos and photos. The following documents must be checked for each delivery: Arrival time (transport time), recipe according to the required order, casting time, casting position, vehicle number.

Delivery control

It is recommended to carry out a delivery control on site, check the flow properties and fiber content (wash-out tests can be applied).

Training

Compared to traditional concrete, the use of self-compacting concrete reinforced with metal fibers and the fiber orientation concept require a stronger connection between design, testing and execution.

Experience

is important and it is preferable, if possible, for people who have previous experience in pouring and handling self-compacting concrete reinforced with metal fibers to be present during execution.

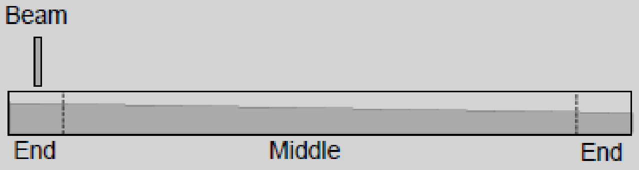
FACTORI DE ORIENTARE A FIBREI

Valorile K_f^f values (red) are calculated by dividing **α_0** with the reference fibre orientation factor. Here, a reference fibre orientation factor of 0,60.

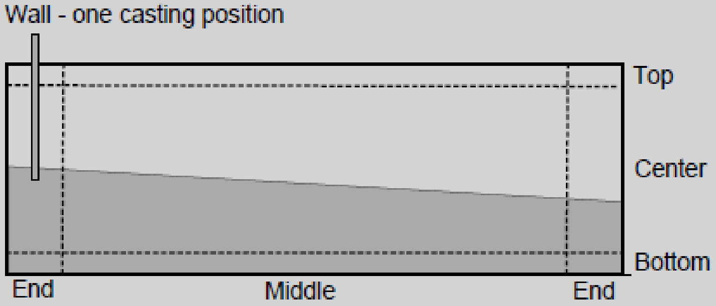
For comparison, the fiber orientation factors for metal fiber reinforced concrete, present in German standards, are shown (in black).

For walls, it is assumed that the inlet position is just below or just above the concrete surface. Thus, the values do not apply to fully submerged inlets like e.g. casting from the bottom.

Regarding shear, fibre orientation factors shall represent the strength in the direction normal to the 45 degrees inclined shear crack. The orientation of the shear crack due to a positive shear force is different from the orientation of a shear crack due to a negative shear force. The fibre orientation factors for shear cracks due to positive and negative shear force can be different and cannot be obtained by interpolation between the normal 0 and 90 degrees orientations. Therefore, for steel fibre reinforced selfcompacting concrete, no general recommendation for fibre orientation factors for shear can be given. They need to be assessed individually for each case.

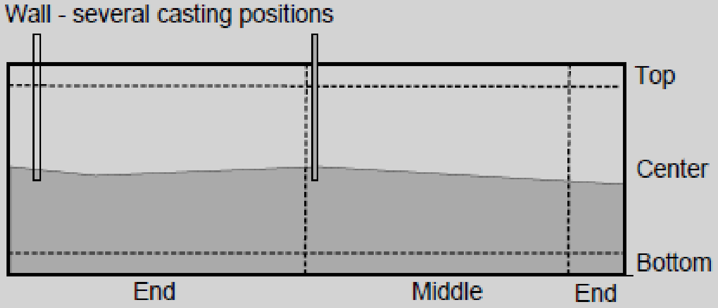


Beam	Steel fibre reinforced self-compacting concrete					
	Middle			End		
	Longitudinal	Vertical	Transverse	Longitudinal	Vertical	Transverse
α_o	0.75	0.20	0.20	0.45	0.25	0.25
κ_f^f	1.25	0.33	0.33	0.75	0.42	0.42
κ_f^f	0.50	0.50	0.50	0.50	0.50	0.50

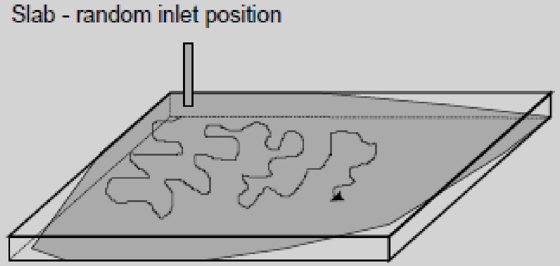


Wall-Bottom	Steel fibre reinforced self-compacting concrete					
	Middle			End		
	Longitudinal	Vertical	Transverse	Longitudinal	Vertical	Transverse
α_o	0.75	0.20	0.20	0.50	0.25	0.25
κ_f^f	1.25	0.33	0.33	0.83	0.42	0.42
κ_f^f	0.50	0.50	0.50	0.50	0.50	0.50

Wall-Center	Steel fibre reinforced self-compacting concrete					
	Middle			End		
	Longitudinal	Vertical	Transverse	Longitudinal	Vertical	Transverse
α_o	0.60	0.25	0.20	0.50	0.25	0.25
κ_f^f	1.00	0.42	0.33	0.83	0.42	0.42
κ_f^f	0.50	0.50	0.50	0.50	0.50	0.50



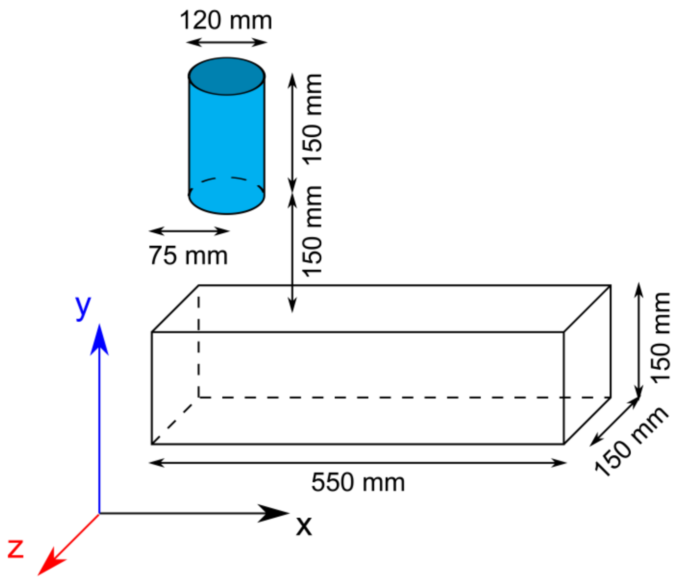
Wall-Top	Steel fibre reinforced self-compacting concrete					
	Middle			End		
	Longitudinal	Vertical	Transverse	Longitudinal	Vertical	Transverse
α_o	0.50	0.25	0.15	0.40	0.30	0.30
κ_f^f	0.83	0.42	0.25	0.67	0.50	0.50
κ_f^f	0.50	0.50	0.50	0.50	0.50	0.50



Slab	Steel fibre reinforced self-compacting concrete		
	Longitudinal	Vertical	Transverse
α_o	0.60	0.18	0.60
κ_f^f	1.00	0.30	1.00
κ_f^f	1.00	0.50	1.00

Summary of fibre orientation factors for beams, walls and slabs.

Examples of fiber orientation



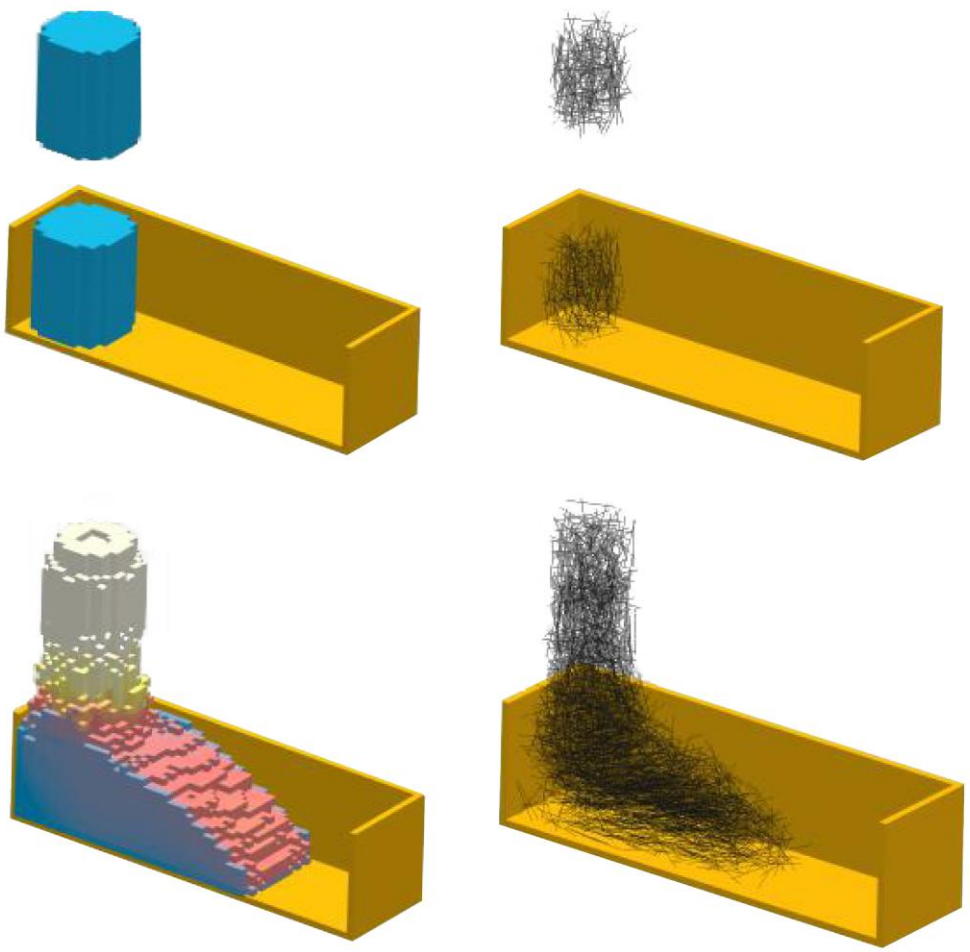
Standard beam for testing

Standard Beam-Simulation

Effect of Rheology on Fiber Orientation

The effect of plastic viscosity and yield stress on fiber orientation factors was investigated.

The standard size beam (550 x 150 x 150 mm) was poured with unreinforced self-compacting concrete reinforced with metal fibers, the concrete density was set to 2500 kg/m3, Fiber length =60 mm, aspect ratio = 80 and fiber content = 40kg/m3 of fibers.



3D views of the initial and intermediate stages of self-compacting concrete reinforced with metal fibers, Left side is self-compacting concrete and right side is metal fibers. The colors of the self-compacting concrete represent the flow rate (blue = low, white = high).

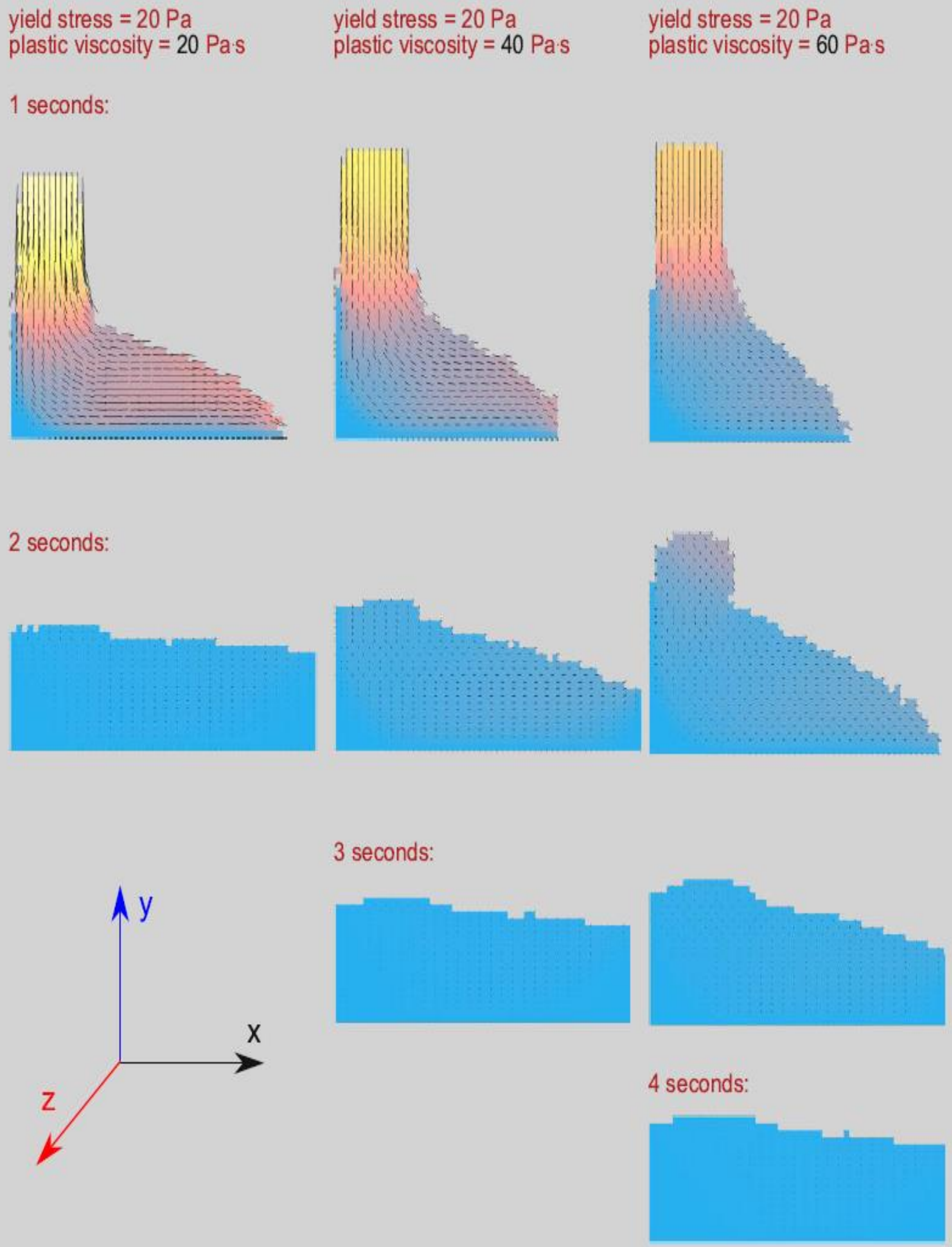


Figure 7.5: Side views of SFRSCC during casting of a standard beam. Each column represents a different plastic viscosity. Each row represents a different time step. The colour represents the flow rate of (blue = low, yellow = high). Black lines represent direction of the flow velocity.

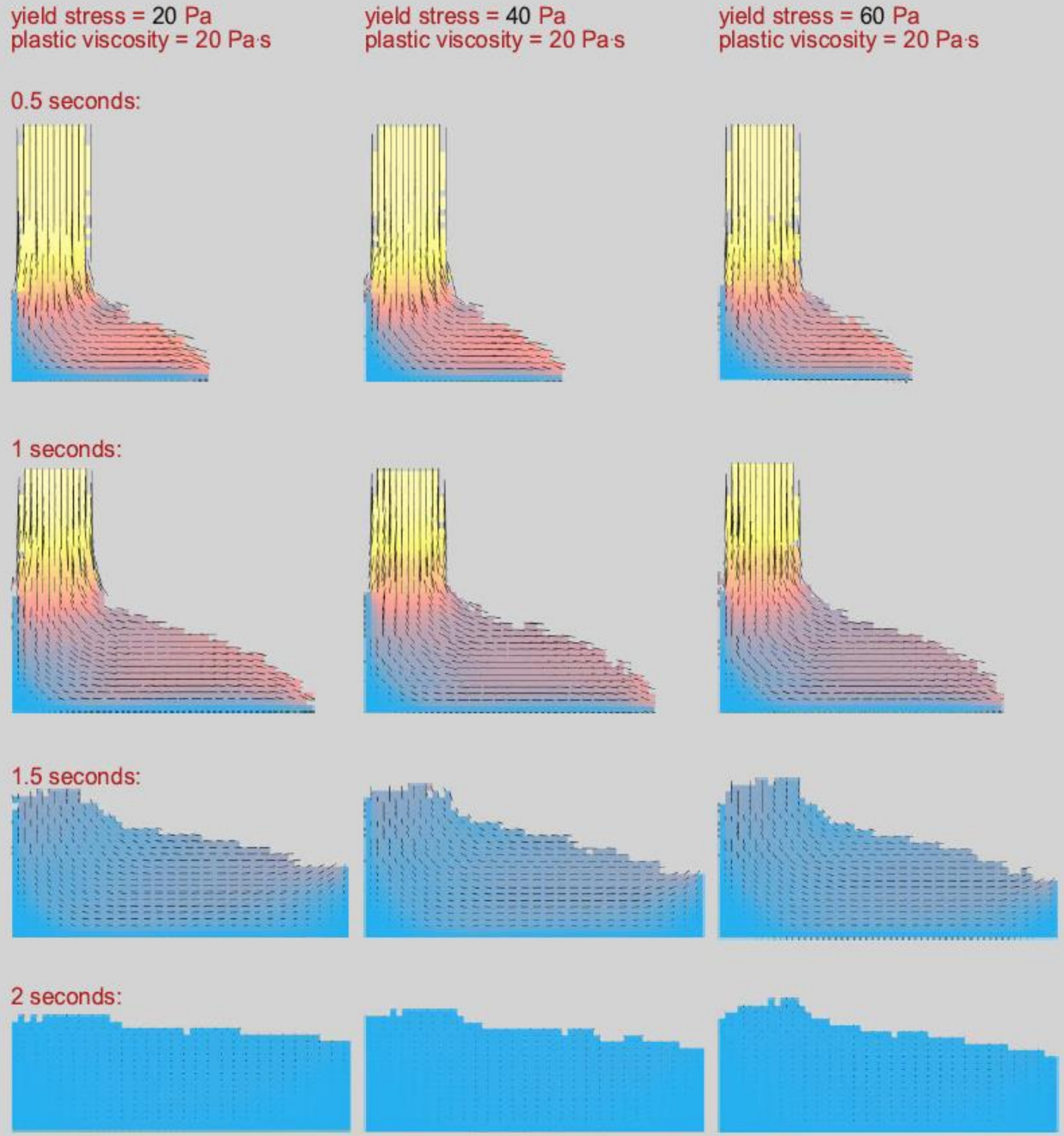
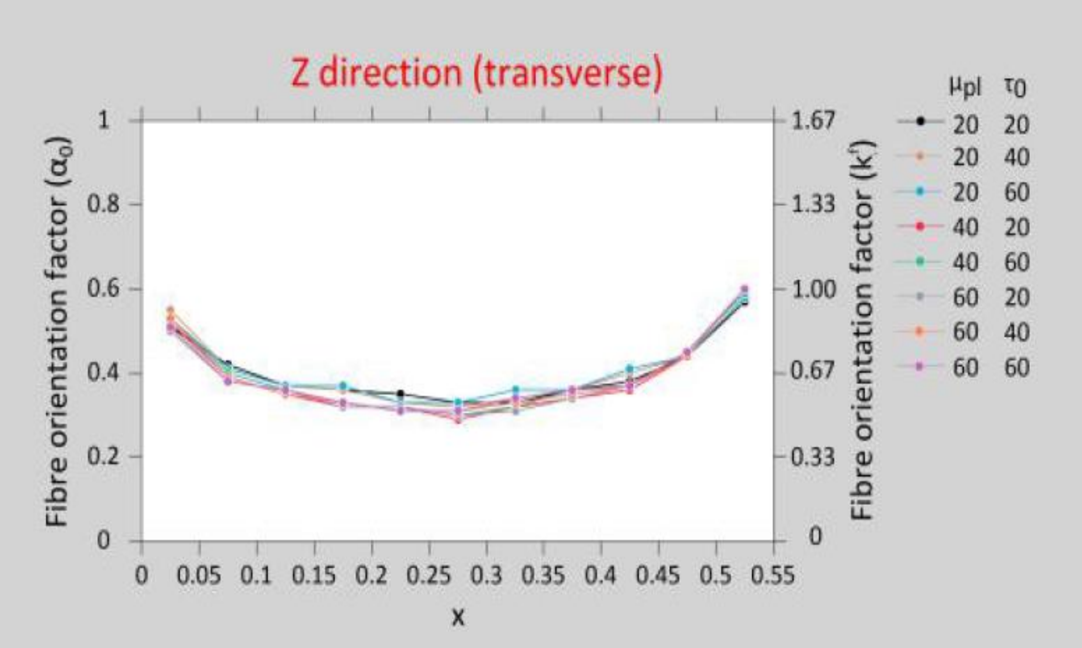
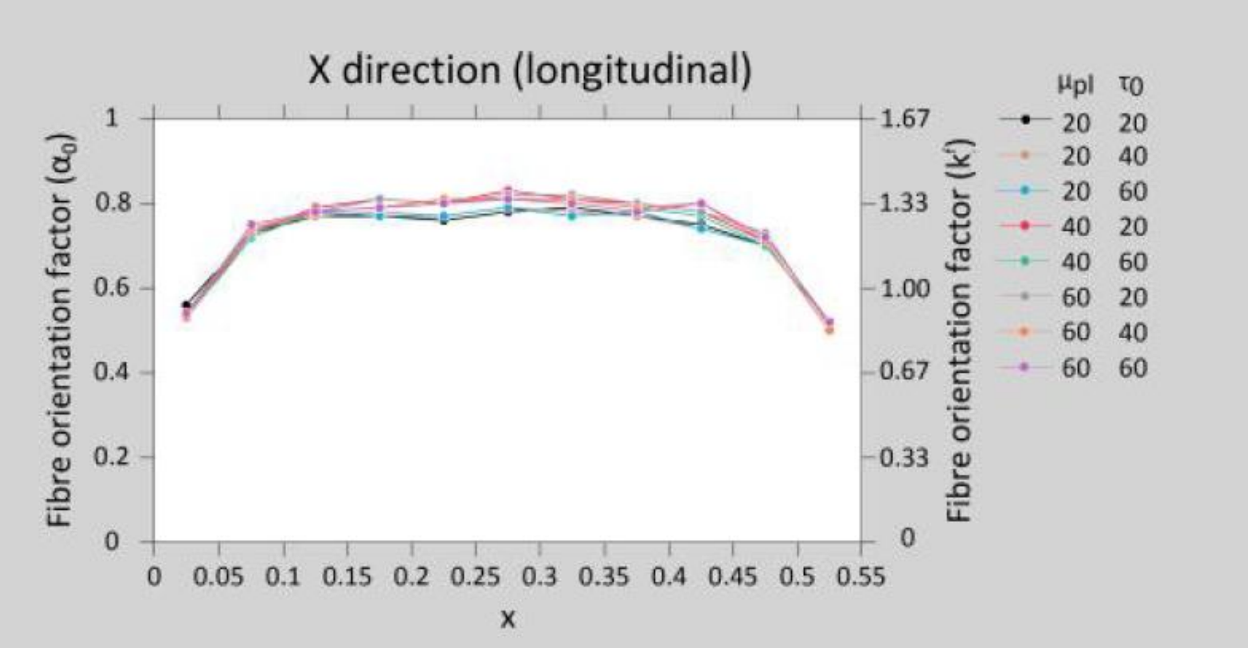


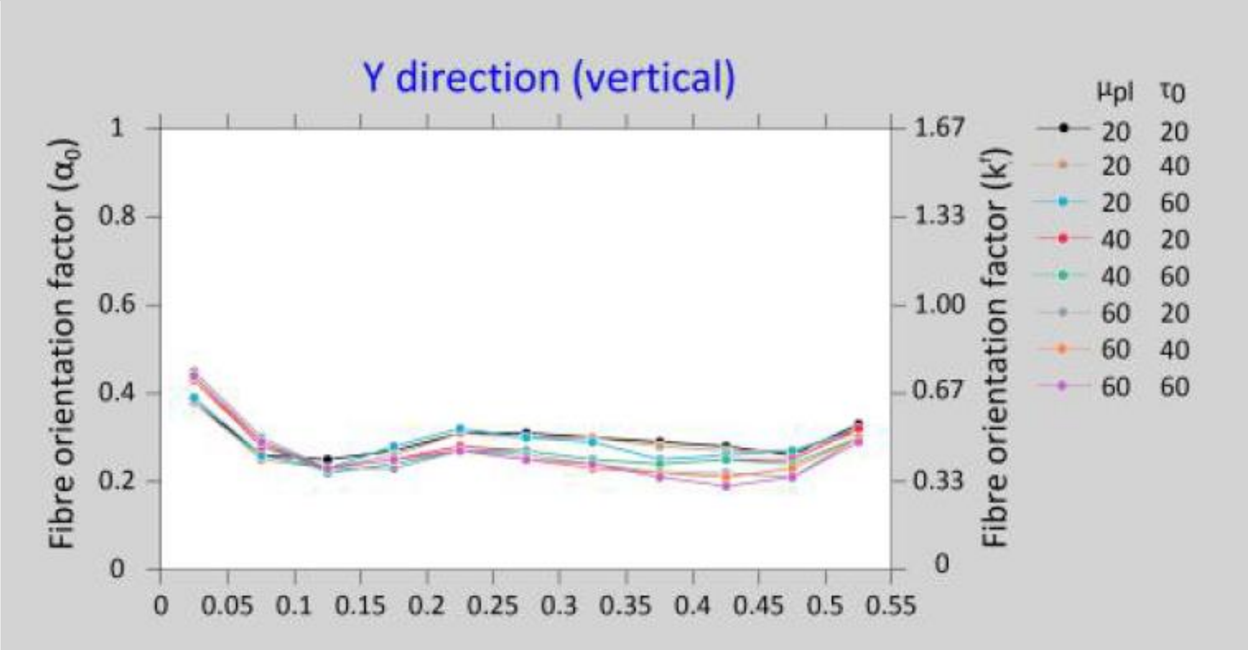
Figure 7.6: Side views of SFRSCC during casting of a standard beam. Each column represents a different yield stress. Each row represents a different time step. The colour represents the flow rate (blue = low, yellow = high). Black lines represent direction of the flow velocity.



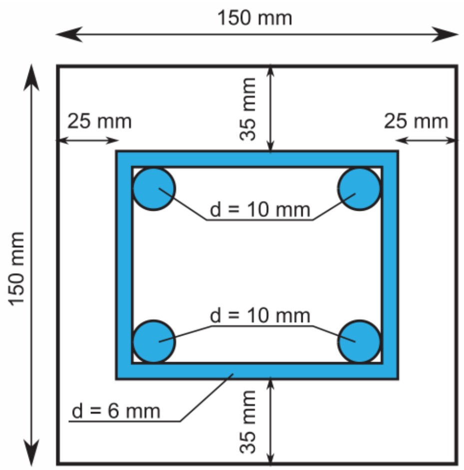


Fibre orientation factors in the X, Yand Z direction as a function of the longitudinal position, X. Standard beams

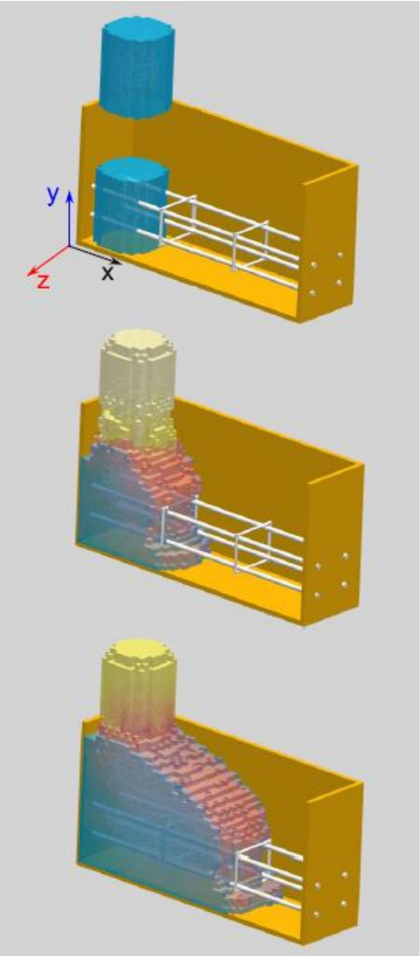
cast with Steel Fiber Reinforced Self-Compacting Concrete with different rheological properties.



Effect of reinforcement on fiber orientation



There are two equally spaced stirrups in the beam specimen.

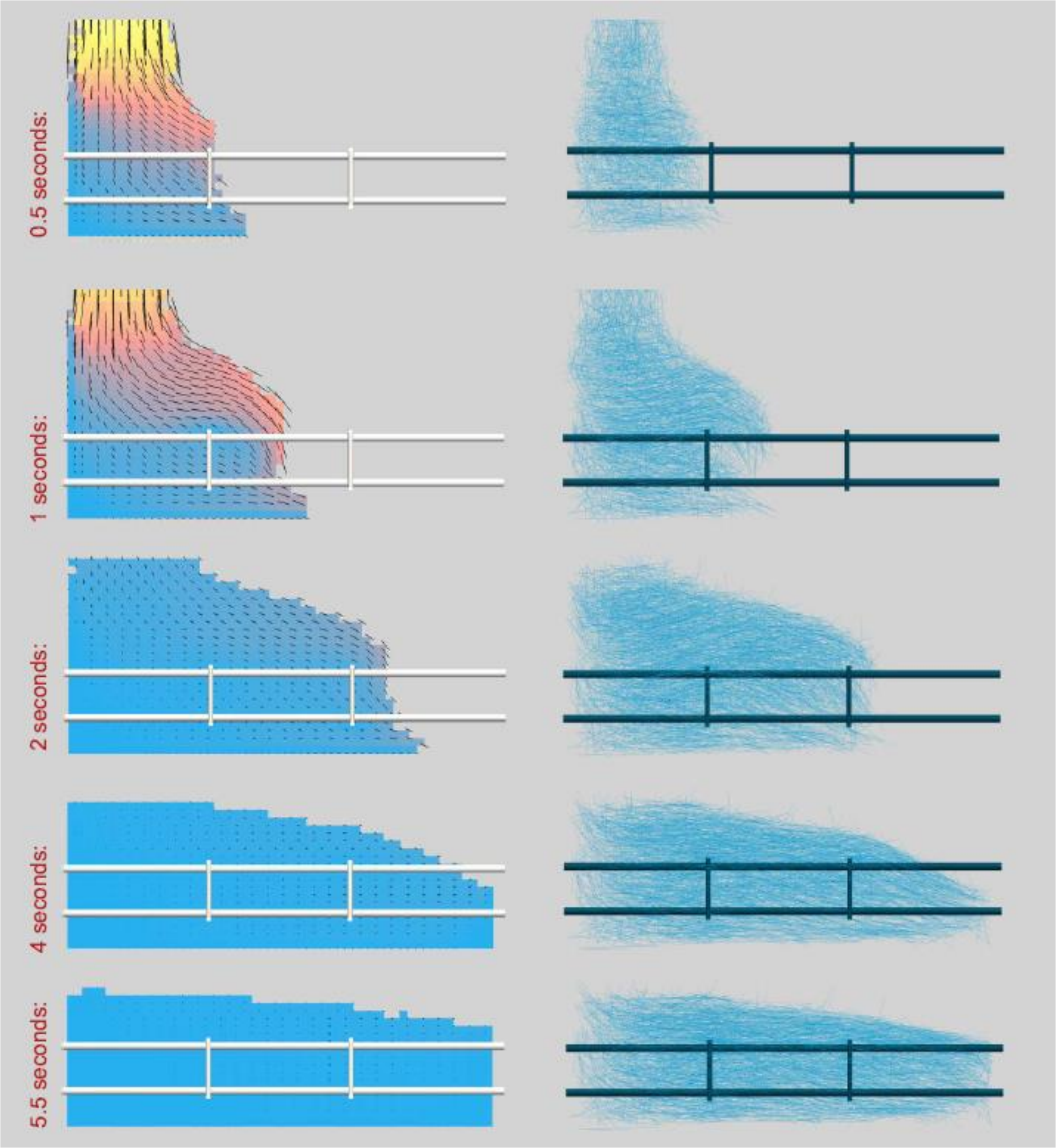


Effect of reinforcement on fibre orientation

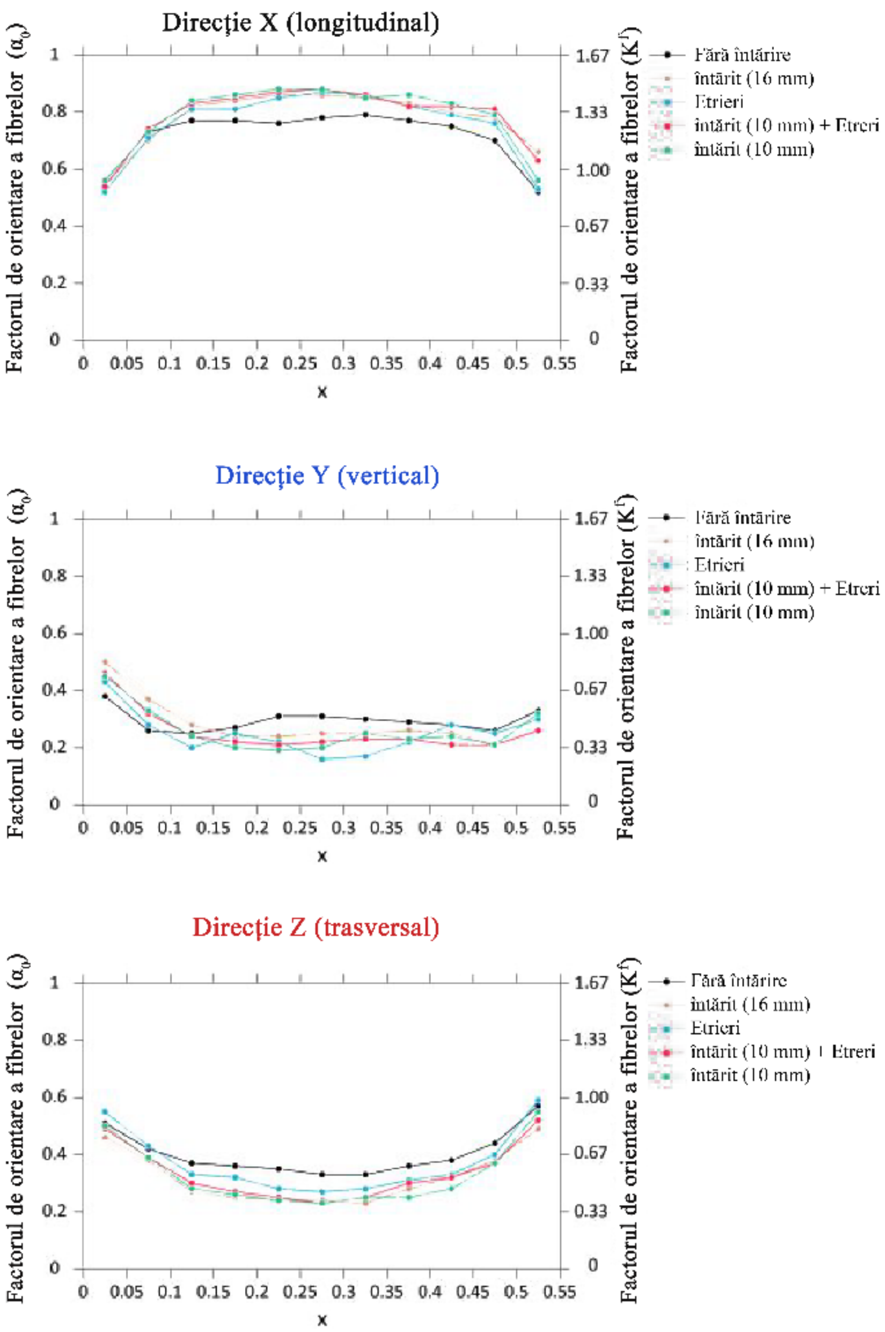
The effect of reinforcement on the fibre orientation factors was investigated. The five different setups were:

- without any reinforcement
- stirrups only
- main longitudinal reinforcement of diameter = 16 mm
- main longitudinal reinforcement of diameter = 10 mm
- main longitudinal reinforcement of diameter = 10 mm and stirrups

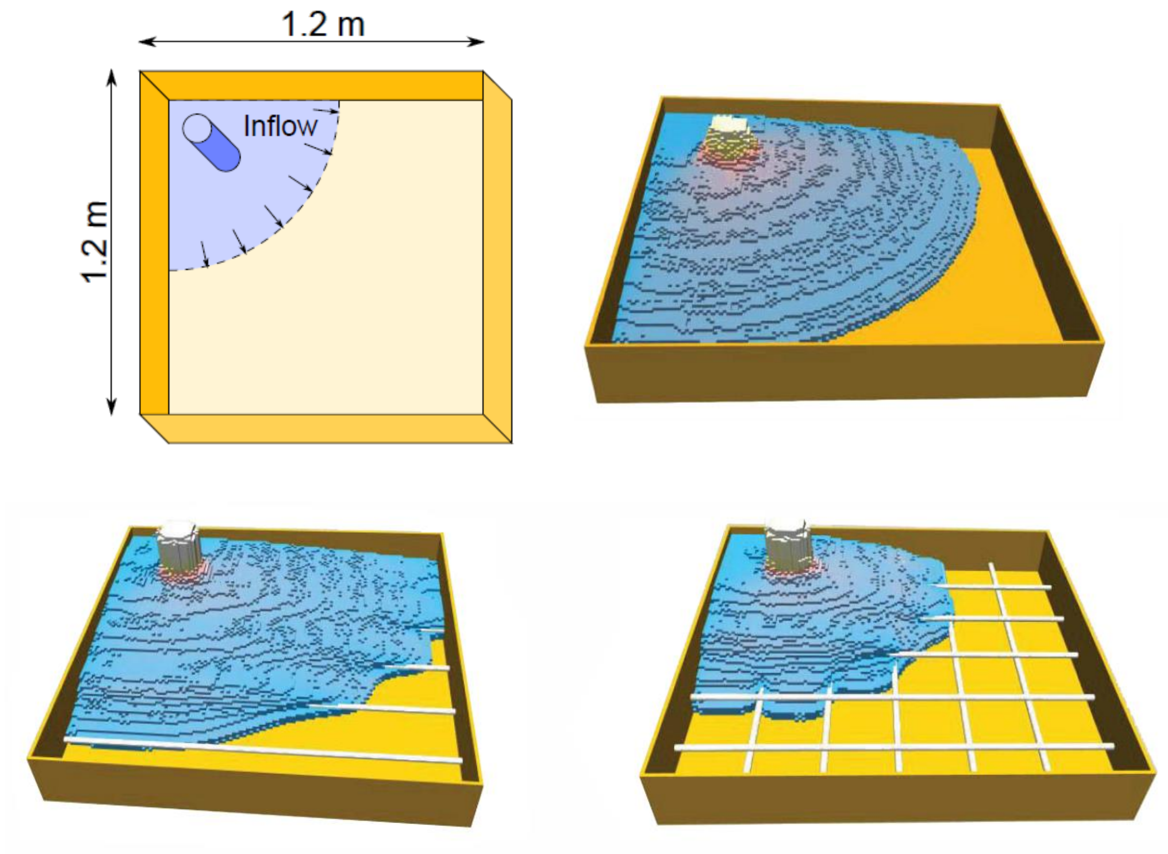
the initial state and two intermediate states of the casting process.



Side views of Steel Fiber Reinforced Self-Compacting Concrete during casting of a standard beam containing both longitudinal reinforcement and stirrups. Individual rows represent different time steps. The left column shows the flow pattern of the Steel Fiber Reinforced Self-Compacting Concrete. Colour represents the flow rate (blue = low, yellow = high). The right column shows the invidual fibres.



Fibre orientation factors in the X, Yand Z direction as a function of the longitudinal position, X, for the case of standard beams cast with Steel Fiber Reinforced Self-Compacting Concrete. Various reinforcement setups were applied



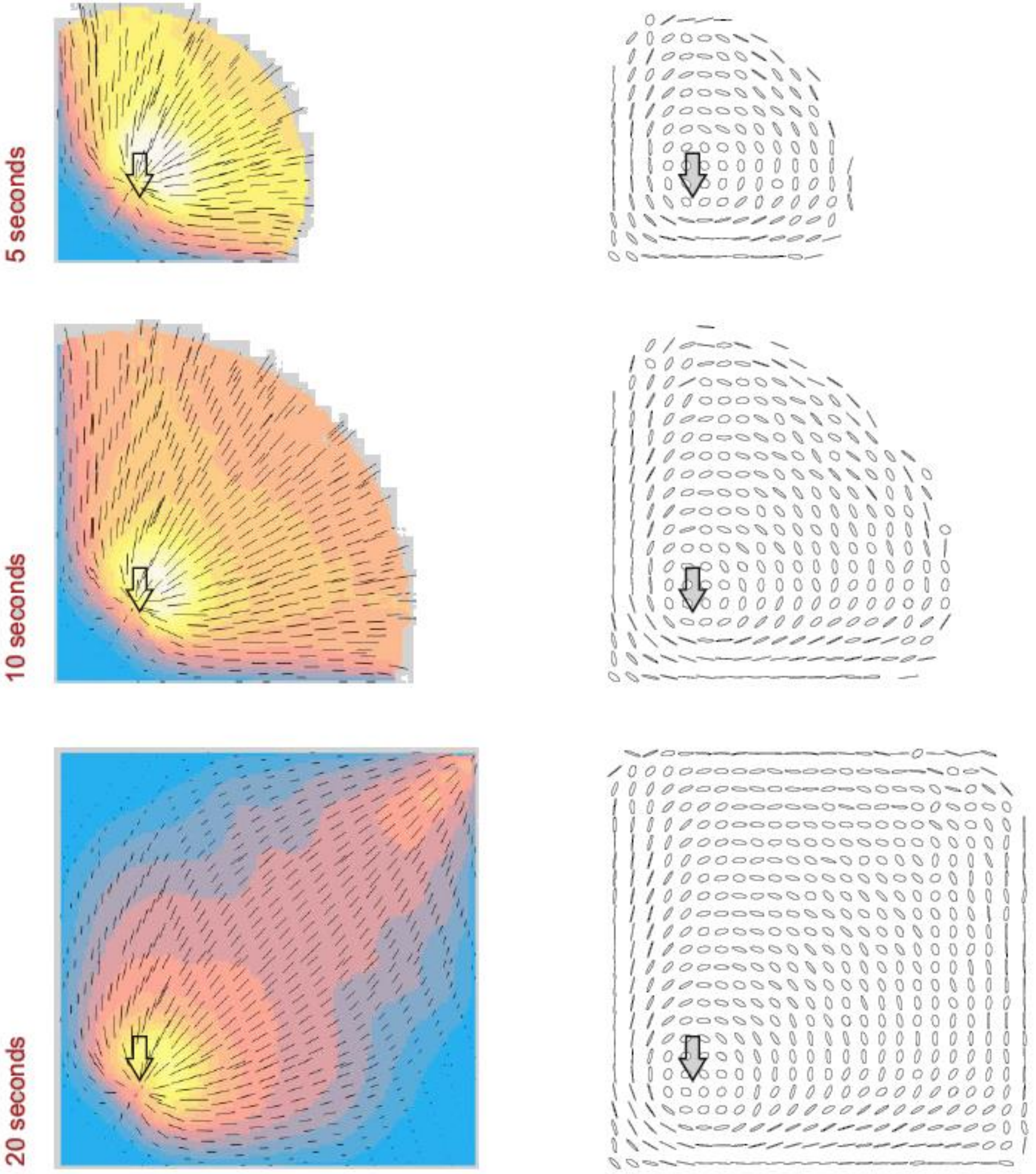
SLAB

A slab casting with Steel Fiber Reinforced Self-Compacting Concrete is presented in this section. Three numerical simulations were run differentiated by the type of reinforcement included in the model.

The three numerical simulations were:

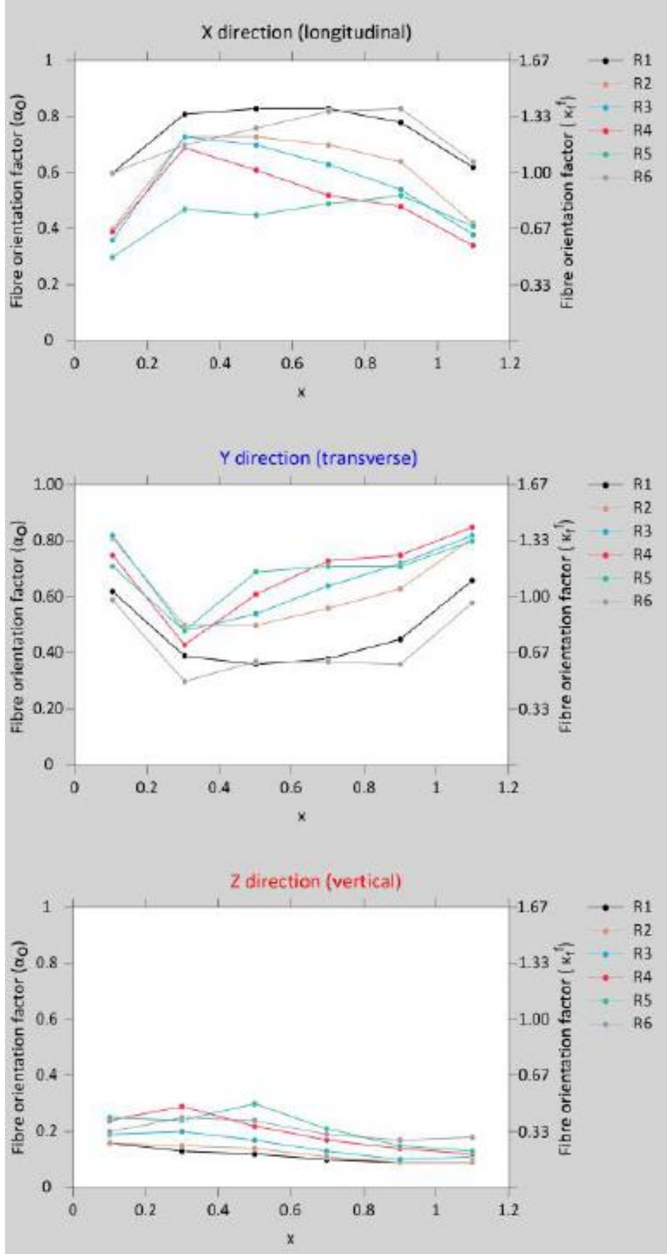
- with no reinforcement.
- with one-way reinforcement.
- with two-way reinforcement.

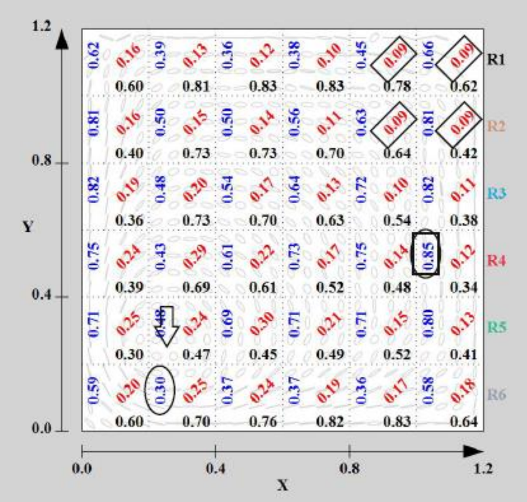
Dimensions of the slabs were 1 .2 m x 1 .2 m x 0.1 5 m. Plastic viscosity, yield stress and density of the Self-Compacting Concrete phase were set to 75 Pa.s, 22 Pa and 231 8 kg/m3, respectively. Fibre length, aspect ratio, and content were 60 mm, 80 and 40 kg/m3, respectively. The casting was performed from a circular inlet positioned at distance of 0.25 m from one of the corners of the slab. The casting rate was approximately 30 m3/h.



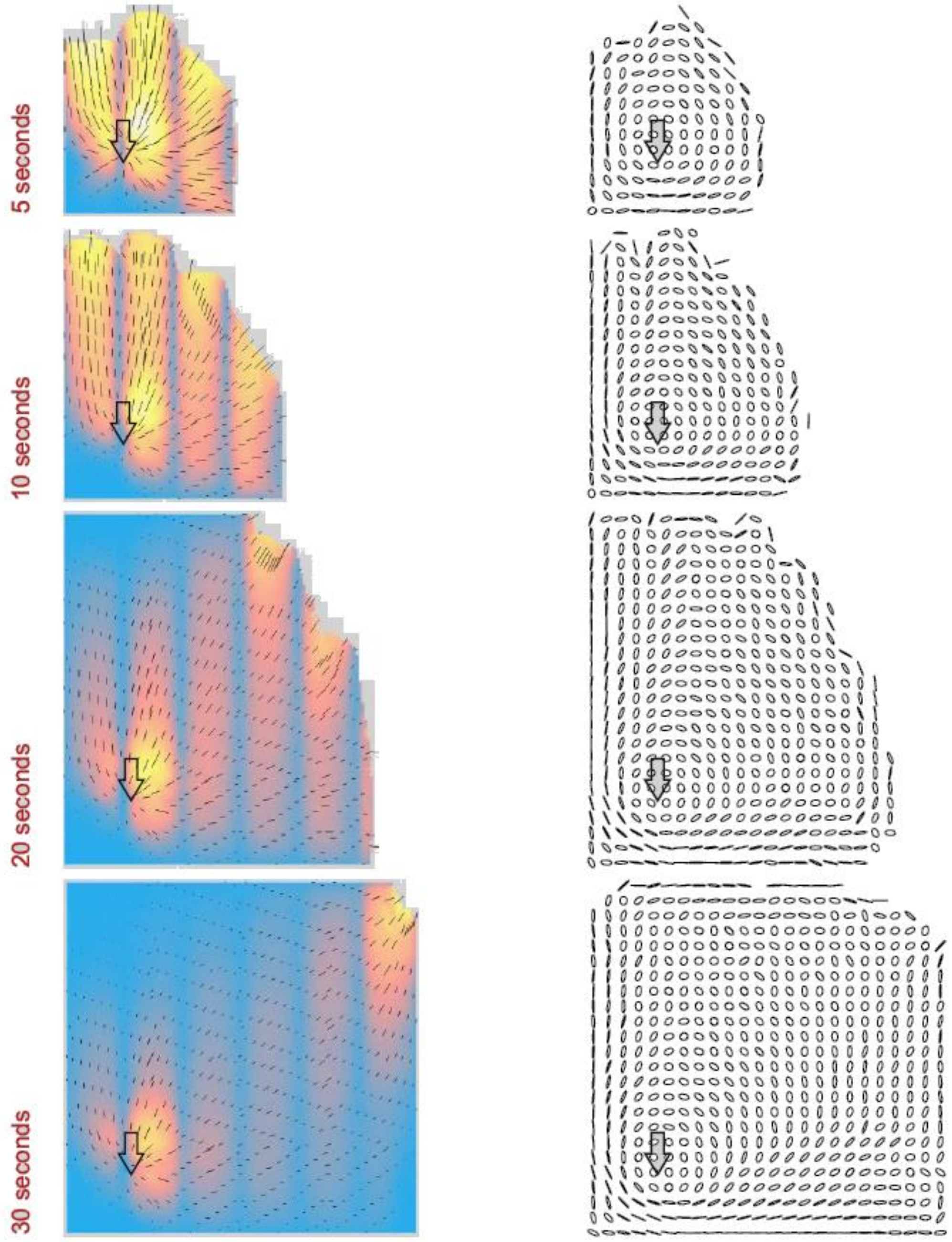
Slab casting with Steel Fiber Reinforced Self-Compacting Concrete. No reinforcement. Top views of the flow pattern (left) and of the fibre orientation ellipses (right) at different time steps. The colour represents the flow rate (blue = low, yellow = high).

Fibre orientation factors. X-direction (black), Y-direction (blue), Z-direction (red).

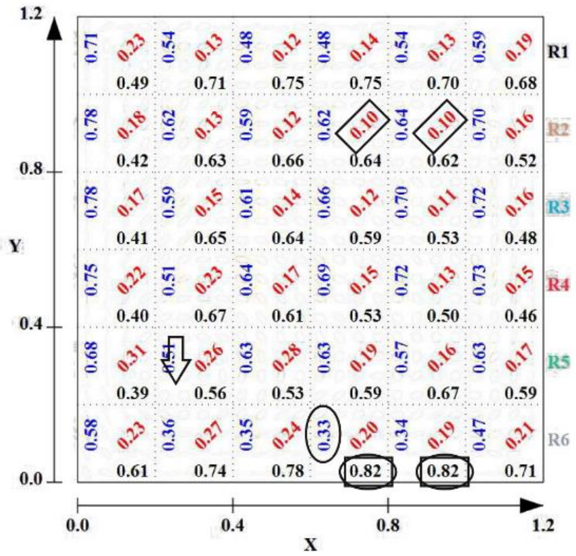


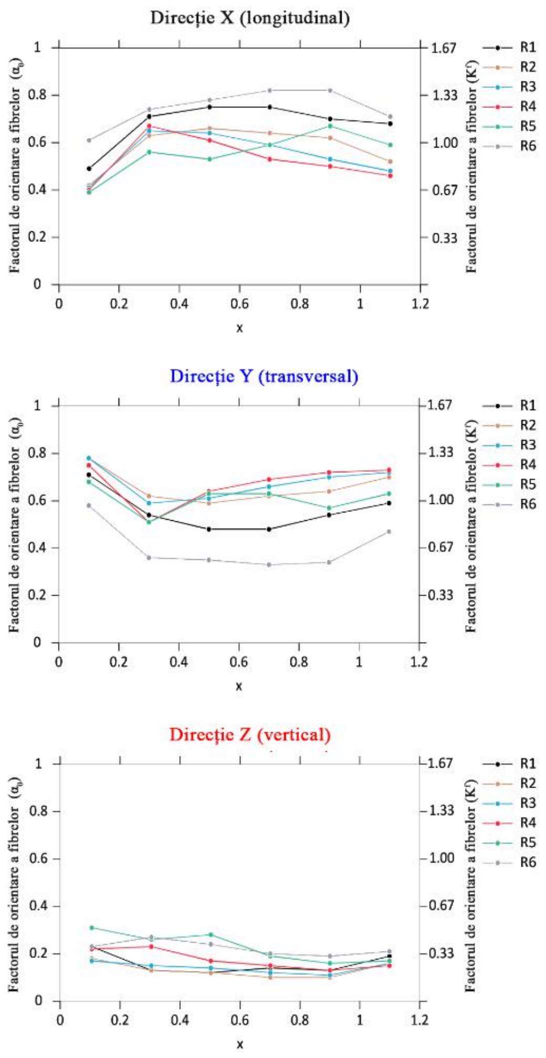


Top view of the slab. Fibre orientation factors in the X, Y and Z direction in individual regions.



Slab casting with Steel Fiber Reinforced Self-Compacting Concrete. One-way reinforcement. Top views of the flow pattern (left) and of the fibre orientation ellipses (right) at different time steps. The colour represents the flow rate (blue = low, yellow = high).

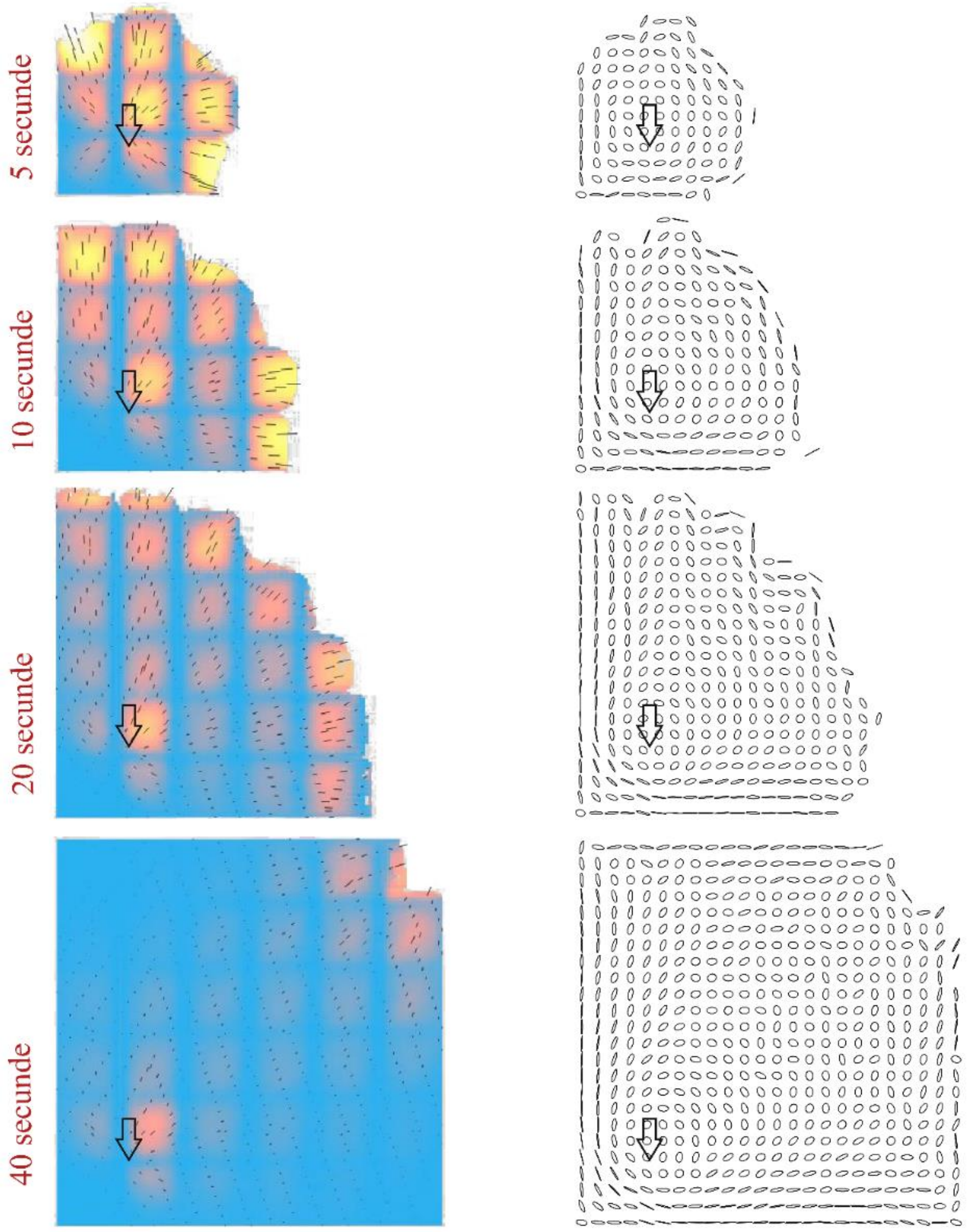


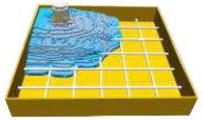


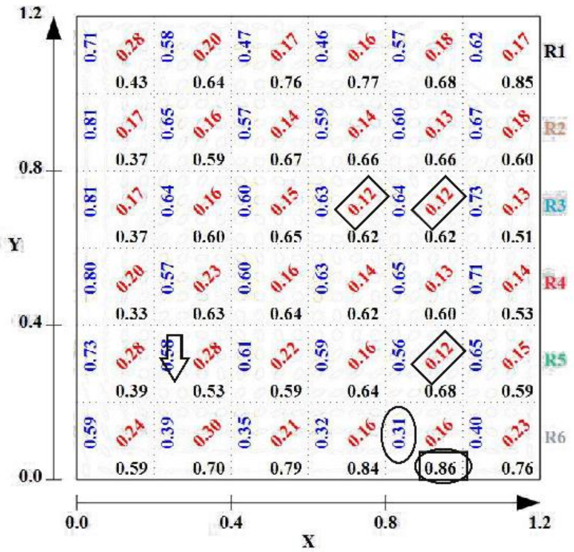
Fibre orientation factors. X-direction (black), Y-direction (blue), Z-direction (red).

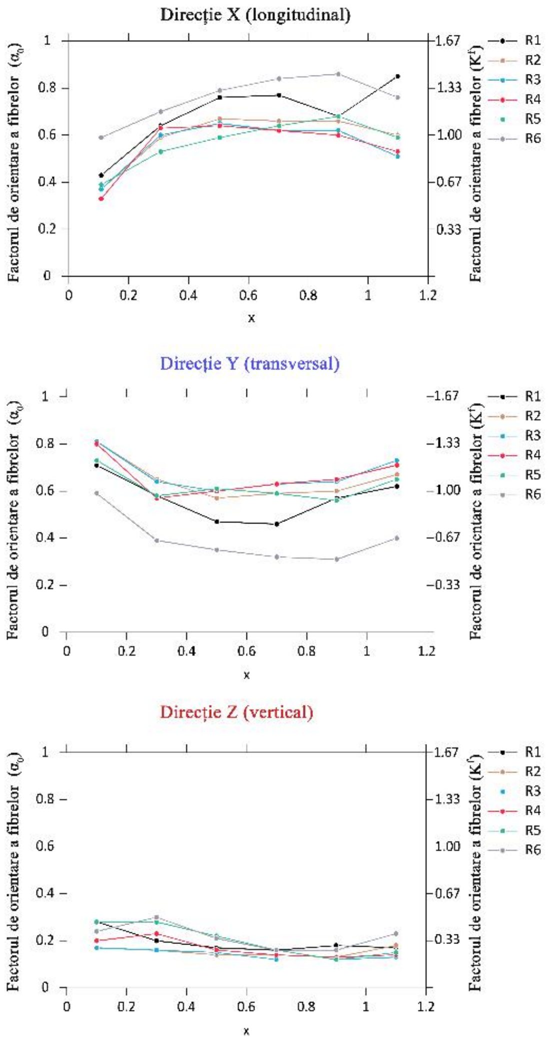
Top view of the slab. Fibre orientation factors in the X, Y and Z direction in individual regions.

SLAB WITH TWO-WAY REINFORCEMENT - SIMULATION



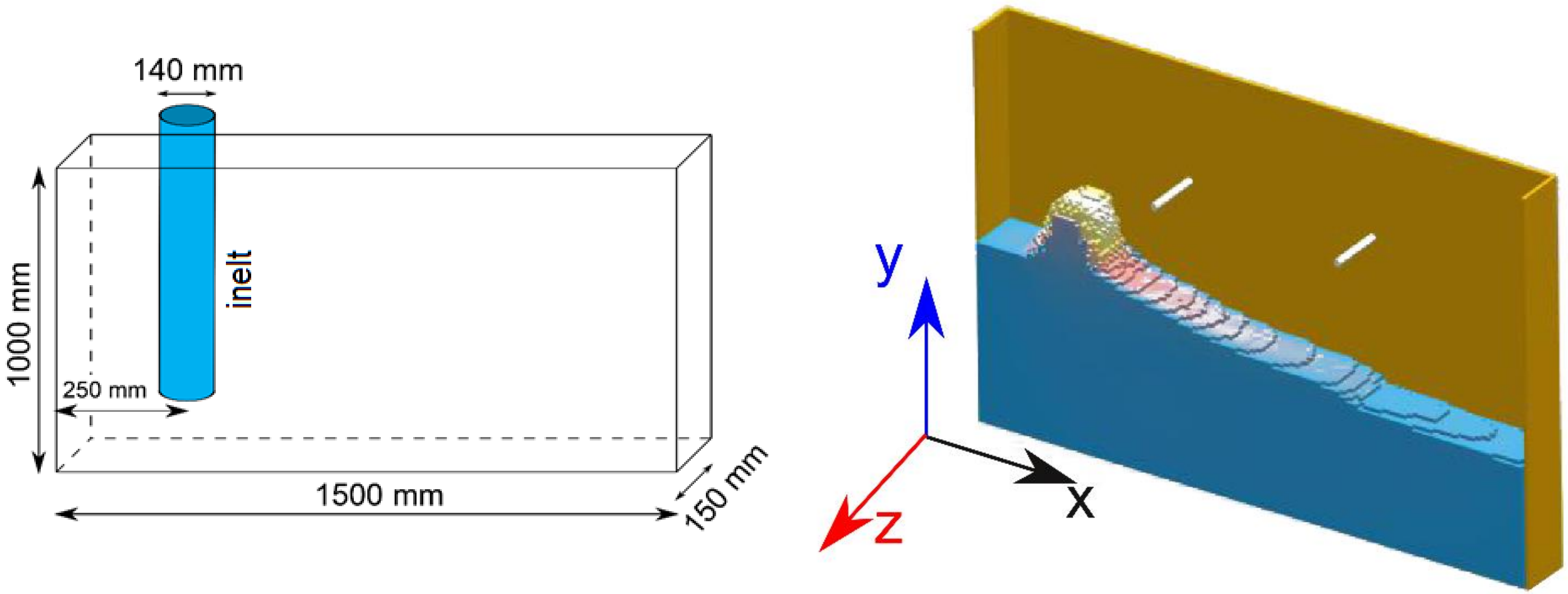




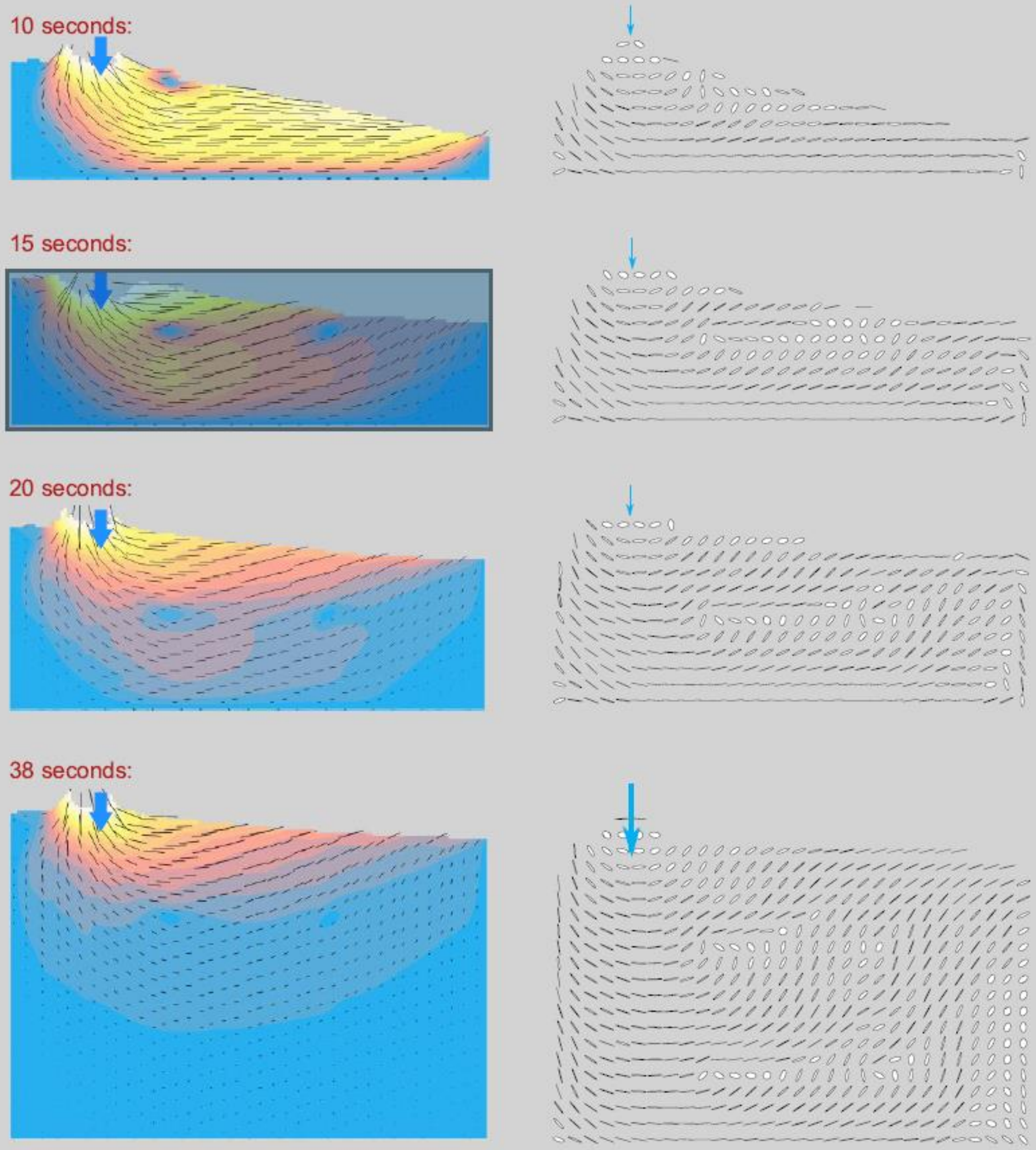


fibre orientation factors in individual regions of Steel Fiber Reinforced Self-Compacting Concrete slab with two-way reinforcement.

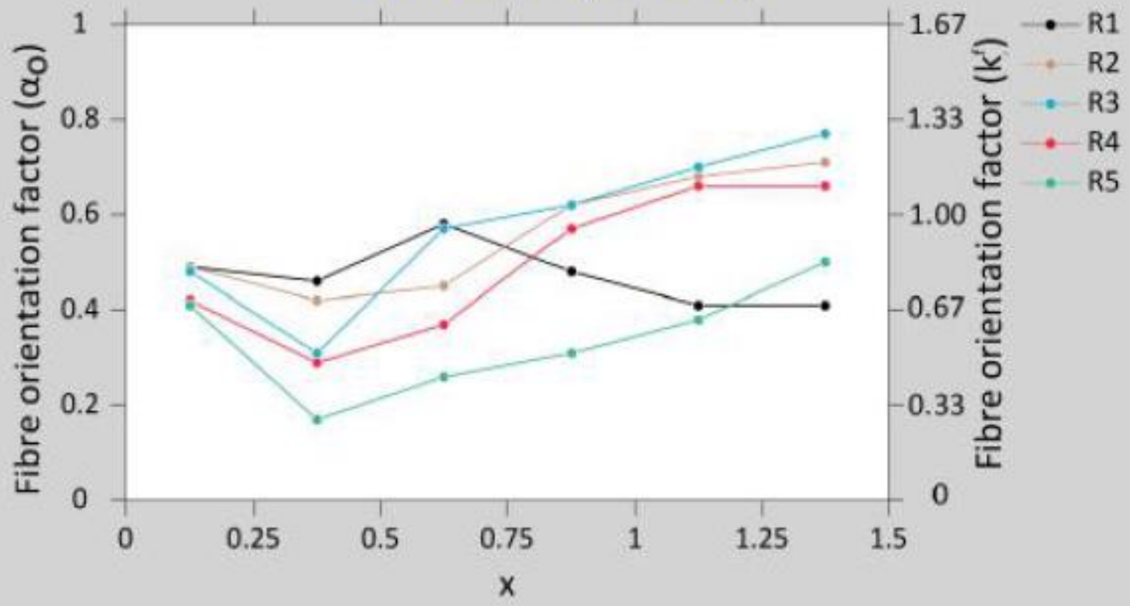
SHORT WALL - SIMULATION



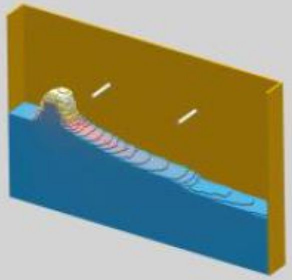
The plastic viscosity and yield stress of the Self-Compacting Concrete phase were 60 Pa.s and 25 Pa, respectively.
Fibre length, aspect ratio and content were 60 mm,
80, and 40 kg/m3, respectively.


10 seconds:
15 seconds:
20 seconds:
38 seconds:

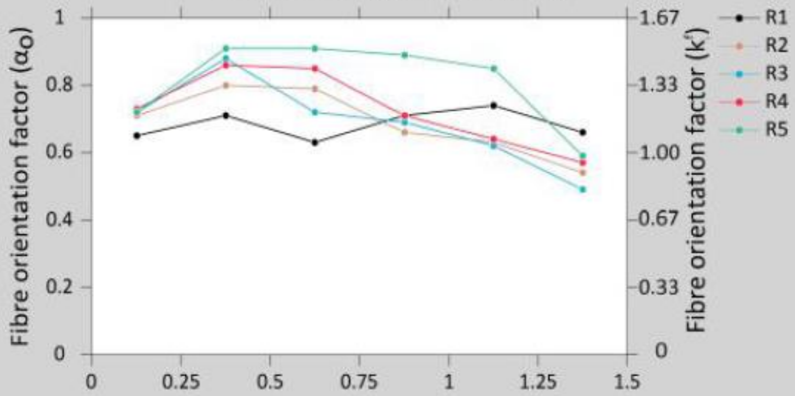
Y direction (vertical)



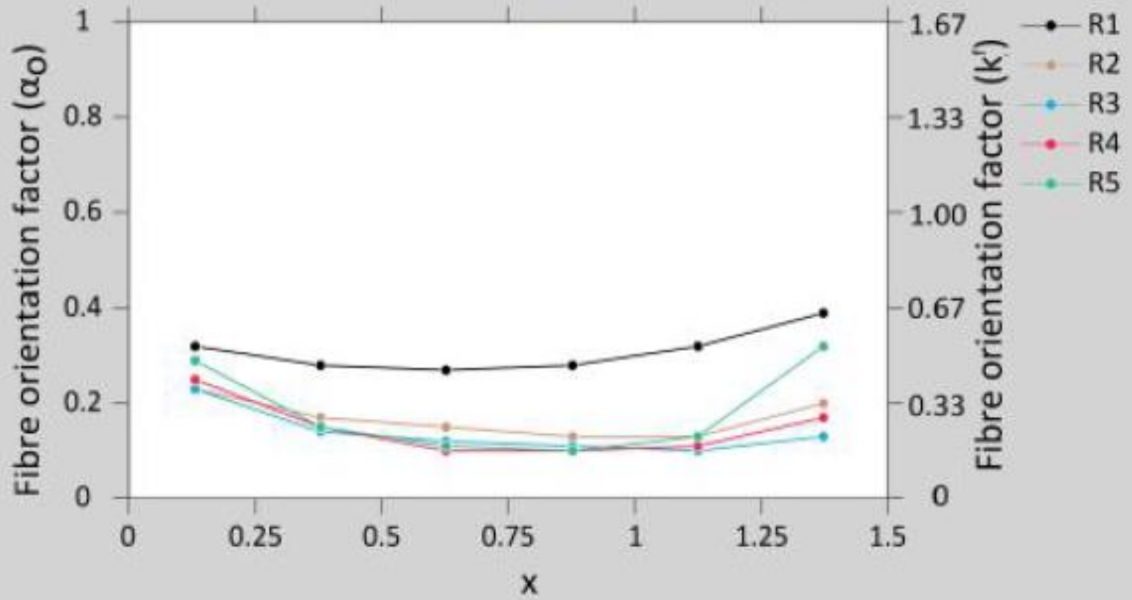
Vertical wall casting
Inlet 10 cm above concrete surface

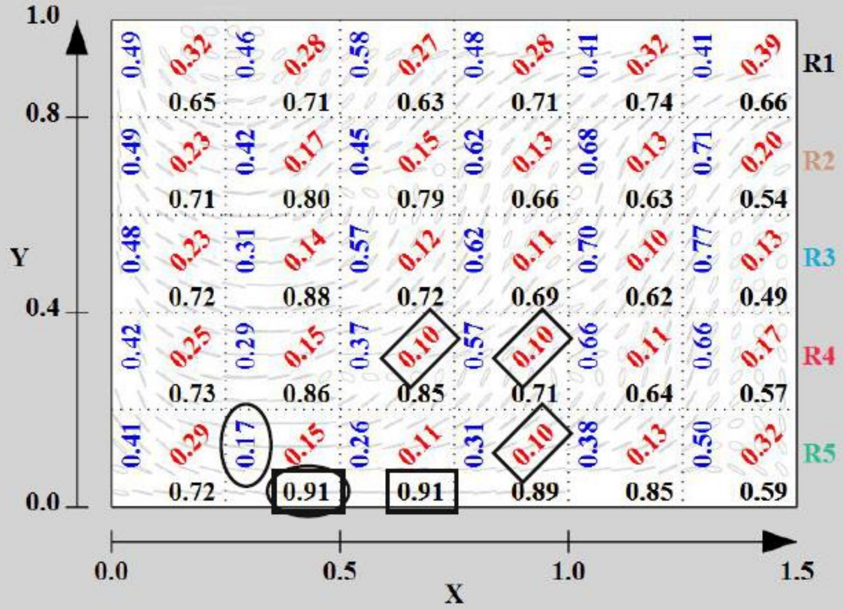


X direction (longitudinal)



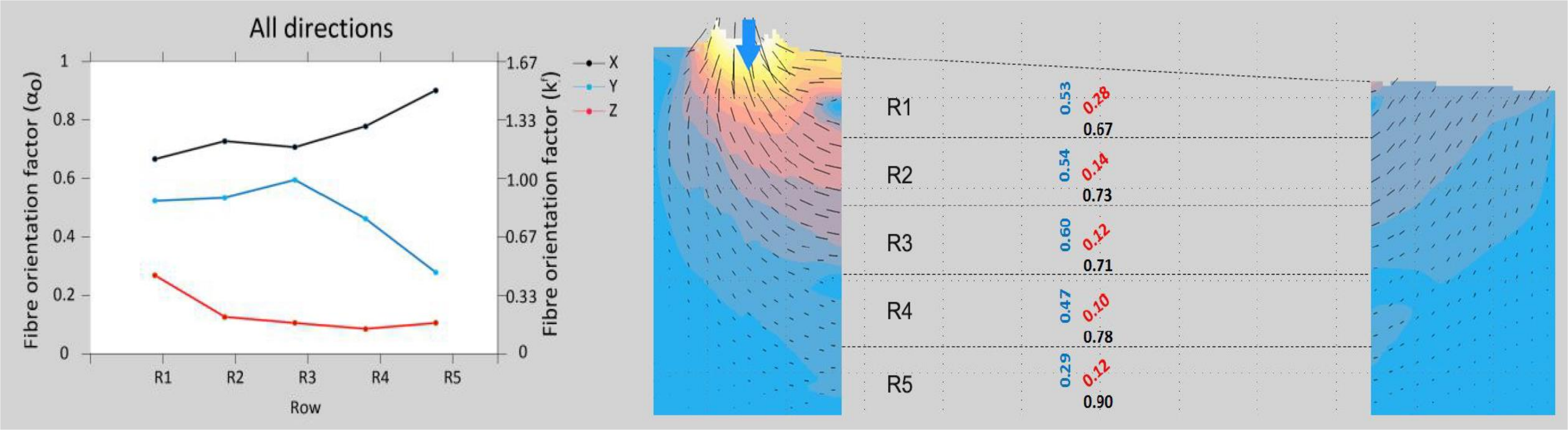
Z direction (transverse)





LONG WALL

The previous example showed a simulation of a 1 .5 long wall. In most cases, walls are longer and the concrete is allowed to flow longer distances from the inlet position. In long walls, it is not uncommon that Self-Compacting Concrete is allowed to flow 5 to 1 0 m..



Estimated fibre orientation factors in a long wall. Longitudinal Xdirection (black), vertical Ydirection (blue), transverse Z direction (red).

VIII. PRACTICE IN EUROPE

In most European countries specification of fibre concrete is simply done by fibre type and content. The fibre content is often determined by the supplier of fibres, in discussion with the design engineer. The agreed fibre type and content are then specified to the concrete supplier. This is the usual practice in, for example, the Czech Republic, Denmark, Finland, France, Netherlands, Norway, Poland, Portugal, Slovakia and the United Kingdom. Some examples of national practice in methods of specification are given in the following sub-sections.

Austria

Austria has a guideline for steel fibre concrete with seven classes for structural performance (T classes) and seven for serviceability (G classes).

The classes are based on measurement of post-crack flexural tensile strength behaviour in a four point beam test on six beams of dimensions 600 - 700 mm x 150 mm x 150 mm. A minimum steel fibre content of 14 kg/m^3 is also specified.

The T classes are based on minimum characteristic values between 0,4 N/mm^2 and >1,9 N/mm^2 calculated from the load-deflection diagram with deflection from 0,5mm up to 3,0mm . Characteristic values are also used to define G classes, ranging from 0,5 N/mm^2 to >2,2 N/mm^2, calculated from the load-deflection diagram at a deflection of 0,5mm.

Czech Republic

In the Czech Republic specification is usually by fibre content, but one supplier offers a fibre concrete with a description including tensile strength class.

Germany

Germany has a system of performance classes (post-crack flexural tensile strength), which are used for specification. The determination of the performance class is part of the initial testing of the producer. Six beams (150 mm x 150 mm x 700 mm) are tested in a four point flexural test to determine the characteristic value of post-crack flexural tensile strength.

Two performance parameters (L1 and L2) are defined. L1 is determined at the point of 0,5 mm deflexion of the beam test. L2 at the point of 3,5 mm deflexion. Nine classes are defined with values of L1 and L2 between 0 and 2,4 N/mm^2. The initial testing of the fibre concrete is undertaken with the minimum fibre content planned by the producer for each mix design for later continuous production. Conformity to the performance class of each fibre concrete is verified yearly by retesting. Routine conformity is assessed by testing of the fibre content and documentation of the type of fibre. Fibre concrete is then specified by compressive strength class, exposure class and performance class. Identity testing of fibre content may be done by the customer. The national regulations are published in "Richtlinie Stahlfaserbeton (2010) by German Association for Reinforced Concrete (DAfStb).

Sweden

In Sweden while specification is, as elsewhere, usually by fibre content, performance requirements are sometimes stated. In accordance with Concrete Report No 4(X) (a Swedish design guideline for fibre-reinforced concrete) the performance is often expressed by means of residual strength factors or R-values, which is the ratio of the post-cracking flexural tensile strength and the flexural tensile strength.

UK

In UK, specification is normally by type and content of fibres, but some ready-mixed companies offer a statement of performance for their ‘proprietary’ concrete. Conformity by performance testing is not usually assessed.

IX. REFERENCES

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