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ABBREVIATIONS

CVC – CONVECTIONAL VIBRATED CONCRETE

SCC – SELF COMPACTING CONCRETE

HPC – HIGH PERFOMANCE CONCRETE

UHPC – ULTRA HIGH PERFOMANCE CONCRETE

CMOD – CRACK MOUTH OPEN DISPLACEMENT

AR – ASPECT RATIO

FRSCC – FIBER REINFORCED SELF COMPACTING CONCRETE

FRCVC - FIBER REINFORCED CONVECTIONAL VIBRATED CONCRETE

HPC – FIBER REINFORCED HIGH PERFOMANCE CONCRETE

W/C – WATER/CEMENT RATIO

W/B – WATER/BINDER RATIO

L/d – LENGTH/DIAMETER RATIO

SF – STEEL FIBERS

Sp – SUPERPLASTISIZER

MPa – Mega Pascal

Generalities

Several researches have been carried out in the field of construction during the last decade. Consequently several scientific works have been developed with the prospect of improving the constructive properties of fresh and hardened concrete. Studies and discoveries have also not ceased to offer new performances and skills in order to find a compromise between workability and resistance.

The idea of employing fibres of different types as a means of reinforcing cementitious materials has not started today. It is an idea that has existed since ancient times. Even by the late twentieth century, long after the invention of steel reinforced concrete, many studies were carried out and applied; on how to use fibres of different materials, to reinforce cementitious materials. Fibres from plants, animal skin, wood, plastic, steel and many other materials were explored.

However, as technology advances and as the demand for better methods of construction needed to shelter the ever-growing population of the world increases; there is need to pursue further uses to which fibre reinforcements can be employed in the construction industry. The possibility of reinforcing the innovative cementitious materials like Self-Compacting Concrete (SCC), High Performance Concrete (HPC) and Ultra-High Performance Concrete (UHPC) has proved to be one of the aspects worth exploring and was hence the basis of our study.

The introduction of fibres to an innovative concrete will certainly come with its own challenges. For an SCC, there is need to investigate the ways to introduce fibres without losing the fluidity of the concrete which makes it self compacting. For a High Performance Concrete there is need to find means to employ fibres in the mixture and still not lose the resistive characteristics of the concrete at its hardened state.

We will therefore present below the progress of our thesis which is divided into four chapters.

In chapter one as we introduce the study, we define what fibre reinforcements are, we discuss the background and history of fibre reinforcements and also their different applications in the construction industry.

In chapter two, by means of two practical examples, we explore the formulations of fibre reinforced concrete while highlighting how it is different in realization from an ordinary concrete.

Chapter three is a study of how the different properties of fibres affect the mechanical characteristics of the cementitious materials in both their fresh and hardened states.

Chapter Four, which is an introduction to the practical part of our study, is a study of the characterization on different materials which are used in the formulation of fibre reinforced concretes.

Finally, we hope that this work will contribute to the development and enhancement of fibre reinforcement in the construction industry.

CHAPITRE I: FIBROUS REINFORCEMENTS

I.1. Introduction

Fibres are the reinforcements that provide strength to the composite material. A fibre is made up of several elementary filaments whose diameters vary between 5 µm and 25 µm depending on the type of fibres (metallic, glass, carbon, aramid, plastic, etc.). The requirements desirable for structural and functional fibres in composite materials are:

- a high modulus of elasticity
- high strength and good elongation at break in tension
- good distribution of forces between the different fibres
- stability of properties during handling and manufacturing
- uniformity of fibre diameter and surface
- high hardness
- durability and an acceptable cost

Fibres provide concrete with many advantages, particularly on the mechanical behaviour under tensile stress. Their use nevertheless requires knowledge of the action mechanisms as well as the implementation precautions.

I.2. History

The concept of using fibres as reinforcement is not new. A deep analysis of this idea tells us that this concept is extremely old and dates back to antiquity. Fibres were used as reinforcement by the Egyptians who are said to have used straw to strengthen the mud bricks in the bible (Exodus 5.6). Historically, horsehair was utilized in mortar and straw in mud bricks. Asbestos fibres were also used in the reinforcement of clay pottery in Finland up to a few years ago. Other sources (Antoine, EN and March 1985 and ACI Committee 554 March - April 1984) indicated that straw was meant to strengthen bricks within the ancients, while animal hair and asbestos fibres were introduced to strengthen the plaster and paste of hydraulic cement. Within the 1900s, asbestos fibres were utilized in concrete. Within the 1950s, the concept of composite materials came into being and fibre-reinforced concrete was one among the topics of interest. Once the health risks related to asbestos were discovered, there was a requirement to seek out a replacement for the substance in concrete and other building materials. By the 1960s, steel, glass (GFRC), and artificial fibres (such as polypropylene) were used in concrete. Research into new fibre-reinforced concretes continues today.

I.3. Roles of Fibres

In the beginning, researchers tried; by adding fibres, to increase the characteristic concrete mechanics like compressive strength and flexural strength, but the result was limited. It has been observed that the main role of fibres in a cementitious material can be assessed in two ways:

- Controlling the propagation of a crack in a working material by reducing the crack opening (**Figure I.1**)
- The transformation of the brittle behaviour of a material into a ductile behaviour which increases safety during the ultimate loading states (**Figure I.1**)

Fibres generally have the role of reinforcing the structure by opposing the development of cracks and their propagation. Depending on the type, dosage and concrete elements in which they are inserted

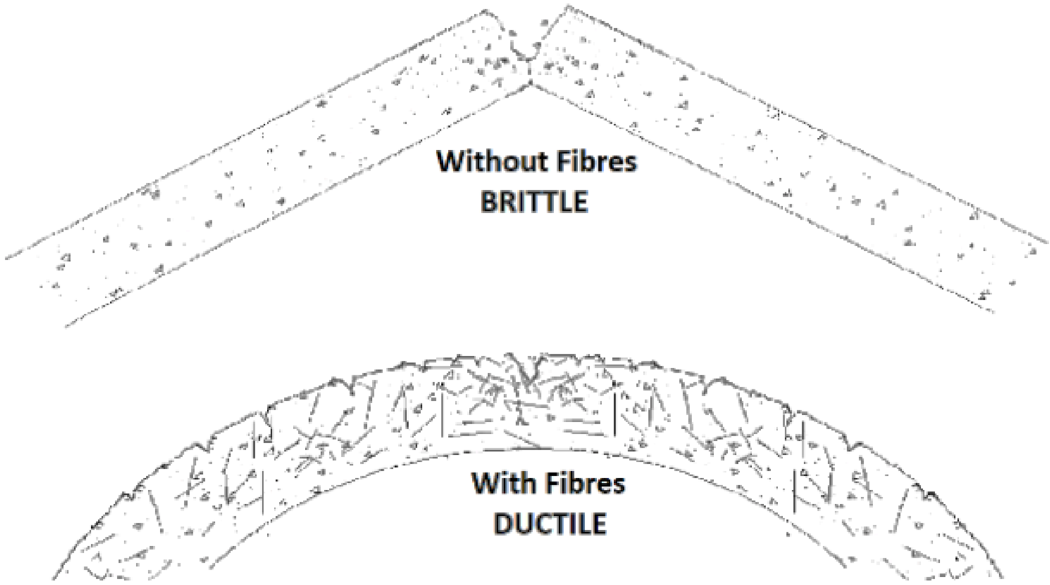

Figure I.1: illustration of the contribution of reinforcement by fibres (Grueward et al. 2004) [1]

The fibres allow

- Improving the cohesion of fresh concrete; for example, rigid fibres change the structure of the granular skeleton
- Increased ductility and post-cracking behaviour
- Reduction of micro cracking due to dimensional variations, particularly at young age
- Reduction of mechanical cracking (external loading)
- increased flexural tensile strength
- Improved fire resistance and resistance to impact, fatigue, wear, and abrasion

I.4. Factors Influencing the Behaviour of Fibre Reinforced Concrete

In reality, fibres affect the mechanical performance of concrete in all failure modes. The different factors influencing the behaviour of reinforced concrete fibres are illustrated in (**Figure I.2**).

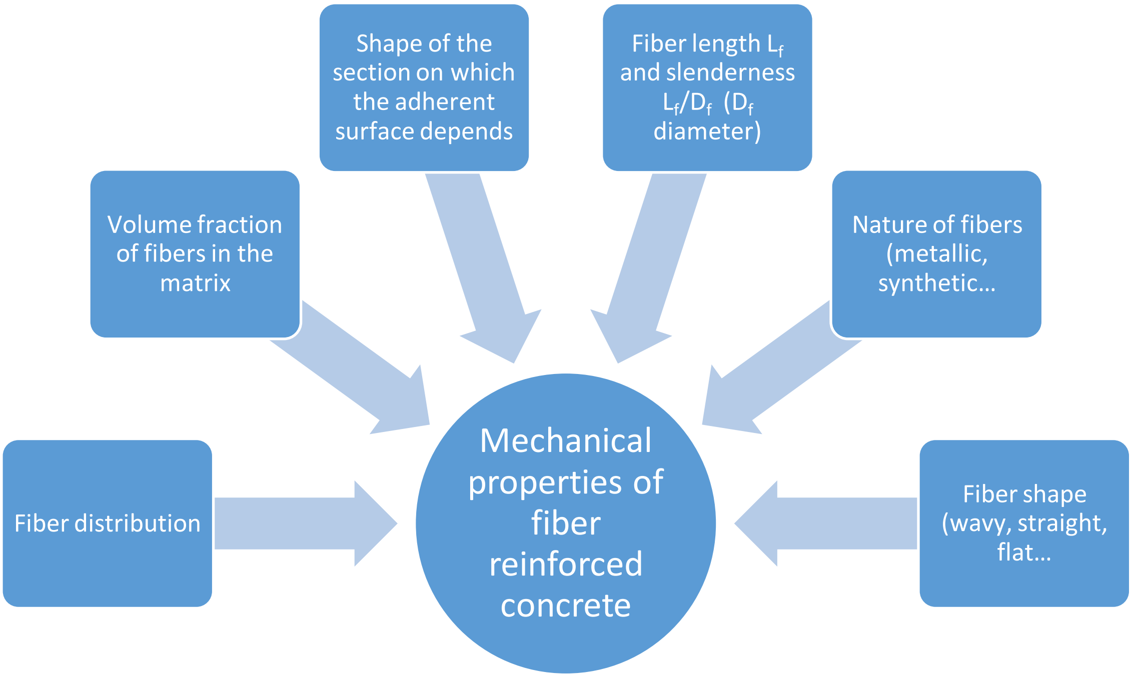

Figure I.2: Different factors influencing the mechanical behaviour of fibre reinforced concrete. (Grueward et al. 2004) [1]

We can therefore understand that it is extremely difficult to generalize the contribution of fibres compared to ordinary concrete because of the numerous parameters influencing its behaviour.

I.5. Different Types of Fibres Used

I.5.1. Metallic Fibres

Metallic fibers (**Figure I.3**) are widely used and their effects on rheological and hardened properties as well as on durability have been the subject of numerous studies [1].

Steel fibres are probably the most used. They have been the subject of several researches. Originally, rectilinear and circular section fibres (of a type identical to those used to arm tyres) have evolved into sheared sheet steel fibres. There are many varieties of fibre that differ from each other by :

- their diameters
- their section (round, square, rectangular ...)
- their length and how they are made

- They can be straight, wavy or have enlargements at the ends, either elbows or hooks to improve grip.

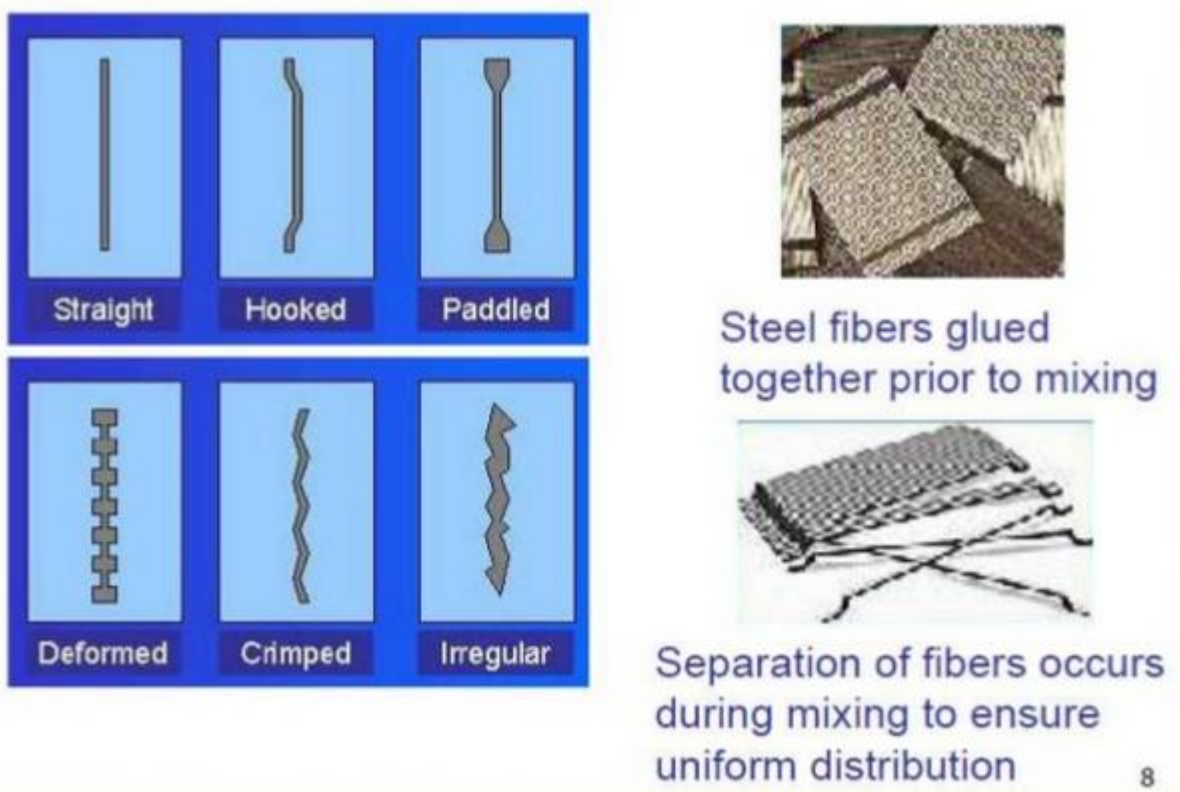

Figure 1.3: Types of steel fibres (Grueward et al. 2004) [1]

It has been pointed out that steel fibres:

- Considerably increase the tensile strength of the material, its toughness or its energy absorption capacity
- They reduce cracking despite the excess weight linked to their high density.

As there are other types of metallic fibres but are not widely used. Let us quote for example; stainless steel fibres, cast iron fibres, etc.

I.5.2. Mineral Fibres

a). <u>Carbon Fibres</u>

Most carbon fibres are produced by the thermal decomposition of polyacrylonitrile (PAN). The manufacturing process for this type of fibre consists of oxidation at temperatures of around 200-300° C, at different stages of carbonization (1000-1500 ° C and 1500-2000 ° C) and finally graphitization (2500-3000 ° C).

Carbon fibres (**Figure I.4**) are characterized by

- high modulus of elasticity and high resistance
- high specific stiffness (stiffness / density ratio)
- a low coefficient of longitudinal thermal expansion (CET)
- low sensitivity to fatigue loads
- excellent resistance to chemicals and humidity
- stable modulus of elasticity and the resistance of carbon fibres when the temperature increases.

However, carbon fibres have low impact resistance because of their low deformability and a high cost (10 to 30 times more than E-glass). This high cost comes from the high price of raw materials and the complexity of the carbonization and graphitization process.

Carbon fibres can be classified as follows:

According to the type of precursor:

- "PITCH" isotropic fibres characterized by a high elastic modulus.
- Polyacrilonitrile fibres "PAN" characterized by ultimate resistance and very high cost.

Depending on the physical and mechanical properties:

- High elastic modulus (HM).
- High resistance (HR)

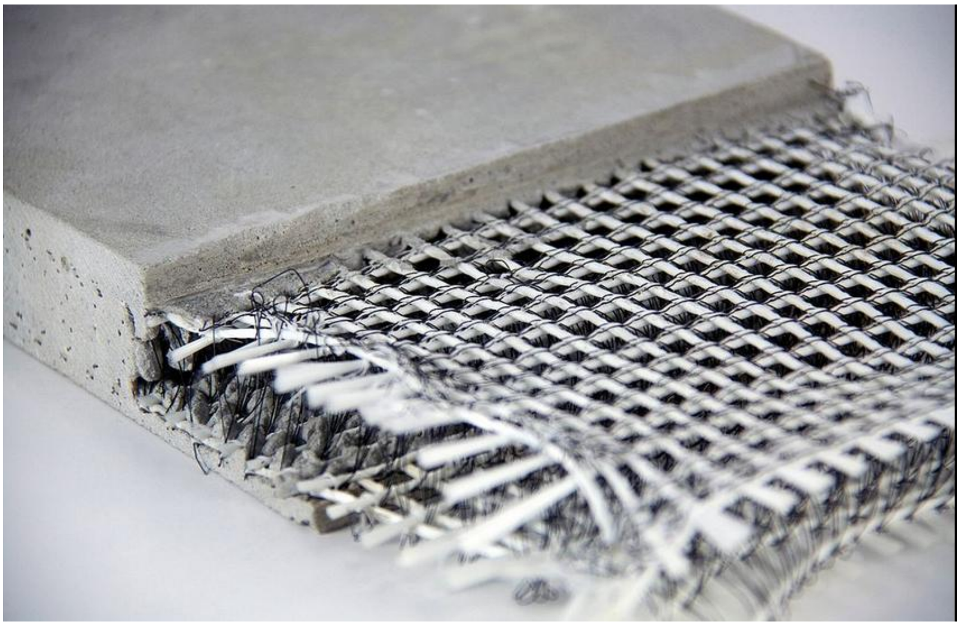

Figure I.4: carbon fibres in concrete (Grueward et al. 2004) [1]

b). Glass Fibres

Glass fibres (**Figure I.5**), due to their mechanical qualities and their moderate cost, were the first artificial fibres to be used in building materials. However, their use is limited because of their low chemical resistance to alkalis. In addition, researchers have shown that the introduction of fibres in small quantities does not significantly modify mechanical performance but can, on the other hand, control the cracking due to the withdrawal of drying at a young age. The same effects have also been observed when synthetic fibres are used.

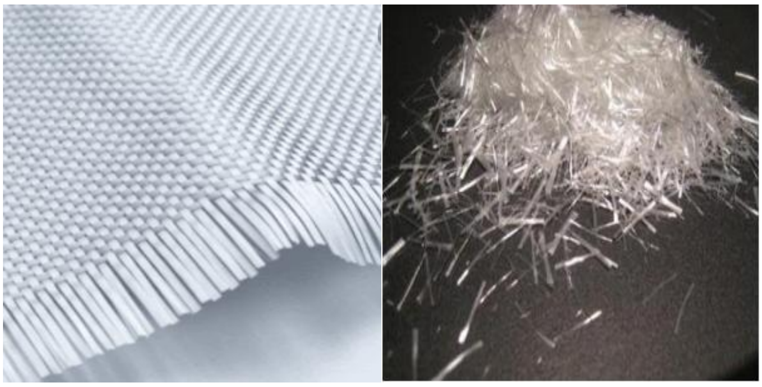

Figure I.5: glass fibres (Grueward et al. 2004) [1]

I.5.3. Organic Fibres

a). Aramid Fibres

Aramid is a generic term for a group of organic fibres of low density and specific strengths (tensile strength/density ratio). They are among the most common reinforcing fibres. Aramid fibres (**Figure I.6**) are characterized by:

- high resistance
- high rigidity
- stability against high temperatures

The typical operating temperature for aramid fibres varies between -200 ° C and + 200 ° C. Three types of aramid fibres are commercially available bearing the brands of manufacturers such as:

- Kevlar (DuPont, USA)
- Twaron (Akzo, Netherlands)
- Technora (Teijin, Japan)

These fibres are resistant to many chemicals, but they can be degraded by certain acids and alkalis.

Figure I.6 : Aramid fibres (Grueward et al. 2004) [1]

b). Polypropylene Fibres

These fibres obtained by extrusion of polypropylene, come in bundles or in the form individual filaments. When used as bundles, they separate during mixing. They are distributed multidirectional in concrete.

Polypropylene fibres in particular make it possible to better control the plastic shrinkage of fresh concrete but do not improve its post-cracking behaviour (unlike metallic fibres). They improve the workability and cohesion of the concrete (in particular in the case of shotcrete). They are particularly flexible and chemically insensitive but not very resistant to fire (melting temperature between 140 to 170 ° C

Figure I.7 : Polypropylène fibres (Grueward et al. 2004) [1]

I.5.4. Vegetable Fibres

Plant fibres are mainly composed of cellulose which is a natural polymer. These fibres are characterized by their interesting mechanical properties as well as their low density which allows the manufacture of concrete that is both light and efficient.

In addition, these fibres do not suffer from corrosion problems, unlike metallic fibres, and they durably resist chemical attack by alkalis, unlike glass fibres.

The use of natural fibres (**Figure I.8**), and in particular plant fibres as reinforcement for composite materials, has two main advantages

- They are widely available at low cost and their use in construction constitutes new outlets for agricultural materials
- The recovery of plant fibres allows the reduction of environmental impacts compared to conventional composites since they are renewable raw materials, biodegradable, neutral vis-à-vis CO_2 emissions and requiring little energy to be produced.

In less industrialized countries, vegetable fibres therefore constitute an alternative at low economic and especially ecological cost to conventional synthetic fibres (metallic, mineral or polymeric fibres).

Studies relating to concretes thus reinforced with these fibres have shown that when they are introduced into the compositions at optimum dosages (depending on their shapes and their nature), they reduce the cracking associated with plastic shrinkage at a young age while increasing the mechanical resistance of the materials.

It is possible to combine two or more types of fibres in concrete in order to have a maximum synergy in terms of resistance to bending and shrinking. Thus, the combination of metallic fibers with polypropylene fibers, leads to a very significant performance in terms of toughness, flexural strength and reduced shrinkage.

Figure I.8: vegetable Fibres (Grueward et al. 2004) [1]

• *Classification of vegetable fibres :*

Plant fibres are classified into four groups according to their origin. These are: leaf, stalk, wood and surface fibres.

a). <u>Leaf Fibres</u>:

These fibres are obtained from monocotyledonous plants. The fibres are made of overlapping bundles which surround and go along the sheets to reinforce them. These fibres are hard and rigid. The most cultivated types of leaf fibres are sisal, henequen and abaca fibre. [2] As a result, several researchers such as: NILSSON [3], AYYAR et al [4] have demonstrated the effectiveness of cement reinforcement with leaf fibres.

b). <u>Stem Fibres</u>:

The stem fibres are obtained from the stems of dicotyledonous plants. Their role is to offer rigidity to the stems of plants. The stem fibres are sold in the form of a horn package and in any length. They are then separated individually by a scrolling process. The fibres, once separated, are used in the manufacture of ropes or textiles or in the reinforcement of cement and concrete. The most used stalk fibres are jute, flax, sunn ramie, kennaf, urena and hemp fibres [54]. NILSSON [3] reports that of all the stem fibres, the most used in cement reinforcement are those of sunn, hemp and jute.

c). <u>Wood Fibres</u>:

The wood fibres come from the crushing of trees such as bamboo or reeds. They are generally short. Several researchers [2], [6] have shown the effectiveness of these fibres in strengthening cements.

d). <u>Surface Fibres</u>:

Surface fibres generally surround the surface of the stem, fruit or grain. The grain surface fibres are the most important group in this family of fibres. We cite among others cotton and coconut (coconut). Coconut fibres have given good results for the flexural strength of fibre cement [7]. It should be noted that, the palm fibres, which surround its trunk, belong to this family of fibres.

I.5.5. Animal Fibres

For animal fibres, we can find

- pile fibres
- wool fibres
- silk fibres

I.6. Uses of Fibres in Construction

Fibres of all kinds are widely used in various works for the purpose of improving mechanical and physical performance. The use of vegetable fibres in strengthening cements is relatively recent. Indeed, a lot of research is underway with the aim to succeed in replacing asbestos fibres with vegetable fibres. Currently, vegetable fibres are increasingly used in slabs and the production of tiles and parking pavements as well as in the reinforcement of plaster [8].

In addition, the use of polymers, carbon and steel fibres is increasingly practiced in several fields and especially in the manufacture of panels and in the restoration and repair of old damaged structures.

TABLE I.1: Applications of fibres

Fibre type	**Application**
Glass	Prefabricated panels, walls, curtains, sewage pipes, thin veil roof, coating
Steel	Cellular concrete roofing element, lintel, pavement, bridge decks, refractory product, concrete pipes, airstrip, pressure tanks, building restoration works.
Polypropylene nylon	Foundation piles, prestressed piles, covering panels, floating landing element and moorings for marinas, road repair, submarine pipe, building restoration works.
Asbestos	Sails, pipe, thermal insulation material panels, sewer pipes, flat and corrugated roofing sheets, wall cladding.
carbon	Corrugated element for the construction of floors, single or double curvature membrane, shells, scaffolding floor.
Mica particles	Panels, pipes, restoration work
Vegetable	Slabs, tiles.

I.7. Fibre Reinforced Concretes

I.7.1. Introduction

Innovation in the construction sciences partly involves the development of new materials and the mastery of their properties. One such material is fibre reinforced concrete. The fibres increase the mechanical resistance of concrete, reduce its plastic shrinkage, increase its impact resistance and improve its fire resistance. With this material, engineers are able to project new original structures by their design and conception, but also by their ability to withstand various external stresses.

The characteristics of this type of material are based on the presence of fibres which can be of different natures: metallic, synthetic, natural, glass or carbon.

The influence of fibres appears in different ways according to different authors; their ability to control cracks, their ability to act as energy absorbers, their ability to transfer loads and their tensile strength. Most authors agree that the parameters conditioning these properties are (besides the nature of the fibres) their density and their orientation.

I.7.2. Definition of Fibre Concrete

In buildings and public works today there is a product whose constituents, manufacturing method, properties and behaviour correspond to those its composite materials. This is fibre concrete, composed of a cement matrix and fibres reinforcing it.

Fibre concrete is a composite material (a mixture of cement, aggregates, water and fibres), which must be considered as homogeneous (with fibres correctly distributed with random orientation), as a conventional concrete can be; unlike the traditional reinforced concrete in which the positioning of the reinforcements is defined according to the applied forces.

In other words, a fibre concrete is a concrete in which fibres are incorporated. Unlike traditional reinforcements, the fibres are distributed in the mass of the concrete, they make it possible to constitute a material which presents a more homogeneous behaviour.

It is therefore not reinforced concrete in which the traditional steel reinforcement (welded mesh and bars) would have been replaced by fibres. Fibre concrete should not be regarded as "equivalent" to reinforced concrete as it is currently known. It is a new product which has a tensile strength which is still lower compared to the compressive strength, but which can however be mobilised under normal safety conditions, for which it is necessary to:

- Define manufacturing and implementation requirements so that there is effectively "fibre concrete"
- Study the laws of behaviour in order to specify its specific fields of use and define sizing criteria
- Incorporate various fibres into the fragile material that this concrete has been and have it continue to be the subject of much research; also for the several applications that have also emerged.

Systematic research has been carried out since 1960 to understand the behaviour under various stresses of fibre-reinforced concrete. The latter has been the subject of particular interest from numerous researchers who have published various articles and reports on the subject [9], [10].

In 1975, during the international conference of RILEM, numerous experimental reports made it possible to popularise the subject, which made it possible to collect enormous information on the properties of composite materials and their applications.

The fibre concrete association constitutes a composite material having a behaviour different from that of conventional concrete, which is mainly characterised by its good tensile and cracking resistance.

I.7.3. History

In 1910, Porter first suggested the use of metallic fibres in concrete to improve the mechanical performance of concrete. [11]

Fibres are added to the matrix, not to improve the bending tensile strength of the concrete, but primarily for the purpose of controlling cracking, preventing cracking from coalescing, and changing the behaviour of the fibre-reinforced material by sewing cracks [12]. However, fibre-reinforced concrete (FRC), as a material in industrial applications, was created in the United States in the early 1960s following the work of [13] leading to the filing of a patent. It was produced using conventional hydraulic cement, aggregates (sand and gravel), water and fibres. To improve the workability and stability of fibre-reinforced concrete, a superplasticizer can also be added to the mix. This concrete is not considered as a substitute for ordinary concrete, but as a different type of material.

I.7.4. Reinforcement Principle

The mechanism of reinforcing concrete with fibres consists in regularly distributing fairly short fibres in the concrete serial number. This network of fibres will oppose, and especially as it is denser, the widening of the crack; the first fibre(s) encountered sew the crack until it stops progressing; if the excessive efforts persist, other cracks will form, which will in turn be sewn with other fibres.

Reinforcement by concrete fibres therefore makes it possible to slow down the uncontrolled propagation of cracks, which allows it to acquire qualities (toughness, resilience) or to improve certain characteristics.

I.7.5. Advantages and Disadvantages of FRC

The following improvements in the properties of fibre concrete are taken for granted.

- Higher impact resistance
- Increase in breaking energy
- Improved ductility.
- Different behaviour at cracking
- Resulting in a noticeable delay in cracking.

But some disadvantages have also been noticed in the use of fibres:

- Reduced manoeuvrability due to the presence of fibres when the percentage of these is high
- Introducing a certain type of fibre into concrete with traditional characteristics proves to be very difficult
- During delivery, the fibres are entangled, hence the formation of sea urchins during mixing involves the difficulty of implementation
- Currently the price of fibres is relatively very high and therefore the cost price per m^3 of fibre concrete may seem excessive compared to that of traditional concrete.

I.8. Conclusion

The first chapter has shown us that the role of fibres in a concrete mixture is to increase the ductility of the end product. We have also observed that there are many characteristics of the fibres which affect the mechanical behavior of Fibre Reinforced Concrete which is to be investigated further along our study. Lastly we have seen the various types of fibres and their and their particular applications.

In the next chapter we are going to study the formulation of fiber reinforced cementitious materials by the use of a few examples.

CHAPTER II: USE OF FIBRES IN CEMENTITIOUS MATERIALES

II.1. Introduction

Fibre concrete is a composite material (cement, aggregate, fibres and voids) which can be considered as homogeneous (same strength in all directions). The cement used is usually hydraulic cement (i.e. it sets and hardens after being mixed with water - even in the presence of excess water). The aggregates can be of various shapes and mineralogical natures and have dimensions varying from a few tens of microns to a few tens of millimetres.

The properties of fibre concrete depend on the quality of the matrix and the characteristics of the fibres. The matrix considered is identical to the matrix of common concrete with smaller aggregates. For reinforcement, the fibres are of various types. They come in different shapes and sizes related to processing technologies. Each of these categories of fibres gives concrete specific properties which depend on the nature, geometric shape, slenderness (the ratio of fibre length to fibre equivalent diameter) and fibre volume content.

The manufacture of fibre concrete is not about mixing a certain amount of fibres with existing concrete. The formulation should be adjusted according to the objectives of implementation and resistance. Fibres are added directly to the concrete mix. The effect of this addition is decreasing handling. For improvement, a higher amount of fine (sand and cement) should be used than for ordinary concrete. As regards the fibres, a short length and an average slenderness are used because there is a risk of forming balls which make processing difficult and adversely affect the mechanical behaviour. Plasticizers can also be used to obtain acceptable workability while keeping the water/cement ratio reasonable.

In this chapter, we are going to look into examples of formulation of different concretes in accordance with their objectives and quality.

II.2. The Fibre Concrete Matrix

In fibre concrete the cementitious matrix is different from that of ordinary concrete in that:

- The cement contents which are usually higher for fibre concrete (FRC) than for conventional concretes; vary from 325 to 450 Kg/m3 for a grain size of 0 to 10 mm.
- In order to improve workability and reduce the water content, fly ash can be used to replace part of the Portland cement, for example 50 to 100Kg/m3 of cement .
- It has an improved plasticity. Due to the lowering of the heat of hydration and fibre concrete thus has a lower cost.
- Water reducing admixtures also have setting retarding effects and usually facilitate the handling of fibre concrete on site. It is recommended that, taking into account the large dosages of cement generally used for fibre concrete, the amount of admixtures be kept at a level lower than that recommended for conventional concrete.

- The Water/Cement ratios used in fibre concrete must be the subject of special attention. The tendency to increase the water content which eliminates some of the beneficial properties expected from the addition of fibre should be avoided. In fibre concrete, water/cement ratios of 0.41 to 0.48 are usual. Applications to special structures, especially paving, result in lower W/C ratios (0.38 to 0.44) but this results in more difficulties in installation.

II.3. Some Cases of Fibre-based Concrete Formulation

II.3.1. Formulation of Fibre Reinforced Self-Compacting Concrete

We are going to take a look into the formulation of reinforced self-compacting concrete according to the experiment by Irki et al. [14] on the effect of the length and the volume fraction of wavy steel fibres on the behaviour of the concrete.

a). <u>Materials</u>

For all concrete mixtures, a local commercial Portland cement CEM II/B 42.5N was used. It has a Blaine fineness of 385 m^2/kg, density of 3150 kg/m3. The coarse aggregates were natural crushed limestone, with maximum size of 20 mm with a specific gravity of 2.53 kg/m^3. The fine aggregates were a combination of 40.17% of fine roller sand (with a fineness modulus of 1.00) and 59.83% of coarse limestone crushed quarry sand (with fineness modulus of 3.35) with fineness modulus of 2.80, specific gravity of 2.55 and water absorption of 1.52%.

Three SF lengths (35, 40, and 50 ± 2 mm) with six different Vf of 0.3, 0.5, 0.8, 1, 1.2, and 1.4% were used in SCC. The mixing water was local tap water. A polycarboxylic super plasticizer (MEDAFLOW 145) with specific gravity of 1.065 kg/m^3 was used to improve the workability of concrete mixtures. The SF used have a wavy form and are shown in Figure II.1. The physical characteristics of SFs are presented in Table II.1.

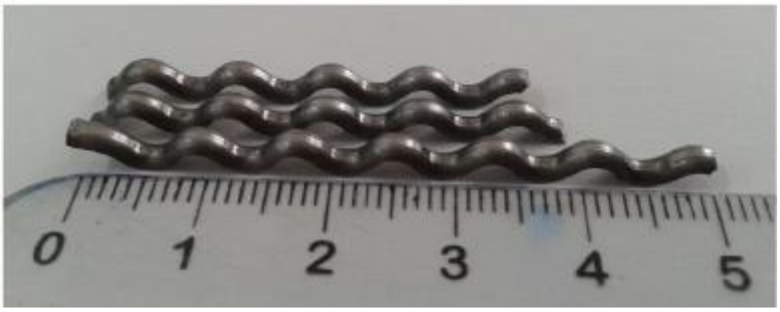

Figure II.1: steel fibres

TABLE II.1: Characteristics of SFs

Fibers	Type (1)	Type (2)	Type (3)
L (mm)	35	40	50
D (mm)	0.60	0.60	0.60
Aspect ratio (*l*/*d*)	58.33	66.66	83.33
Shape	wavy	wavy	wavy
Young's modulus (GPa)	210	210	210
Rupture elongation (%)	4	4	4
Tensile strength (MPa)	1180	1180	1180

b). <u>Mixing and Testing Procedures</u>

Fourteen mix designs with three families of SCC with SFs and a reference SCC (RSCC) without any fibres are made. The prefix F35, F40, and F50 (in **Table II.2**) are the length of 35, 40, and 50 mm of SFs used and Vf is the SF volume fraction in per cent of 0.3, 0.5, 0.8, 1, 1.2 and 1.4%. The mix proportions of all considering mixes are given in Table II.2. Rossi et al. [15] proposed a mix design method for fibre-reinforced concrete that was based on Baron–Lesage method. While the self-compacting formulation criteria's based on JSCE (Japanese Society of Civil Engineers) [16] were assured. The content of sand in the mortar was kept constant at 45% of volume of the mortar and 0.90% of Super plasticizer (Sp) by weight of cement. The SFRSCC mixing procedure is summarized in Figure 10.

TABLE II.2: Proportions of the SCC mixtures

Mixture	RSCC	F35-SCC-V_f					F40-SCC-V_f				F50-SCC-V_f			
Water/Cement	0.40													
Water (kg/m^3)	210													
Cement (kg/m^3)	524													
Fine agg. (kg/m^3)	803													
Coarse agg. (kg/m^3)	800													
Sp (kg/m^3)	4.72													
SF (%)	–	0.3	0.5	0.8	1	1.2	0.3	0.5	0.8	1	0.3	0.5	0.8	1
SF (kg/m^3)	–	15	25	40	50	60	15	25	40	50	15	25	40	50

The process of making SCC with fibres is the same as that of ordinary concrete with fibres. The SCC mixture is made in three steps. First, the cement is added to the aggregates and all are mixed in dry form for 30 s.

Figure II.2: Mixing procedure for FRSCC

After that 60% of necessary water was added and the material is mixed for 1 min and after, the rest of the water containing the superplasticizer is added and the material is mixed for

1 min. At the end, SFs are added and the material is mixed for 5 min. Two minutes of repose are taken and finally after that the material is mixed for 30s. To guaranty the homogeneous distribution of fibres inside concrete volume, some characteristics should be verified; the SFRSCC should be able to fill out the form with its weight. Besides, it should be of an acceptable level of resistance against segregation and able to pass through spaces between reinforcement bars, and finally, it needs to have a smooth surface after demolding [15, 16].

c). <u>Characterization of Fibre-Reinforced Self-Compacting Concretes</u>

The slump flow time and diameter tests are two common methods to determine the flow characteristics of unobstructed concrete in horizontal surface. A combination of both qualitative observations and quantitative measurements was applied to characterize this kind of material [17].

With the L-box test, it is possible to test the filling capacity and passing ability of self-compacting concrete. The concrete is put in the 'tower' of the device (height of 600 mm), either about 12.7 L of concrete. The concrete is preserved for one minute to see if there is segregation and then the pitfall was withdrawn. This test allows the characterizing of the mixture's viscosity. Besides, the presence of bar simulating armatures of a framing informs on the filling capacity of the mixture. After having raised the pitfall and once the out flow of the concrete finished, we measure the heights H1 and H2.

The V-Funnel test, developed by Okamura and Ozawa in 1995 allows the evaluation of the passing capacity of the concrete through confined areas with the measure of the outflow time to the funnel (in seconds). The funnel of concrete is filled and set to stand for 1 min. The test consists in observing the out flow of the concrete through the funnel and to measure the time of out-flow between the moment where the pitfall is free and the moment where we see the light by the opening. In order to determine the rheological properties of SCC, the measures and the acceptable minimal and maximal values should be in conformity with the EFNARC. [17].

Cubic (100 × 100 × 100 mm), prismatic (70 × 70 × 280 mm), and cylindrical (160 × 320 mm) specimens were used to evaluate the compressive strength, the splitting tensile strength, and modulus of elasticity of the concrete according to EN 12390-1 and 2,[12,13] EN 12390-5 [18] and ISO 1920-10 [19], respectively. All the moulds were covered by plastic sheets and stored for 24 h in the laboratory prior to demoulding afterwards; they were cured into water at 20°C. The tests are conducted at different test ages of 7, 28 and 90 days. Also to show the strength gain with the time, all experiments were performed on three specimen replicates.

II.3.2. Formulation of Ultra High Performance Fibre Reinforced Concrete

a). <u>The Principle of Formulation</u>

The formulation of UHPC involves the use of materials with very specific characteristics. The cementitious matrix of UHPC is composed of a large amount of cement, superplasticizer, silica fumeor optionally another ultrafine such as metakaolin, and fine sand whose maximum diameter size is between 0.5 and 4 mm. Ground quartz can be added in the case of heat treatment. A large dosage of metal fibres, greater than or equal to 2% by volume is generally incorporated into the matrix in order to improve the tensile strength and ductility of the material.

At present, there is no general method of formulating UHPFRC, but rather principles. These principles proposed by (Richard and Cheyrezy, 1995) [21], and (De Larrard and Sedran, 1994) [22] are based on different criteria:

- reduction of the Water/Binder ratio (W/B);
- improvement of the homogeneity of the mixture by reducing the size of the inert grains(aggregates);
- increase in fines content (cement and additions);
- improvement and optimization of the compactness of the granular skeleton;
- addition of fibres to improve the ductility of the concrete (≥ 2% by volume);
- possible improvement of the microstructure by heat treatment.

The approach adopted aims to reduce the porosity of the material and increase the compactness of the granular skeleton. For this, the W/L ratio is reduced to values below 0.2 thanks to the optimized use of superplasticizers which deflocculate fine particles [44].

Optimization of the granular backbone occurs at two levels. The first level consists in reducing the size of the aggregates to obtain a more homogeneous mixture and to limit the intergranular porosity. The second is to improve the compactness of the mixture by increasing the content of binder, which fills the gaps between the grains. The application of heat treatment is possible to further increase mechanical performance. Finally, the addition of fibres improves the ductility of concrete.

Wille et al., 2012 [23] proposed an experimental method for optimizing the UHPFRC matrix based on measurements of spreading and occluded air. It is known that the compressive strength depends not only on the Water/Cement (W/C) ratio, but also on the entrained air content. The relationships between the entrained air content and the spread values and between the entrained air content and the compressive strength are shown in Figure II.3.

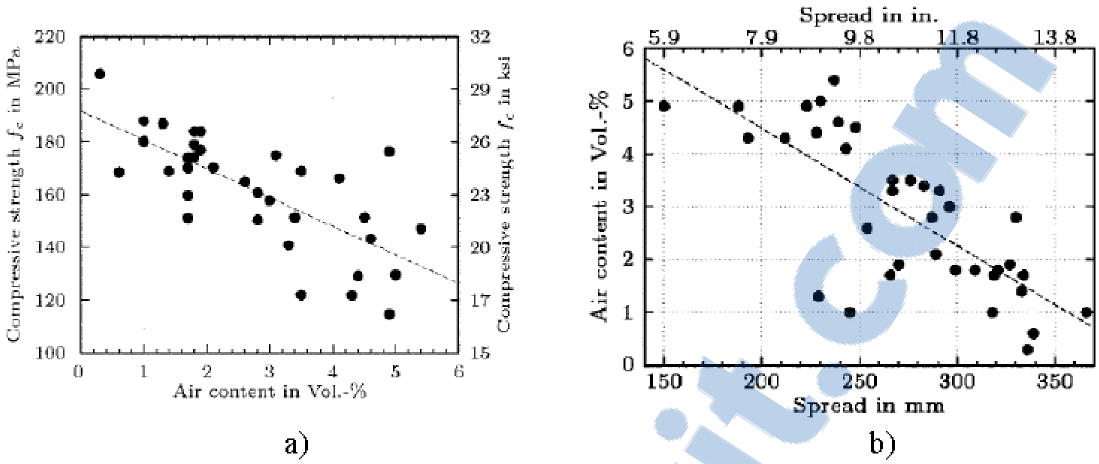

Figure II.3 a) Relationship between compressive strength and entrained air content

b) Relationship between spreading and occluded air according to Wille et al., 2012 [23]

In **Figure II.3a**, the high compressive strengths are obtained for a percentage of occluded air less than 2%. **Figure II.3b** shows low levels of occluded air when the spread varies between 250mm and 350mm. Thus, these results highlight evidence of the close link between behaviour in the fresh state and mechanical strength. If the material exhibits poor workability characterized by reduced spreading, it can entrain and trap, probably due to its high viscosity, a significant amount of occluded air which affects its compressive strength.

The addition of fibres can influence the compactness of the mixture significantly. Rossi, 1998 [24], has shown that the disturbance exerted by fibres on the granular arrangement increases with their length. If sufficiently short fibres are put in an agranular mixture, they can penetrate into an interstice of coarse grains without disturbing the real compactness. For a mixture with a close granular extent, the influence of fibres on each grain depends on the ratio of fibre length to grain diameter. If this ratio is large, the arrangement of the mixture is little disturbed by the presence of fibres, [25]

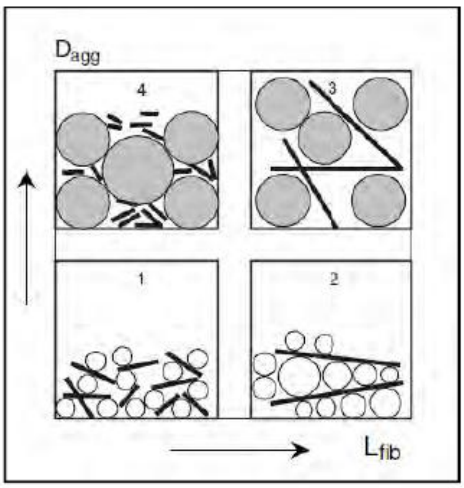

Figure II.4: Influence of fibres of different lengths and grains of different sizes on the compactness of the mixture according to (De Larrard and Sedran, 1999) [25]

Figure II.4 shows the interactions that exist between fibres of different lengths and grains of different sizes and their effect on the compactness of the mixture:

- When two grain diameters are combined that are small compared to the length of the fibres (case 2), the smaller grains can fill the voids around the long fibres. If the mixture contains two types of aggregates with sizes greater than the length of the fibres (case 4), the latter can be placed in the granular skeleton without creating significant disturbance. These two configurations provide the best compactness.
- Mixtures 1 and 3 are the most unfavourable for granular stacking. This is because these blends contain more empty spaces than the other cases, because they combine fairly comparable aggregate sizes and fibre lengths. Filling this surplus porosity therefore requires additional fines (cement + addition).

The study also showed that the combination of two types of fibres, microfibers and macrofibres, greatly reduces the compactness of the mixture. It is important to note that the fibre content in the mixture also influences the compactness of the mixture. Moreover, the fibres constitute a major part of the cost of the UHPC product.

b). <u>An Example of Formulations</u>

Typical UHPFRC formulations are generally established empirically, based on a few principles that we have just outlined. The first UHPC project was the construction of a pedestrian bridge in Sherbrook (Canada) in 1997. The composition of these concretes is detailed in **Table II.3**.

TABLE II.3: UHPC and UHPRC used for the construction of a footbridge in Sherbrook in Canada (Aïtcin et al., 1998)

	Cement	**Silica fume**	**crushed quartz**	**steel fibres**	**Sand**	**superplastifier**	**w/c**	**F_{cm}28**
Without fibre(kg/m^3)	750	230	210	-	1010	45	0.28	163
With fibre(kg/m^3)	695	225	210	200	990	45	0.28	217

We can see that these concrete, with or without fibres, use a large quantity of binder (from 920 to 980 kg/m^3). Crushed quartz is used in combination with high temperature heat treatment at 90°C to increase compressive strength.

The W/C ratio is reduced to a value of 0.28, which justifies a large dosage of superplasticizer. These concretes reached a compressive strength of 163 MPa without fibres and 217 MPa with 2.5% fibres by volume.

There are many UHPCs marketed such as Ductal® from Lafarge, BSI® from Bouygues, BCV® from Eiffage, and CEMTEC® from IFSTTAR, used on exceptional structures for which they are unrivalled. Their use currently is limited by their high costs associated with high dosages of expensive components (silica fume, cement, specific aggregates, metal fibres and superplasticizer). As an example, we presented the composition of UHPFRC from different suppliers in **Table II.4.** These UHPFRCs are marketed in the form of a pre-mix, the user agreeing to respect the supplier's instructions of the mixing procedure and heat treatment if necessary, as well as the water, adjuvant and fibre content to ensure the performance of the final product.

TABLE II.4: Example of formulation of FRHPC

	Ductal®	**BSI®**	**CEMTEC®**
Cement CEMI 52,5R	712	1114	1050
Silica fume	231	169	268
Crushed quartz	211	-	-
Fine sand (100-300 µm)	1020	-	514
Aggregates (0-6 mm)	-	1070	-
Superplasticizer	60.7	40	44
Steel fibres	156	234	858
Percentage volumic of fibres (%)	2	3	11
Heat treatment at 90 °C	yes	No	No
Water/cement ratio	0.2	0.19	0.2

Overall, these concretes incorporate a high amount of cement, in particular in the case of UHPC without high temperature heat treatment. In the case of Ductal®, we can note a lower cement content compared to BSI® and CEMTEC®, the high mechanical strengths being obtained through the application of a heat treatment at 90°C. Silica fume is used in the three products mentioned, at a content of 15 to 32% of the mass of cement. The fibre content by volume is 2 to 11%. The water/cement ratio is reduced to a value of 0.19 to 0.2, which justifies the use of a large amount of superplasticizer to maintain workability. Finally, fine sands are preferred in the case of Ductal® and CEMTEC®, while aggregates with larger dimensions 0-6mm are incorporated in BSI®.

c). <u>Laboratory Manufacturing</u>

The manufacture of UHPFRC requires a specific mixing procedure and type of mixer. Studies concerning the mixing sequence of UHPFRC are rare. An in-depth study by Cazacliu et al, [26] looked at the problem of mixing a UHPC.

To choose the type of mixer, preference should be given to mixers with a high shear gradient which have high dispersing power, such as the EIRICH R08W mixer recommended by Cazacliu et al, [26]. However, Bonneau et al, [27] showed that it is possible to make UHPFRC with a low volume ordinary concrete mixer, about half the maximum capacity on an industrial scale.

A manufacturing protocol was established by [26] with the use of the EIRICH R08W mixer to obtain good workability:

- pre-kneading dry materials for 1 minute;
- adding water and superplasticizer, the superplasticizer being mixed with water;
- wet mixing for 5 minutes at high speed (4.17 rpm);
- introduction of fibres, then kneading for 1.5 minutes.

According to this study, the mixing time is one of the dominant parameters which influence the mechanical properties of concrete. Five minutes wet mixing is sufficient for the matrix to achieve optimum mechanical properties. The excessive prolongation of the mixing with the fibres leads to an increase in the air content and therefore a drop in the mechanical properties of the hardened concrete. It is important to note that the introduction of fibres before the liquid phase (pre-mixing with other constituents) causes a decrease in flow properties, air entrainment, and a decrease in compressive strength and pressure elastic modulus. They therefore recommend the incorporation of fibres in a last step of the mixing sequence. The total mixing time obtained with this mixer is approximately 8 minutes. The latter can become very long, from 18 to 20 minutes, in the case of using a conventional mixer for ordinary concrete, which can lead to situation of resumption of concreting in the case of successive castings for the production of large volume parts.

II.4. The Advantages of Fibre Concrete by Domains of Application:

We can distinguish two ways of using fibres:

- Concrete reinforced with fibres alone
- Concrete reinforced with traditional reinforcements in which we introduce fibres (structural application of fibre concrete)

In the first case, the properties of the fibre concrete are used, which will be linked to the type of matrix used, that of the fibres, and the method of implementation adopted.

- Use of flexural properties, to produce thin shells.
- Improved holding of parts at a young age.
- Modification of dimensional variations, fight against cracking.

In the case of structural applications subjected to bending:

- The opening of cracks is reduced by 40%.
- Increase in rigidity after cracking.
- Little increase in ultimate resistance.
- Increase in shear strength.

In the case of structure with compression:

- Improved ultimate charge.
- No catastrophic rupture.

In the case of structures subjected to combined stresses:

- Improvement of resistance and rigidity obtained under simple stresses but that we do not necessarily find in the case of the behaviour of structures under combined loads.

In the case of a gantry:

- Increased overall stiffness by 25%.
- 100% increase in energy dissipation capacity.
- Better resistance to determinations in the face of cyclic loadings.
- Modification of the failure modes: shear, bending.
- For identical stiffness values the cracking phenomena are less important.
- Resistance to local destruction is better in the case of fibre concrete than with concrete alone.

In the case of shock type stress:

- Compared to concrete: the constitutive law of the material is strongly modified, the energy absorbed is greater, the impact duration is increased, and the modes of failure are different (location, bending-shearing-punching).

TABLE II.5: Applications of fibre-reinforced concrete

Applications	Benefits of adding fibre to concrete
Slightly stressed pipes and thin shells	-Improvement of the hold of the pieces at young ages - Modification of dimensional variations, fight against cracking
Pavements, concrete pavements, manufactured pavements, and structural elements subjected to bending	- 40% decrease in crack opening - Increased stiffness after cracking - Increased shear strength - Increased wear resistance
Structural elements subjected to compression (posts, piles, foundations ...).	- Improvement of the ultimate load - No fragile rupture
Structures subject to dynamic stresses (airport runway)	- Higher absorbed energy - Increased impact resistance - Law of behaviour of the material greatly improved
Repair of road surfaces, bridge decks	- Improved impact resistance - Improved deformability and durability
Parts exposed to strong temperature variations and even very high temperatures	- Successful replacement of refractory lining - Reduction in the cost of repairing refractory elements
Stabilization of rock walls, embankments, tunnels, and underground galleries	- Elimination of the work of fixing the mesh usually used - Reduction in the cost of repair and/or stabilization of rock walls and embankments
Manufacture of piles, fire-retardant insulating coverings, facade cladding panels	- Increased impact resistance

	- Increased resistance to wear - Increased coating durability

II.5. Conclusion

In this chapter we have realised that there is no one way but plenty of formulating fibre influenced concretes depending on the objective of the end product. Most fibre reinforced concretes are formulated using the mix design method.

In the following chapter we are going to be looking into how the physical aspects of these fibres influence the behaviour of concretes in both fresh and hardened states.

CHAPTER III: INFLUENCE OF FIBRES ON THE CHARACTERISTICS OF CEMMENTITIOUS MATERIALES

III.1. Introduction

The aim for this chapter is to research the key factors length, ratio and dosage of steel fibres as well as distribution and orientation of fibres within fibre reinforced concrete matrix. We will also discuss the influence of fibre positioning on the mechanical properties which include compressive strength, flexural strength, flexural toughness/energy absorption and the residual flexural strength by which ductility through the post-cracking strength of the fibre reinforced concrete examined.

III.2. Dosage of Fibres in Concrete

A. Rheological Properties

The effects of the dosage of fibres in the concrete matrix on the rheological properties of fibre reinforced concrete have been studied. The values of slump tests carried out on fresh plain concrete as well as fresh steel fibre reinforced concrete with varying fibre dosages for the workability vary between 15 and 140 mm for ordinary concrete. From the results of the slump test from a thesis by Olubisi A. Ige 2004, [42] it can be deduced that there was a decrease in slump values as dosages of fibres increased in concrete, which was connected with effect of 'fibre balling' which is very much noticeable at higher fibre dosages in the concrete.

The inclusion of steel fibres in concrete had a negative effect on the workability of the concrete mixture as checked by the slump test; it reduced the workability. These results are also in agreement with the results of previous studies on the workability of steel fibre reinforced concrete, [32].

B. Shrinkage and Mechanical Properties

The effects of dosage of fibres (otherwise referred to as fibre content) in the concrete matrix on the mechanical properties of fibre reinforced concrete have been explored by many researchers because of their outstanding influence on the transformation of the resulting composite from brittle to ductile material.

- Eddy (2012),[28] has reported that high dosage of steel fibres distributed in the right order into fresh concrete will control and re-distribute the stresses that occur during the shrinkage of concrete and bridge the cracks that appear in hardened concrete thereby providing a degree of post-cracking load transfer which also helps to prevent micro–cracks from developing into macro cracks, which means, with fibre dosage rates of between 30 and 50kg/m^3, steel fibre reinforced concrete typically shows partial ductile behaviour.

• The effect of volume fraction of steel fibres on the mechanical properties of high performance silica fume mortars has been carried out where four different volume fractions of 0.5 %, 1.0 %, 1.5 % and 2.0 % and two different lengths of steel fibres, 6 mm and 13 mm were used. It was found that the flexural strength and toughness of mixtures with steel fibres were significantly better than that of the control mixture without steel fibres. Also, the test results showed a drastic improvement of the mechanical performance at higher fibre dosages with longer fibre resulting in better performance which was also pronounced at higher fibre dosages. **Figure III.1** shows a typical result from the study, of load-displacement curves with a particular steel fibre and different dosages in concrete mixture, [29].

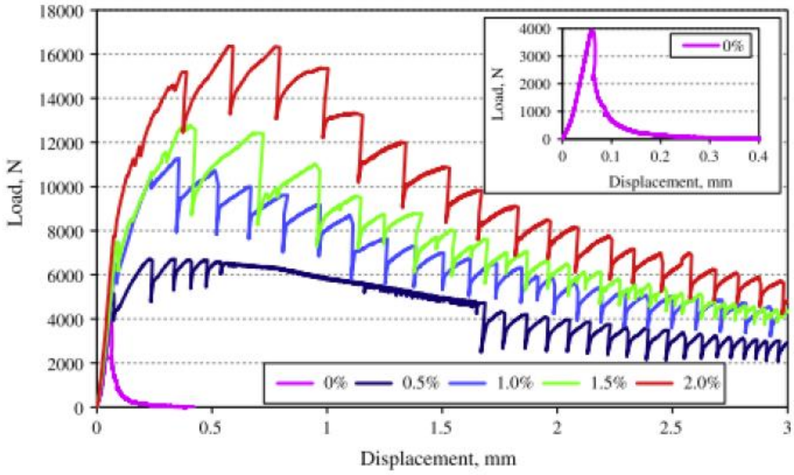

Figure III.1: Load-displacement curves of concrete mixture of different fibre dosages [29].

Results from other previous studies have shown a reduction in workability of fresh concrete with increase in steel fibre dosages in concrete matrix, however, more studies have concluded that an increase in the volume fraction of the fibres in the concrete mixture led to an increase in the post-cracking strength and it increased the first peak strength, the peak strength, the residual strength as well as the flexural toughness of the composite material, [30]. All other research works considered on steel fibre dosage in concrete concluded in agreement with the findings of Aydın and Baradan [29] on the importance of fibre dosage in ductility behaviour of steel fibre reinforced concrete and how the effects of any other parameters were more pronounced at higher dosages of steel fibres in concrete, [31].

• The 28-day compressive strength results conducted on 100 mm cubes showing the influence of steel fibres in **Figures III.2 and III.3**. It can be deduced that there is not a significant increase in the compressive strength initiated by increasing the steel fibre dosages in the mixture. The results do show a slight improvement in the compressive strength by the addition of steel fibres in most cases while reductions in compressive strength are also noticed in a few cases after the addition of fibres. The mean strength of Steel Fibre Reinforced Concrete was between 57.7 to 64.9 MPa for 10mm aggregates and 58.1 to 68.1 MPa for 20 mm aggregates respectively while plain concrete had 59.2 MPa for 10 mm maximum aggregate size and 59.7 MPa for 20 mm maximum aggregate size. The maximum increase in compressive strength brought about by the inclusion of steel fibres in

10 mm maximum aggregate size mixtures is about 5 MPa, translating to about 9% increase while that of 20 mm maximum aggregate size mixtures recorded the maximum increase of about 8 MPa, which is a 14 % increase.

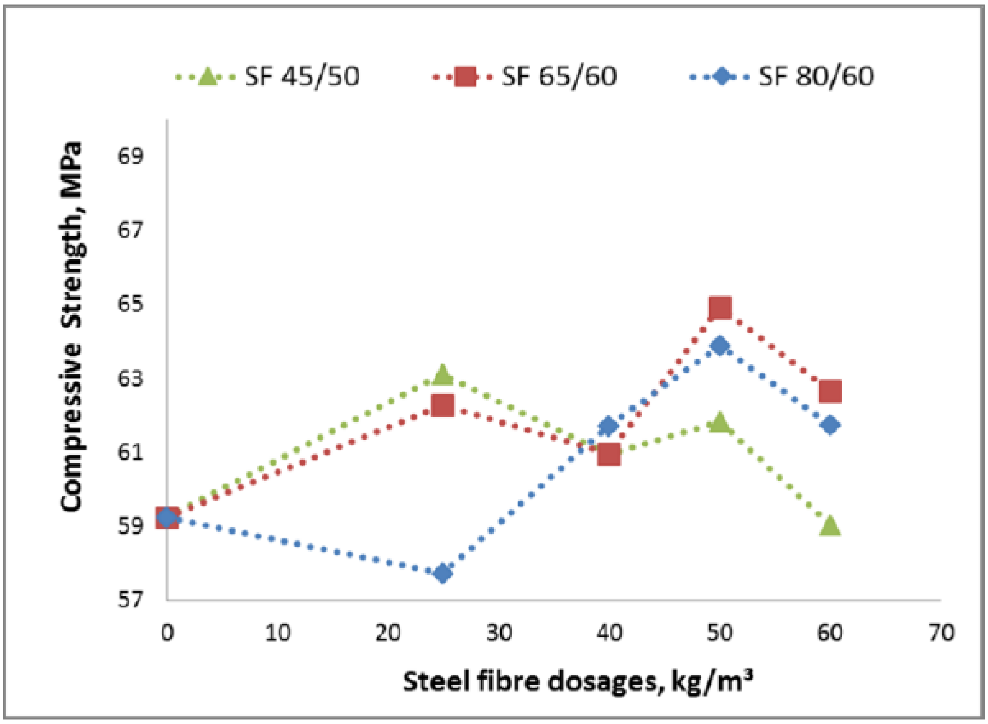

Figure III.2: Relationship between compressive strength and dosages of different fibres with 10 mm aggregate size, [42]

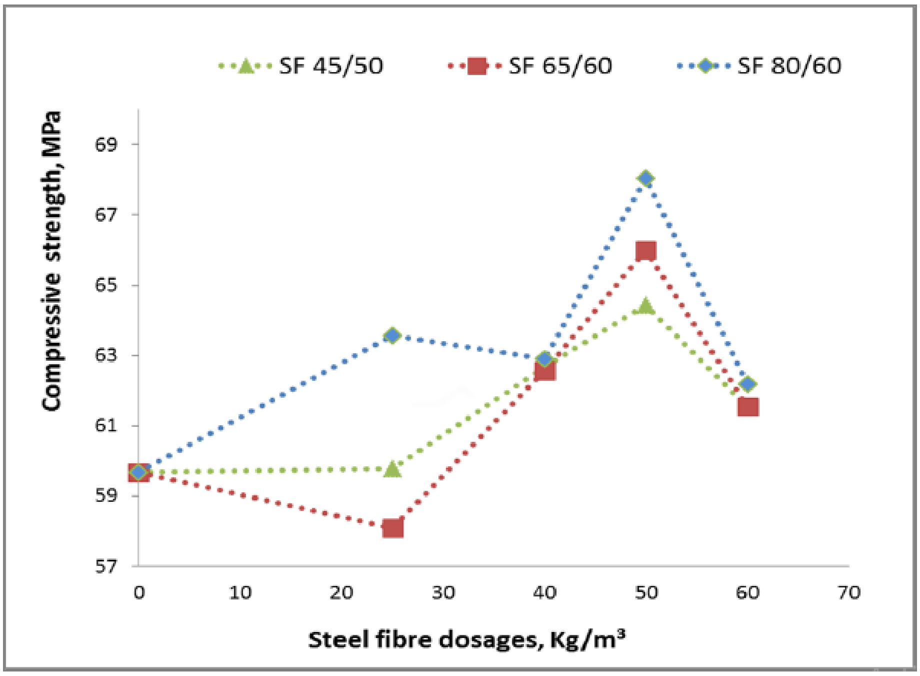

Figure III.3: Relationship between compressive strength and dosages of different fibres with 20 mm aggregate size, [42] The compressive strength of SFRC as shown in the results increases with increase in fibre dosage until optimum compressive strength was achieved at 50 kg/m³ fibre dosage. The steel fibre 80 l/d and 65 l/d gave the optimum strength at 50 kg/m3 dosage, from this it can be deduced that the compressive strength ascending and then declining with increasing fibre dosage is due to compaction effects on the mixtures. The highest dosage of steel fibre in this research work which is at 60kg/m3 in concrete made the compaction of the mixture more difficult to be accomplished, this resulted in much lower strengths as seen in all the mixes.

• Flexural toughness of steel fibre reinforced concrete beam specimens under the load – CMOD (crack mouth open displacement) curve is obtained from a flexural test of the beams while the residual flexural strength is a concept of characterising the flexural toughness and evaluate the post-cracking response of steel fibre reinforced concrete material. The flexural toughness average values of three specimens of steel fibre reinforced concrete beams are presented in **Figure III.4**. The influence of steel fibre inclusion in concrete is more significant in flexural toughness and residual strength of the composite as the ductility parameter of the material is appropriately measured.

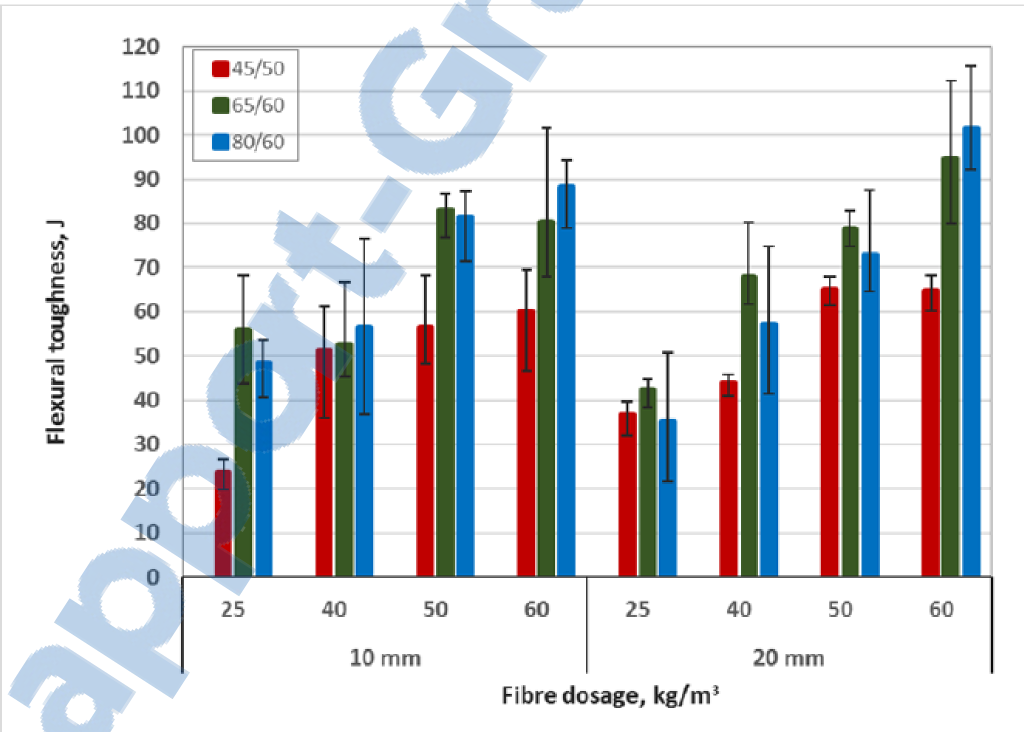

Figure III.4: Flexural toughness (mean) of SFRC beams at different dosages of steel fibres. 10 mm and 20 mm denote maximum aggregate sizes, (Olubisi A. Ige, 2004)

From the presented results in **Figure III.4**, it clearly shows that the flexural toughness of steel fibre reinforced concrete increased substantially as the dosage increased irrespective of the fibre geometry (length and aspect ratio) and maximum aggregate size.

The trend that has been noticed in the values of the flexural toughness was the same regarding the flexural strength results in the case of influence of dosage, aspect ratio and length of steel fibres on the performance of steel fibre reinforced concrete, but more clearly pronounced in the flexural toughness results, especially in the post-cracking region of the curve. The mixes of 10 mm maximum coarse aggregate size with steel fibre 45/50 (aspect ratio of 45 with 50 mm length) at 25 kg/m^3 dosage of steel fibre in concrete had the lowest performance in flexural toughness with value of about 23J, while the highest value of about 100J was obtained from mixes of 20mm maximum coarse aggregate size with steel fibre 80/60 at 60kg/m^3 dosage. Consequently, there existed the differences of about 78J between the lowest and highest value of flexural toughness which translated to 332% increment. Besides, the highest value of flexural toughness in 10 mm maximum aggregate size mixes is about 88J obtained from the mix containing steel fibre 80/60 at 60kg/m^3 dosage, hence, there existed differences of flexural toughness values of about 13J, translating to an increase of 15% between the highest values recorded in 10mm aggregate and that of 20mm maximum aggregate with mixes containing same steel fibres of 80/60 at the same dosage 60kg/m3 but of different coarse aggregate sizes.

• The good performances of the specimens at high dosages of steel fibres observed from the results have a significant influence on mechanical properties of steel fibre reinforced concrete, especially ductility parameters. The more steel fibres in the concrete the greater the enhancement of energy absorption and post-cracking ability to carry the imposed load. The lowest values of flexural toughness recorded at 25kg/m3 and with mixes containing steel fibres 45/50 could be due to two facts; firstly, the length of fibres which makes it possible for them to get pulled out easily resulting in not being able to bridge the initial cracks as expected. The second factor is the numbers of fibres that are readily available to do the 'bridging' of the crack. Again, considering the fibre networking through which theoretical calculation of number of fibres in each specimen is done revealed that fibre 45/50 type of fibre has the least number per each specimen. Since the dosage is low, this also affected the number of fibres in the mix, and hence the adequate distribution within the matrix. The outstanding performance of fibre reinforced concrete at higher dosage of steel fibres was made possible because there were more steel fibres in the matrix to bridge the crack at micro-crack level and stop the propagation into macro-crack.

III.3. Geometry of Fibres in Concrete

Geometry of fibres relates to the shape, length, surfaces and the diameter of the fibre. Usually, when referring to a particular type of steel fibre, shape and surfaces are already defined and the geometry can be referred to as fibre dimension which specifically relates to its length and diameter, and hence the fibre aspect ratio. Aspect ratio is the ratio of the length to diameter of a fibre. In general, the most common steel fibre length is said to vary from 12.7 mm to 63.5 mm and the diameters are in range of 0.45 mm to 1. O mm, [33]. **Figure III.5** shows a typical hooked end steel fibre that is glued for easy dispersion during mixing.

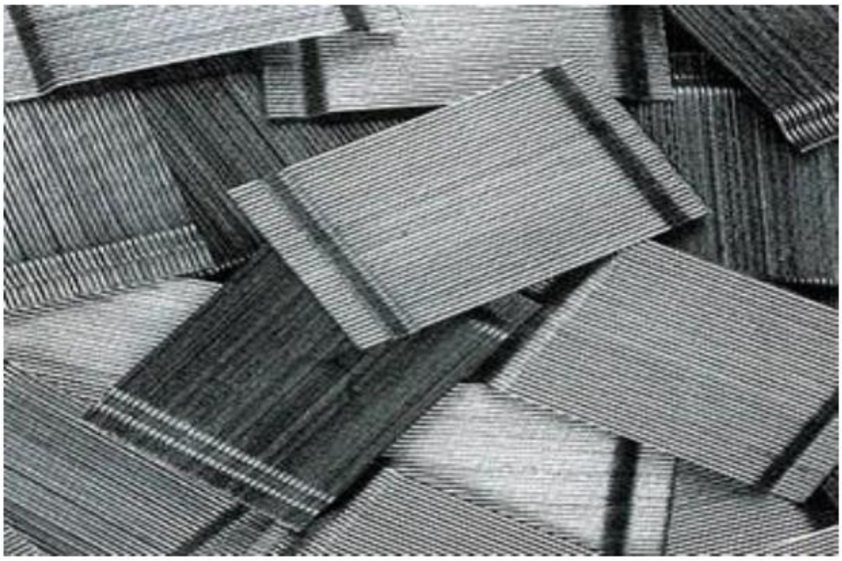

Figure III.5: Typical glued high strength hooked end steel fibres

The aspect ratio of steel fibre has been noted as one of the key factors that influence the mechanical properties of SFRC, The Portland Cement Association (1991) reported that bond between fibre and matrix increases as the length of the fibre increases, hence, the longer the fibre the greater the strength of the composite which makes it desirable to have a long fibre sufficient to induce enough stress in the fibre for a tensile failure to occur. This is usually difficult to attain since fibres with aspect ratios greater than 100 are not able to disperse freely and not workable resulting in balling effects, [34].

Other investigations have studied the effects of length and often, the aspect ratio of fibres on the resulting composite materials and have concluded that the fibres with high aspect ratio decreased the workability of concrete mixtures while split tensile strength of the test samples increases with the increasing aspect ratio and flexural strength of SFRC was significantly improved with increasing l/d ratio as well. Longer fibres show better results where the same fibre types (the hooked end steel fibres) and dosage but different aspect ratios were used [34]. Investigating steel fibre reinforcing characteristics on concrete has observed that longer fibres have tendency to get aligned along the direction of the beam axis thereby affecting the orientation of fibres in the concrete.

We are going to be analysing the effects of the geometry of fibres in concrete using the results of an experiment of Factors Affecting Distribution and Orientation of Fibres in Steel Fibre Reinforced Concrete and Subsequent Effects on Mechanical Properties done by (Olubisi A. Ige, 2004).

III.3.1. Length of Steel Fibres

One other factor that could be responsible for steel fibres positioning in the concrete matrix is the length of the fibres. This variable is very crucial when considering the post-cracking tendency of steel fibre in concrete as well. Two fibres of 60 mm and 50 mm in length have been considered in this research, investigating the effects of the length in the interaction ability of the steel fibres with other components of the concrete and how this is demonstrated in fibres' orientation and distribution and hence, the result in mechanical properties of steel fibre reinforced concrete. Details of steel fibres used in this research work are given in **Table III.1** by, (Olubisi A. Ige, 2004)

III.3.2. Aspect ratio of steel fibres

As defined in the previous chapter, the aspect ratio of steel fibre is the ratio of length to diameter of the steel fibre. It shows how thick or slim a fibre is and this can also affect the interaction with other components of the concrete. For this study, steel fibres of aspect ratio 45, 65 and 80 were used for the investigation, [31]. The research also studied the different aspect ratios but of the same length (details in Table III.1). The length was 60 mm with different aspect ratio of 65 and 80.

Fibre Series		TYPE I	TYPE II	TYPE III
Material properties	Tensile Strength	1115 MPa	1160 MPa	1225 MPa
	Young's Modulus	±210000 MPa	±210000 MPa	±210000 MPa
Geometry	Hook Shape (3D)			
	Length	50 mm	60 mm	60 mm
	Diameter	1.05 mm	0.90 mm	0.75 mm
	Aspect ratio (l/d)	45	65	80
Fibre network		2802 Fibres/kg	3183 Fibres/kg	4584 Fibres/kg

TABLE III.1: Steel fibre properties, (Olubisi A. Ige, 2004)

III.3.3. Slump Test

From slump by, (Olubisi A. Ige, 2004), It can be seen from the results that the mixes of fibre length of 60 mm and aspect ratio (l/d) 65 and 80 with 10 mm maximum aggregate size gave the least slump values of 15 mm and 18 mm respectively at 60 kg/m^3 dosage.

III.3.4. Flexural strength

In an experiment by, (Olubisi A. Ige, 2004) on the flexural strength, each type of concrete mixture is denoted according to its constituents, the type of steel fibre which is 'aspect ratio/corresponding length of the fibre' and the maximum coarse aggregate size. For example, 45/50 + 10 mm refers to the concrete mix which contains steel fibres with aspect ratio (l/d) of 45 and length 50 mm in a concrete mix of 10 mm maximum coarse aggregate size.

The results from (Olubisi A. Ige, 2004) show graphs of flexural stress versus Crack Mouth Opening Displacement (CMOD) relationship of the notched beams determined by three-point bending tests. The results show the effects of, various dosages of steel fibres in concrete, fibre geometry, 10 mm and 20 mm maximum aggregate size in the mixes, and in comparison with plain concrete. Crack Mouth Opening Displacement is used to describe the change in distance, normal to the crack plane, between the two faces of a fatigue-cracked notch in a fracture toughness test specimen

The results of flexural strength reveal that the addition of steel fibres to concrete remarkably improves the strength of steel fibre reinforced concrete when compared to plain concrete as there were up to 83% and 54% increases in maximum stress reached for concrete with maximum coarse aggregate sizes of 20 and 10 mm respectively. The important factors affecting the performance of SFRC are revealed in the results shown. The significance of the length of the fibre can be clearly recognised from the results as the shorter fibre length of 50 mm exhibited the least flexural strength when compared to results from another beam containing steel fibres of length 60 mm. This pattern is seen in all dosages of fibres. The improvement in flexural strength from plain concrete to the highest strength recorded for mixes containing fibre length 50 mm is about 40%. The post cracking tendency of the SFRC beams is also affected by the length of the fibre. Most of the results from beams containing steel fibres of 50 mm length had the first cracking value as the highest flexural value achieved yet results from beams containing steel fibres of 60 mm length show a better post cracking capability.

It could also be observed that effectiveness of SFRC is dependent on fibre aspect ratio as the best result in flexural behaviour is with the highest aspect ratio of 80. The thinner fibres remarkably improved the flexural strength of SFRC and the matrix with the fibres l/d 80 resulted in better post-cracking strength which is in line with earlier studies by Gopalaratnam and Gettu (1995), [35]. This is due to the fact that fibre with aspect ratio 80 has the highest quantity in every mixture according to the fibre properties in Table II. The fibre dosage was by mass, resulting in different numbers of steel fibres in a mixture depending on their length and diameter. Fibre aspect ratio 80 having a 0.75 mm diameter had the highest number in the beam samples.

The bar chart showing the average response of maximum stress of the three specimens at 50 kg/m3 dosage of steel fibres is presented in **Figure III.6**. The results as shown in the mean values of maximum stress are slightly different from those presented in the typical values in relation to better performance of 20 mm maximum aggregate size.

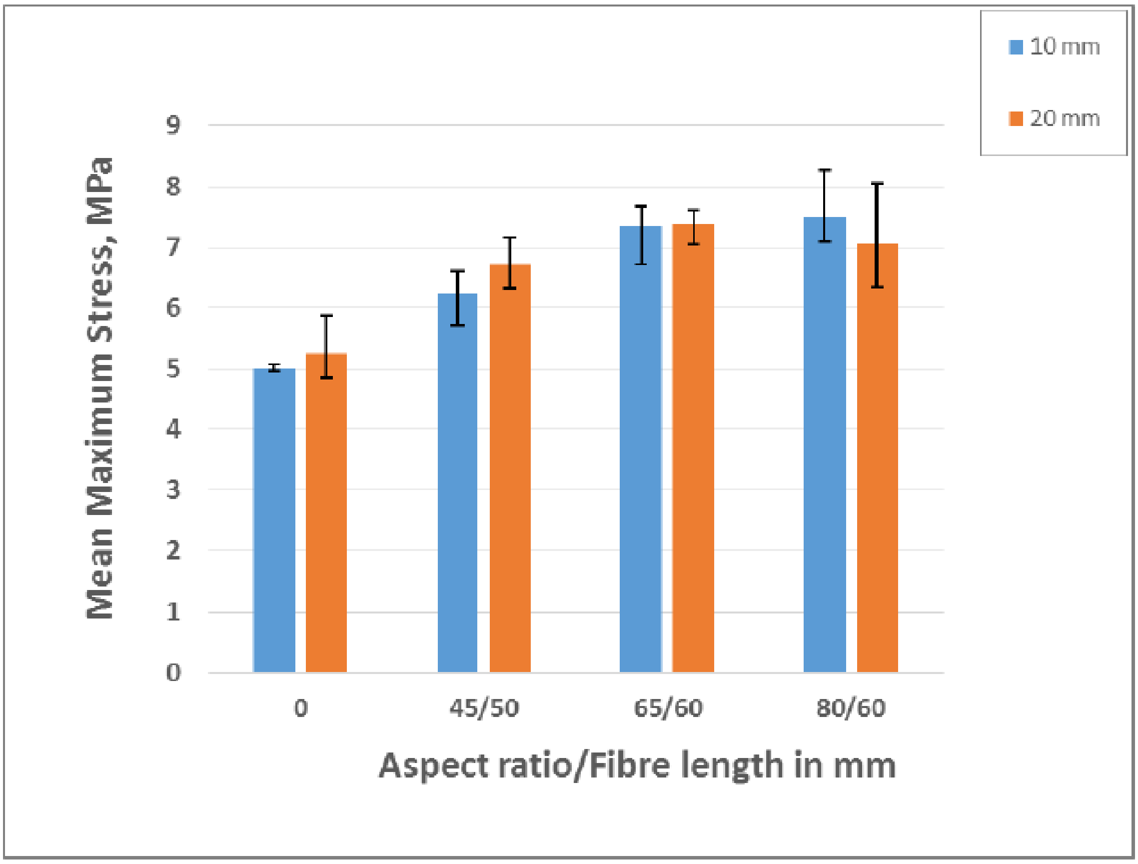

Figure III.6: Mean maximum stress of plain and steel fibre reinforced concrete beams, (Olubisi A. Ige, 2004)

The flexural behaviour of steel fibre reinforced concrete beams as represented by maximum stress of the beams revealed that concrete mixtures of both 10 mm and 20 mm maximum aggregate size performed relatively better side by side with best performance recorded for the mixture containing steel fibre of higher length of 60 mm.

III.3.5. Flexural Toughness and Residual Strength

The geometry of steel fibre especially the length and aspect ratio have been equally and distinctly identified from the results to affect the flexural toughness of the beams. Concrete mixtures containing steel fibres of 60mm length are in the highest range of toughness value while mixtures with steel fibres of 80 aspect ratio performed best in strain hardening and hence, giving the overall best results.

Also, the second best performance in all the beams tested for flexural toughness was recorded against the mixes of 20mm maximum coarse aggregate size at dosage 60kg/m^3 containing steel fibres 65/60. This means that beams with the same dosages of fibres, containing steel fibres of the same length of 60mm and same maximum coarse aggregate sizes of 20mm have demonstrated both best and second best performances of flexural toughness in the test carried out on beam specimens. But, the only differences between these two mixtures are the aspect ratios. While the concrete mix of steel fibre of aspect ratio 80 had the best result, the concrete mix containing steel fibres of aspect ratio 65 was recorded as having the second best result. There was therefore a difference of almost 7J between the two mixes as a result of differences in the thickness of the fibres in the concrete mixes. These results identified aspect ratio as a factor influencing post-cracking performance of steel fibre reinforced concrete.

III.4. Distribution and Orientation of Fibres in Concrete

Orientation and distribution of fibres within the concrete matrix is crucial for the utmost performance of the material. The understanding and good knowledge of the positioning of fibres in concrete and the way it affects the mechanical properties of the concrete will help in the development of structural design procedures which will fully promote fibre reinforced concrete as a cloth that exhibits its strength after the concrete cracks. To optimize the contribution of fibres for controlling crack width, it's important to gauge the distribution and orientation of the fibres. Fibres are simpler when aligned mainly within the direction of the principal stresses, [36]. **Figure III.7** shows the proper alignment of fibre in concrete matrix at right angle to the crack formation, during which fibres are ready to bridge the cracks as they form. The fibres gave in effectively when in a parallel position to the direction of crack propagation.

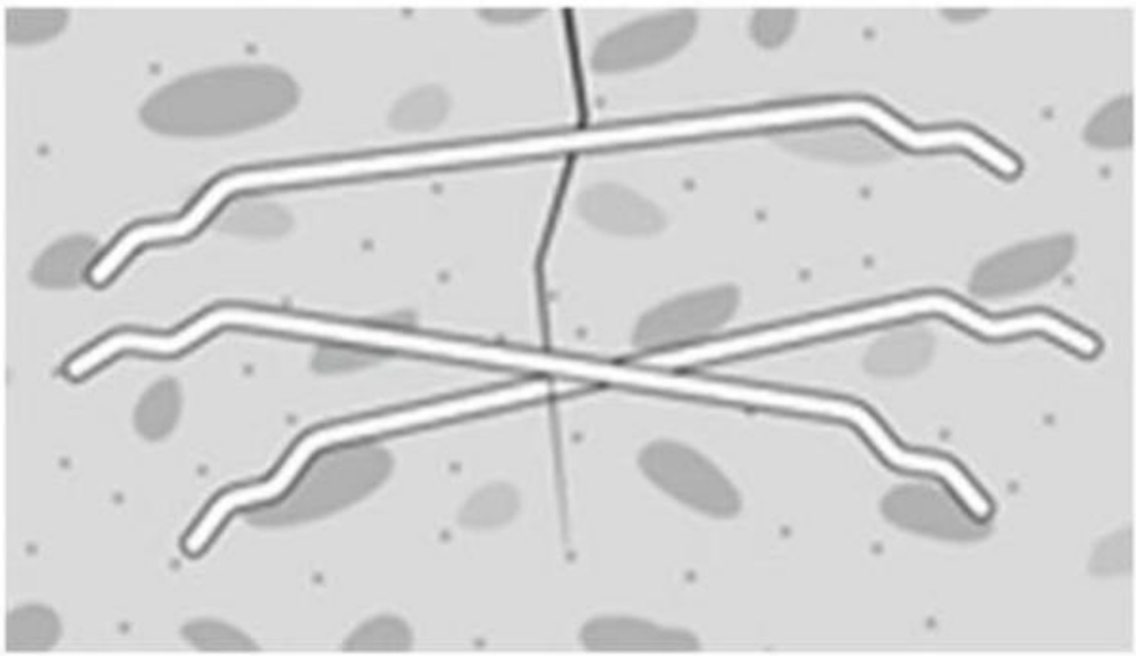

Figure III.7: Fibre alignment in concrete matrix

In a study conducted by Barnett et al., [37] steel fibre of 13 mm length and dosages of 2% and 4% by volume, thickness of panel of 25 mm and 50 mm and three patterns of panel casting, from centre, randomly and from edge were employed as variables. The researchers investigated the effect of fibre distribution and orientation on flexural strength of ultra-high performance fibre reinforced concrete using electrical resistivity measurement and confirmed by X-ray computed tomography imaging. In the study they explored how pouring specimens in different ways could influence the orientation and hence the flexural strength of the panels used for the experiments was determined. It was reported that panels poured from the centre were found to have the highest strength since fibres tend to align perpendicular to the flow of the concrete. The study also affirmed that fibre orientation has a significant effect on the flexural strength and other mechanical properties of UHPFRC in particular and fibre reinforced concrete in general, suggesting that fibre orientation and distribution should be considered during structural design of steel fibre concrete materials.

In another study conducted by Wang and Wang (2013), [38] the dynamic and static properties of steel fibre reinforced lightweight aggregate concrete were examined. It had been reported that the toughening mechanism of fibres within the concrete, especially on the impact resistance, comes mainly from great deal of energy absorbed in de-bonding, stretching of steel fibres and intrinsically occurs and acts after the cracks emerge in concrete. It had also been indicated that when concrete cracks, the randomly oriented fibres arrest a micro cracking mechanism and limit crack propagation, the direct advantage of which is to enhance the strength and ductility of the concrete.

Michels et al. [30] in a related study investigated post-cracking behaviour of SFRC and reported that crucial impact factors are the fibres' dispersion in the cement matrix and orientation in the direction of the applied stress. The study further showed that the dispersion of the fibres through the concrete volume and the fibre alignment in the matrix are both governed by several influence factors during production, such as concrete consistency at fresh state, casting direction, compacting technique, formwork dimensions, and concrete composition. Also, stated as part of the findings of the study was the fact that a perfect fibre alignment in stress direction offers the highest fibre efficiency resulting in higher post-cracking strength than for a random orientation. These results are in agreement with the earlier research findings of Barnett et al., [37].

III.4.1. Workability, Fibre Distribution and Post-cracking Behaviour of SFRC

The relationships between the performance or the workability of SFRC at fresh state and the distribution of fibres in the hardened concrete with the effects on the mechanical properties, especially, post-cracking behaviour of the composite material have been studied. In a study where we analysed the correlation between workability, fibre distribution, and mechanical properties of SFRC, Ferrara and Meda, [39] aimed at optimising the fresh and hardened state properties of SFRC to assess the reliability in a series production of precast SFRC roof elements. They recognised that a homogeneous distribution of randomly oriented fibres is an important point in guaranteeing a suitable structural performance. The researchers employed fibres of length 30 mm and aspect ratio 45 at 70 kg/m3, 50 kg/m3 and 30 kg/m3 dosages with slabs of different thickness as test subjects while concrete mix designs were without the effects of vibration (a self-compacting concrete) the main cause of fibre segregation. Comparison was made with vibration-compacted SFRC in the investigation. X-ray studies were also carried out on the cores from the test specimens. It was observed that usage of viscosity enhancing admixture was effective in producing a rheologically stable fresh concrete resulting in homogeneity of fibre distribution along the casting direction. In addition, when the mechanical properties of both materials were analysed, it was observed that despite a lower compressive strength, the concrete mix design that needed no vibration, SCSFRC has almost the same first cracking strength as SFRC and a better performance in its toughness due to better bond between concrete and fibre matrix and more uniform distribution of fibres within the concrete because the concrete mass was not influenced much by casting processes of vibration leading to fibre-concrete segregation.

In a related study, [36] studied the experimental connectivity of distribution and orientation of fibres (noted to be affected by flow ability of concrete) to the post-cracking behaviour of steel fibre reinforced self-compacting concrete (SFRSCC) of hooked-end steel fibres (with a length of 33 mm, and an aspect ratio of 60) using panels that were cast from the centre point and cylindrical specimens extracted from the panels. The cylindrical specimens were notched either perpendicular or parallel to the direction of concrete flow and the post-cracking behaviour of the materials assessed by both uniaxial tensile tests and splitting tensile tests while on the other end, high resolution digital camera and Image software were used for distribution detection and fibre orientation. The results of the study showed that the wall effects are negligible since the casting process adopted was from the centre and the flow velocity is uniform and diffuses outwards radially from casting point showing also that fibres tend to orient themselves perpendicular to the concrete flow direction. Also, in the case of distribution and orientation influence on cylindrical specimens, it was reported that in the series with crack plane parallel to the concrete flow direction, there were significantly higher post-cracking parameters than the other case with a perpendicular crack plain to concrete flow direction as a result of the earlier case possessing higher numbers of effective fibre intersecting the parallel crack plain than the later which showed less fibres in the orthogonal crack plain.

III.4.2. Influence of Fibre Orientation on Compression and Bending Behaviour

As for the influence of the distribution and orientation of fibres in concrete, we are going to be analysing results from the experiment by Bensaid Boulekbache et al., [41] on INFLUENCE OF THE RHEOLOGY OF METALLIC FIBER REINFORCED CONCRETE ON THEIR MECHANICAL PROPERTIES.

III.4.3. Compression Behaviour

The compression tests are carried out according to the standard (NF EN 12390-3) on three cylinders (11x22cm). The presence of fibres slightly reduces the compressive strength, [40] or at most does not influence it. The fibres reduced the compressive strength by 7%, 6% and 5% for Fibre Reinforced Conventional Vibrated Concretes (FRCVC), Fibre Reinforced Self-Compacting Concrete (FRSCC) and Fibre Reinforced High Performance Concrete (FRHPC) respectively. In fact, fibres work efficiently when subjected to tension. They thus prevent the propagation of cracks. During crushing under compression, this role is significantly reduced or even non-existent in the pre-cracking phase, even inducing additional defects in the matrix which can lead to low compactness. The pre-peak behaviour is therefore logically almost identical with or without fibres. In contrast, the presence of fibres improves post-peak behaviour and reduces the downward slope of the stress-strain curve (**Fig. III.8**). This observation is particularly spectacular when it comes to FRHPC.

DEFINITION OF TERMS: BAPF – FRSCC

BOF - FRCVC

BHPF – FRHPC

BAP – SCC

BO – CVC

BHP - HPC

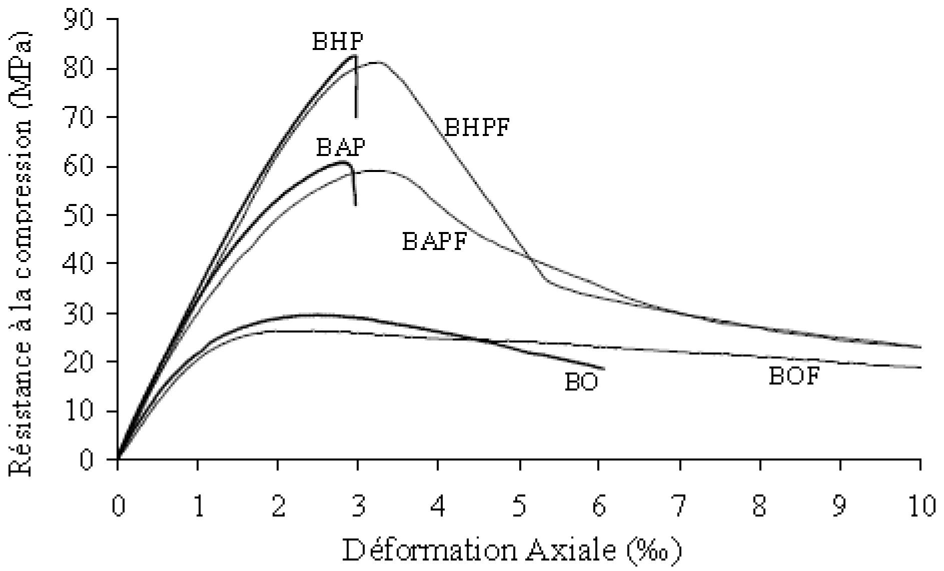

Figure III.8: Effect of fibres on the behaviour in compression according to the type of concrete, [41]

III.4.4. Bending Behaviour

The test consists of breaking the 15x15x70 cm prismatic specimens in four-point bending. The displacement is controlled at a speed of 0.004 mm / s.

The HPC tested logically had the greatest resistance (**Table III.2**). It is 17.5% higher than that of SCC and 13.31% higher than that of CVC. In the fibre configuration, the role of the fibre is activated if it is oriented in the direction of traction. This efficiency is more important for high performance concretes, thanks to good adhesion of the fibre-matrix couple. Note however, that the effect of rheology, in particular the shear threshold, is fundamental. Regarding fluid concrete, the distribution of fibres observed is homogeneous. Moreover the fibres are oriented in the direction of the tensile stress induced by bending. On the other hand, in plastic concretes (high shear threshold), one notices a random orientation and a partial detachment of the fibres pre-glued in plates.

In the end, only the orientation of the fibre and therefore the rheology had a very significant influence on the flexural strength of the beams. Quantitatively, an increase in flexural strength of 60%, 66% and 114% respectively for FRCVC, FRHPC and FRSCC is observed in comparison with non-fibre concretes.

TABLE III.2: Bending resistance parameters, [41]

MIX	ORIENTATION FACTOR α	1st CRACK DEPTH	FINAL CRACK DEPTH	FORCE AT 1st CRACK	FORCE AT FINAL CRACK
FRC	0.60	0.110	1.794	17.44	27.99
FRSCC	0.66	0.154	3.458	19.08	40.77
FRHPC	0.35	0.100	0.794	18.14	33.21

Ductility was consistently much higher for FRCVC and FRSCC (**Fig. III.10**) showing the importance of fibre orientation compared to concrete strength. FRSCC consistently exhibited better ductility compared to FRCVC and FRHPC (**Fig. III.9**). This shows the importance of the distribution and orientation of the fibres compared to the strength of the matrix. The efficiency of the fibre is certainly improved when the cementitious matrix is dense, ensuring better fibre-matrix adhesion, the fact remains that the orientation is the essential parameter to activate the transfer of charge towards the fibre. This transfer of load from fibre to fibre is at the origin of the multi-cracking observed in the case of FRCVC and FRSCC. Conversely in the case of HPC, localization of forces at mid-span leads to localization of cracking without the possibility of transfer, as observed on fluid concretes. In summary, the threshold stress of the concrete was the determining parameter of the performance of the behaviour in bending.

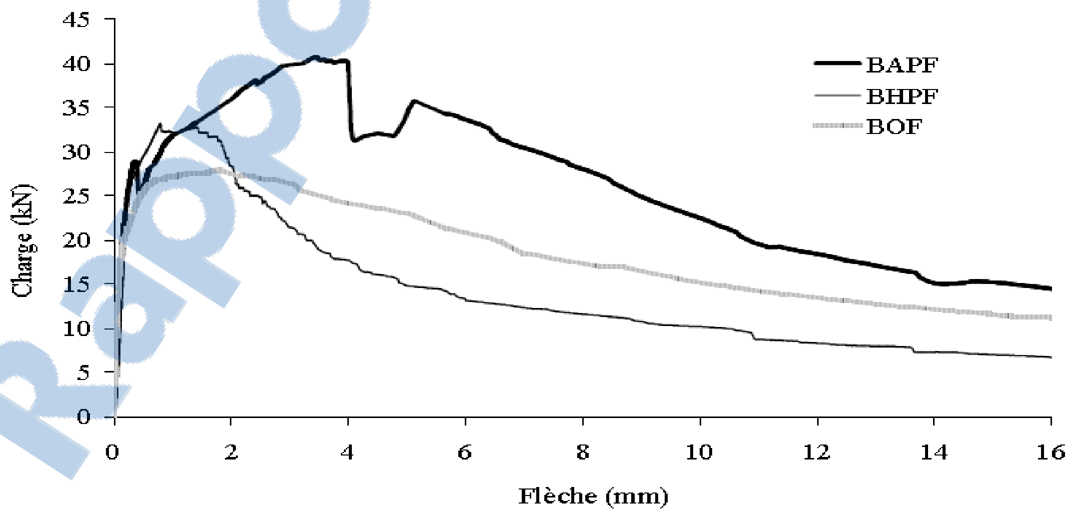

Figure III.9: Load-deflection curves of fibre-reinforced concrete (Bensaid Boulekbache et al., 2009), [41]

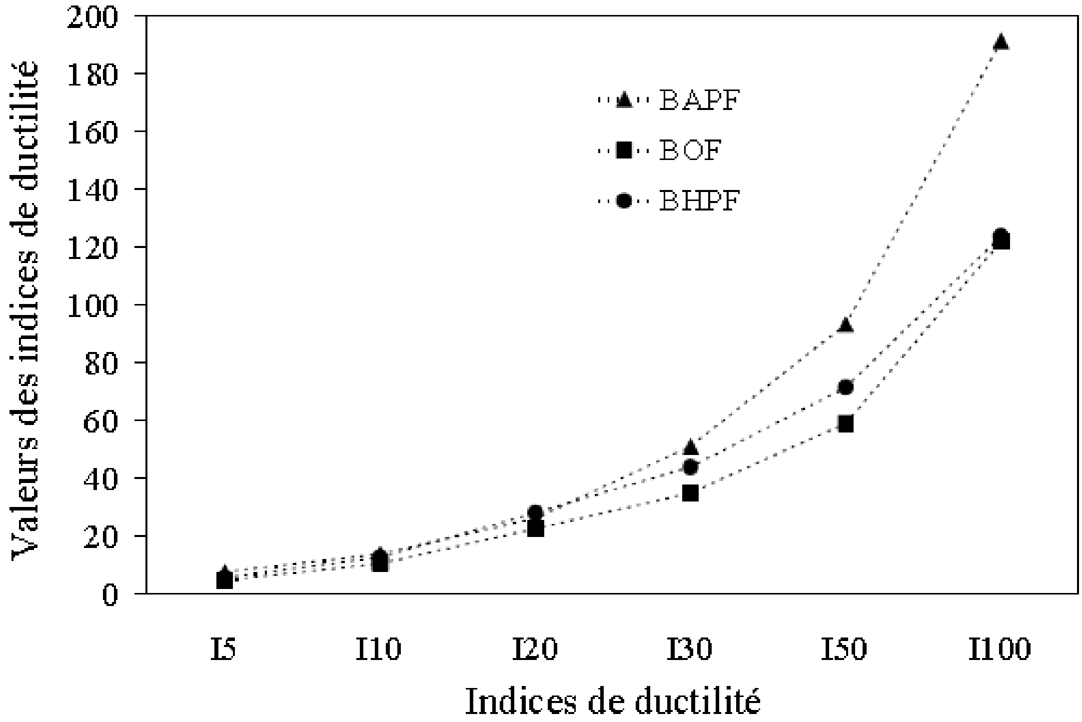

Figure III.10: Ductility indices of fibre-reinforced concrete (Bensaid Boulekbache et al., 2009)

III.4.5. Conclusion

The main objective of this study is to examine the influence of the rheology of concrete on the orientation of fibres and therefore on the performance of concrete. The conclusions are summarized as follows:

- The preliminary visualization tests of the orientation of the fibres in a translucent threshold fluid with rheological behaviour comparable to that of concrete showed a natural orientation of the fibres in the direction perpendicular to the flow (slab). The orientation of the fibres is however greatly modified by the presence of walls (channel flow). The fibres then align mostly parallel to the direction of the wall.

- The shear threshold is the fundamental rheological variable which determines the orientation and the homogeneity of the distribution of fibres. A low stress threshold (<50 Pa) ensures a homogeneous distribution and an orientation perpendicular to the flow, only hampered by the presence of walls. For a strong threshold (> 100 Pa), the distribution as well as the orientation become less homogeneous with the formation of fibrous clusters.

- The workability of concrete is the parameter which governs the efficiency of the addition of fibres and therefore the flexural strength and ductility of the fibre concrete. The presented tests showed a relative increase in flexural strength of 22.76% for low threshold SCC (= 36 Pa), compared to high performance HPC relatively high threshold concrete (= 120 Pa). Without fibres, the SCC tested had a flexural strength 24% lower than that of HPC.

- A homogeneous distribution of fibres ensured by a low threshold stress induces a markedly improved ductility of the fibre-reinforced concrete. Load transfer is provided throughout the specimen. A very pronounced stress location is observed in the case of firm concretes (FRHPC).

III.5. Conclusion

From this chapter we can conclude that the inclusion of steel fibres in concrete had a negative effect on the workability of the concrete mixture as checked by the slump test. The workability of steel fibre reinforced concrete reduced as the fibre dosage increases with worst results observed at the highest dosage of 60 kg/m3 steel fibre in concrete. Fibre effect on compressive strength is slightly pronounced, with optimum compressive strength noticed at fibre dosage of 50kg/m³ and with fibre of 80l/d ratio. Compressive strength increases with increase in fibre dosage until optimum compressive strength was achieved after which it will decline. Addition of steel fibres to concrete remarkably improves the strength of steel fibre reinforced concrete beams when compared to plain concrete. The influence and effectiveness of steel fibres in concrete are distinctively noticed at higher dosages of fibres. There was a significant improvement of ultimate flexural strength attained at higher dosage of fibres in concrete (50 kg/m3 and 60 kg/m3), which resulted in better post-cracking tendency with composite exhibiting strain hardening behaviour with stresses increasing even after first crack. This is attributed to more availability of steel fibres within the concrete matrix leading to a better distribution of steel fibres within the concrete as a result of adequate dosage of fibres providing effective multi-directional reinforcement within the concrete matrix. The post cracking tendency of the steel fibre reinforced concrete beams is affected by the fibre length, most of the results from beams containing steel fibres of 50 mm length had the first cracking value as the highest flexural value achieved, whereas, results from specimens containing steel fibres of 60 mm length show better post-cracking capability with strain hardening behaviour. Good post-cracking behaviour of all the steel fibre reinforced concrete specimens was also noticed at higher dosages of steel fibres and at highest fibre aspect ratio of 80.

CHAPTER IV: CHARACTERISATION OF MATERIALS

IV.1. Introduction

In this chapter, we will first define the materials used for the preparation of our concretes as well as methods for their characterization. The quality of concrete depends on these components; this is why it is necessary to characterize them well. The source of the components also has a big role in the economic cost of concrete and its strength and durability.

IV.2. Materials

This part concerns the determination of the characteristics of the various constituents used for the preparation of the concrete subjects of our work. The different materials used to formulate concrete are as follows:

IV.2.1. Water

The water used for the manufacture of concrete is that which runs through the taps at the university centre of Chetouane in Tlemcen. Its chemical composition is obtained by analysing a water sample at the West Public Works Laboratory of the wilaya of Tlemcen (LTPO). This analysis allowed us to obtain the chemical composition grouped in **Table IV.1**

TABLE IV.1: Chemical composition of the water used (LTPO)

CATIONS	mg/l	méq/l	ANIONS	mg/l	méq/l
Calcium	110,621	5,520	Chlorure (Cl)	99,400	2,800
Magnésium (mg)	42,282	3,477	Sulfates (SO_4)	312,740	6,515
Sodium (Na)	-	-	Carbonates (CO_3)	NEAT	NEAT
Potassium (k)	-	-	Bicarbonates (HCO_3)	473,515	7,760
Balance cation	-	8,997	Balance Anion	885,655	17,075

IV.2.2. Admixtures

Admixtures are water-soluble products which, when incorporated into concrete at doses which must be less than or equal to 5% of the weight of the cement, improves some of these properties. In our study we used the masterglenium sky 3080 Superplasticizer: (high water reducer with very long rheology retention / Complies with standard EN934-2), allowing to obtain very high quality concretes and paste.

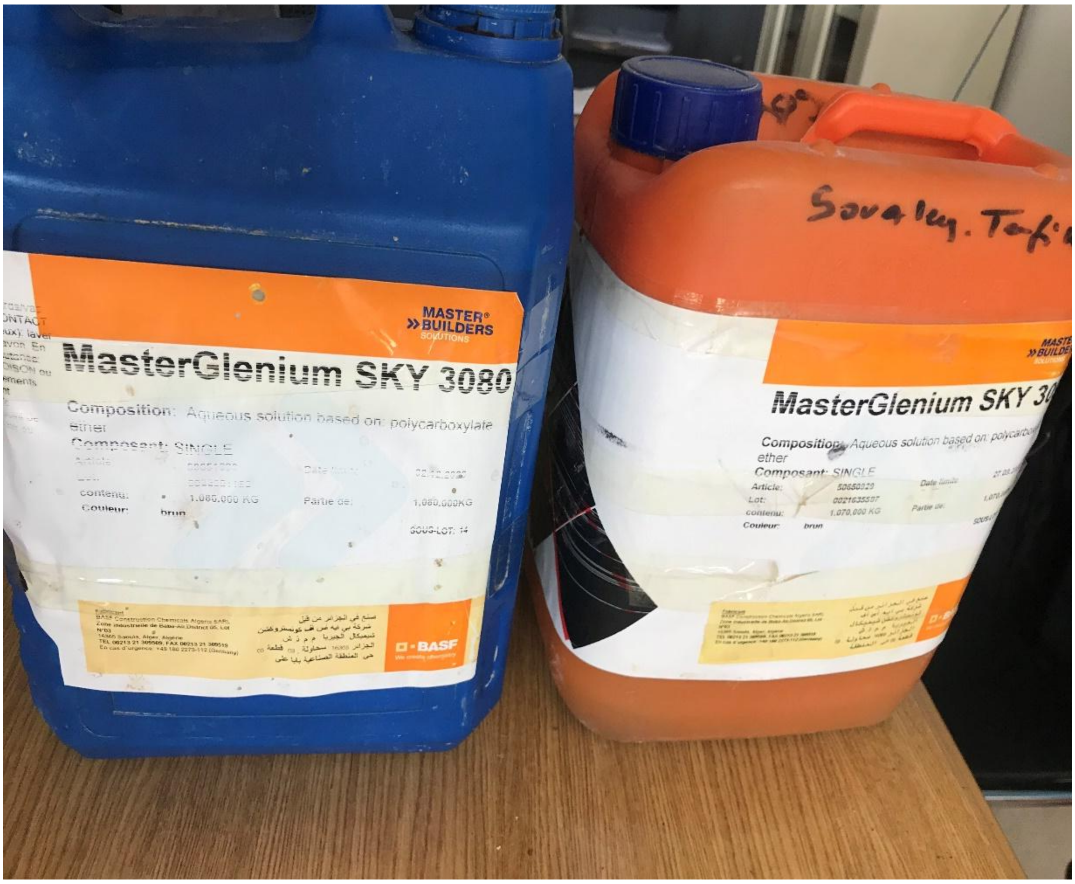

Figure IV.1: Superplasticizer used in the formation of concrete

In addition to its main function as a superplasticizer, it considerably reduces the water content of concrete. The Superplasticizer is introduced into the mixing water; it is recommended to add the admixture to the concrete after 50 to 70% of the mixing water has been introduced.

IV.2.3. Aggregates

For the composition of the concretes studied, we used the crushed aggregates from the Side Abdelli Quarry, owned by the National Aggregate Company (ENG) located in the wilaya of Tlemcen. These crushed limestone aggregates are marketed as granular classes: 0/3 sand and gravel of classes 3/8, 8/16, 16/25.

IV.2.4. Limestone Fillers

The limestone fillers (**Figure IV.2**) come from the quarry of Sidi Abdelli (ENG), they present a (Dmax = 125µm). Their chemical composition is summarized in the **Table IV.2**

Figure IV.2: Limestone fillers

Eléments	S_iO_2	CaO	MgO	Fe_2O_3	CO_3	Anhydrite Carbonatée	Eau de combinaison	Perte au feu
Min %	4.73	33.81	18.59	0.49	93.64	41.2	0.49	41.69
Max %	5.64	34.09	20.06	0.54	96.97	42.67	0.56	43.23
Moy %	5,18	33,95	19.32	0.51	95.30	41.93	0.52	42.46

TABLE IV.2: Chemical properties of limestone (Taleb, 2009)

The limestone fillers have an absolute density equal to 2700 kg / m3 and an apparent density equal to 971 kg / m3. The specific surface of Blaine is equal to 2416 cm2 / g, (ELBAHI and Boukli, 2014).

IV.3. Particle Size Distribution Test

Granularity is the grain size distribution of an aggregate. It allows the determination of the geometric characteristics of the various families of aggregates.

Particle size analysis is the test method to determine granularity. This operation consists of sieving the aggregate on a series of square mesh sieves whose dimensions are placed in descending order and weighing the residue obtained on each sieve. The curve is then drawn.

Figure IV.3: Particle size distribution test

To characterize these aggregates, we tested the particle size analysis according to the standard (NF P18-540) and the results of this analysis are presented in **Tables IV.3**, **IV.4**, **IV.5** and **IV.6**, as well as in **figure IV.4**

TABLE IV.3: Particle size distribution of sand

Sand 0/4				
	Mass of sample	**= 1kg**		
sieve size (mm)	Weight on sieve (g)	Cumulative Weight (g)	Cumulative weight (%)	Passing through a sieve (%)
6.3	0.6	0.6	0.06	99.94
5	0.6	1.2	0.12	99.88
4	31.2	32.4	3.24	96.76
3.15	50.2	82.6	8.26	91.74
2.5	96.2	178.8	17.88	82.12
2	86	264.8	26.48	73.52
1.6	112.8	377.6	37.76	62.24
1.25	61.4	439	43.9	56.1
1	64.4	503.4	50.34	49.66
0.8	45.6	549	54.9	45.1
0.63	52.2	601.2	60.12	39.88
0.5	71.2	672.4	67.24	32.76
0.4	39.2	711.6	71.16	28.84
0.315	62.8	774.4	77.44	22.56
0.250	4.2	778.6	77.86	22.14
0.2	17.6	796.2	79.62	20.38
0.16	37.2	833.4	83.34	16.66
0.125	15.8	849.2	84.92	15.08
0.08	16.8	866	86.6	13.4
Total	134	1000	100	0

TABLE IV.4: Particle size distribution of gravier 4/8

Gravier 4/8				
	Mass of sample	**= 1.6 kg**		
sieve size (mm)	Weight on sieve (g)	Cumulative Weight (g)	Cumulative weight (%)	Passing through a sieve (%)
12.5	0	0	0	100
10	6	6	0.375	99.625
8	98	104	6.5	93.5
6.3	468	572	35.75	64.25
5	576	1148	71.75	28.25
4	328	1476	92.25	7.75
3.15	66	1542	96.375	3.625
2.5	24	1566	97.875	2.125
2	6	1572	98.25	1.75
Total	12	1584	99	1

TABLE IV.5: Particle size distribution of gravier 8/16

Gravier 8/16				
	Mass of sample	**= 3.2 kg**		
sieve size (mm)	Weight on sieve (g)	Cumulative Weight (g)	Cumulative weight (%)	Passing through a sieve (%)
25	0	0	0	100
20	0	0	0	100
16	56	56	1.75	98.25
12.5	736	792	24.75	75.25
10	1600	2392	74.75	25.25
8	682	3074	96.06	3.94
6.3	90	3164	98.875	1.125
5	10	3174	99.19	0.8125
Total	26	3194	99.81	0.19

TABLE IV.6: Particle size distribution of gravier 16/25

Gravier 16/25				
	Mass of sample	= 5 kg		
sieve size (mm)	Weight on sieve (g)	Cumulative Weight (g)	Cumulative weight (%)	Passing through a sieve (%)
40	0	0	0	100
31.5	0	0	0	100
25	100	100	2	98
20	1912	2012	40.24	59.76
16	2386	4398	87.96	12.04
12.5	540	4938	98.76	1.24
10	32	4970	99.4	0.6
Total	30	5000	100	0

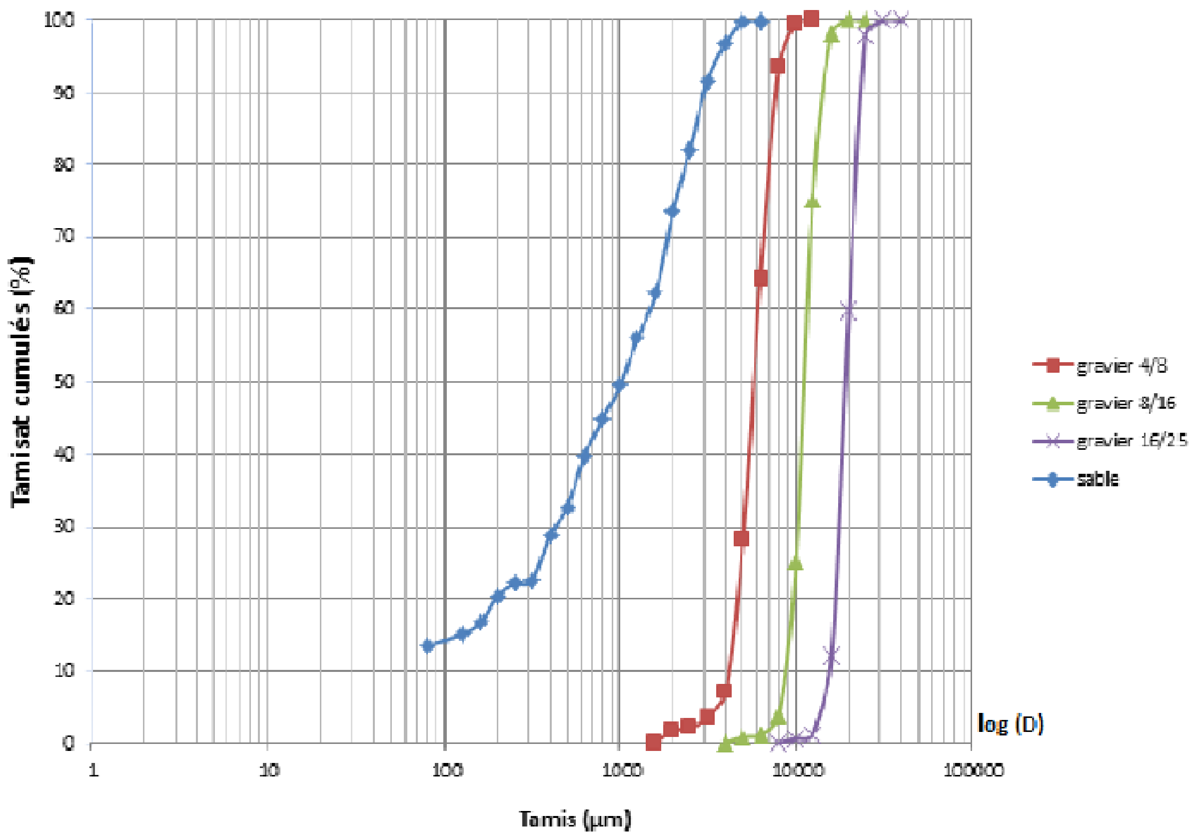

Figure IV.4: Particle size Distribution curve

IV.4 Apparent Density

The apparent density is suitably determined in standard NF P 18-554. We call apparent density; the mass of the unit volume of the bulk material, i.e. including voids.

Conduct of the test:

The sample is taken between two hands forming a funnel. Both hands are placed approximately 10 cm above the container. The material is let fall, neither too quickly nor too slowly, being arranged without being settled in successive horizontal layers. Pour the material in this way, always in the centre of the container, until it overflows all around, forming a cone. Level the top layer of aggregate with a ruler. Weigh the contents (**Figure IV.5**), i.e.' the operation is performed three times for each sample. The apparent density of the sample "PP" is then calculated by the following relationship: Pp = (M'-M) / Vr such that:

M': mass of container + sample.

M: mass of empty container.

Vr : container volume.

Figure IV.5: Test to measure apparent density

TABLE IV.7: Apparent Density of aggregates

Agg. Class	Sand 0/4	Gravel 4/8	Gravel 8/16	Gravel 16/25
M.V app (kg/m3)	1583.46	1378.66	1333.3	1316.66

IV.5. Absolute Density

The absolute density is suitably determined in accordance with standard NF P 18-554.The absolute density "Ps" is the mass per unit volume of the material which constitutes the aggregate, without taking into account any voids which may exist in or between the grains.

IV.5.1. Graduated Cylinder Method

Fill a graduated cylinder with a volume V. Weigh a dry sample of mass aggregate M, and introduce it into the test tube, taking care to remove any air bubbles (**Figure IV.6**). The level rises in the test tube. Read the new volume V2. The absolute density is then:

$$Ps = M / (V2 - V1)$$

Figure IV.6: Test to measure Absolute Density

TABLE IV.8: Absolute Density of aggregates

Agg. Class	Sand 0/4	Gravel 4/8	Gravel 8/16	Gravel 16/25
M.V abs (kg/m3)	**2542.37**	**2500**	**2500**	**2500**

IV.5.2. The Pycnometer Method

The absolute density was determined using the pycnometer method described in the standard. BS EN 1097-6: 2012 (**Fig IV.7**). It is useful to note that this method gives a higher precision than that known as the "graduated cylinder". The results obtained are listed in **Table IV.9**

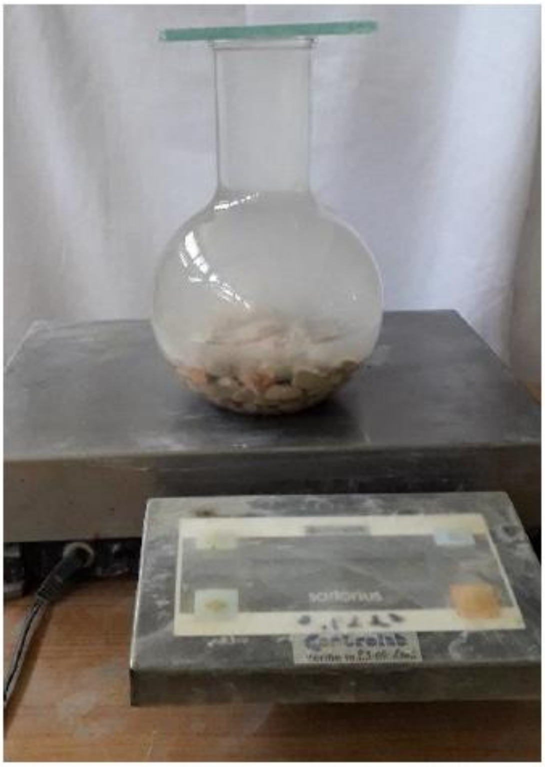

Figure IV.7: Test to measure Absolute Density

TABLE IV.9: Absolute Density of aggregates

Agg. Class	Sand 0/4	Gravel 4/8	Gravel 8/16	Gravel 16/25
M.V abs (kg/m3)	2648.6	2650.17	2626.9	2669.03

IV.6. Sand Equivalent Test

In order to assess the cleanliness of the sand used; the sand equivalent test is carried out in accordance with standard NF P 18-597. The test is carried out on a sand, which consists of introducing a defined quantity of sand into a standard test tube filled with a washing solution, after stirring, the mixture is left to settle for 20 minutes, then measure the heights.

Fill the test tubes with the washing solution up to the first mark. Pour in the correct amount of sand, making sure to remove any air bubbles, let stand 10 minutes. Stopper the test pieces and stir them automatically by the machine.

Wash and fill the test tubes with the washing tube; to do this: rinse the stopper above the test tube, lower the washing tube; wash the inside walls of the test tube in this way, wash the sand by slowly lowering and raising the washing tube, removing the washing tube (and closing the tap) when the liquid level reaches the upper line.

Leave to stand for 20 minutes, avoiding any vibration, visually measure the heights h1 and h2, slowly lower the calibrated piston into the liquid through the flocculate, the sleeve resting on the upper edge of the specimen, and immobilize it in contact with the sand. Measure h1.

Repeat the same operations 3 times and calculate the average sand equivalent (ES)

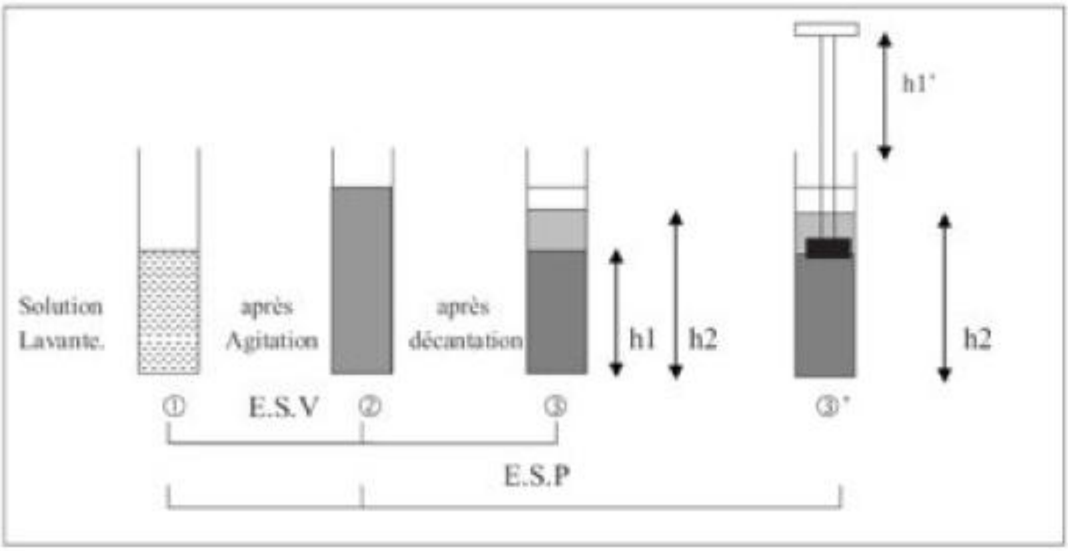

Figure IV.8: Sand equivalent test

Figure IV.9: Sand equivalent test

TABLE IV.10: Sand equivalent percentage

Sand equivalent (%)	**ESV**	**93.73**
	ESP	**79.59**

From these values it can be seen that the sand is relatively clean according to standard P 18541 which sets the limits for ESV and ESP, for crushed or ground sands, ESP > 80% for very clean sands, lack of plasticity of concrete.

IV.7. Absorption

The absorption coefficient expresses the quantity of water that the aggregate can absorb during 24 hours of total immersion in water (**Fig IV.10**). In the present study, this parameter was measured in accordance with the rules of BS EN 1097-6: 2012. First, the sample is dried for 48 hours at 105 ° C. Then it is immersed in water for 24 hours.

Figure IV.10: Absorption of water by aggregates

The next step is to dry the surface of the sample with a cloth for 4/8 and 8 / 16mm gravel, and using a dryer for sand. The absorption coefficient is calculated at the end using the following equation:

$$\textbf{Ab (\%)} = \frac{\mathbf{Msat - Ms}}{\boldsymbol{Ms}}\ \mathbf{X100}$$

With:

Ms: mass of dry aggregates (g)

Msat: mass of saturated aggregates (g)

The absorption coefficients of the three granular classes are grouped together in **Table IV.11:**

TABLE IV.11: Coefficients of absorption of aggregates

Aggregates	Sand	Gravier 4/8	Gravier 8/16
Absorption (%)	2.12	1.57	1.28

IV.8. Formulation of Fibre Reinforced Self-Compacting Concrete

Figure IV.11 summarizes the different steps in a proposed approach to the formulation of SCC according to a research done by TALEB O et al., [43 - 44].

The batching sequence consisted of homogenizing the mixture of powder, fine and coarse aggregates for 1 min in a planetary rotary mixer, then adding about 1/3 of mixing water into the mixer while continuing to mix for 1 min. The remaining 2/3 of water containing the superplasticizer are next poured into the mixer. The reinforcement fibres are then introduced into the mix right after the addition of the water containing the superplasticizer. The total mixing lasts 5 min.

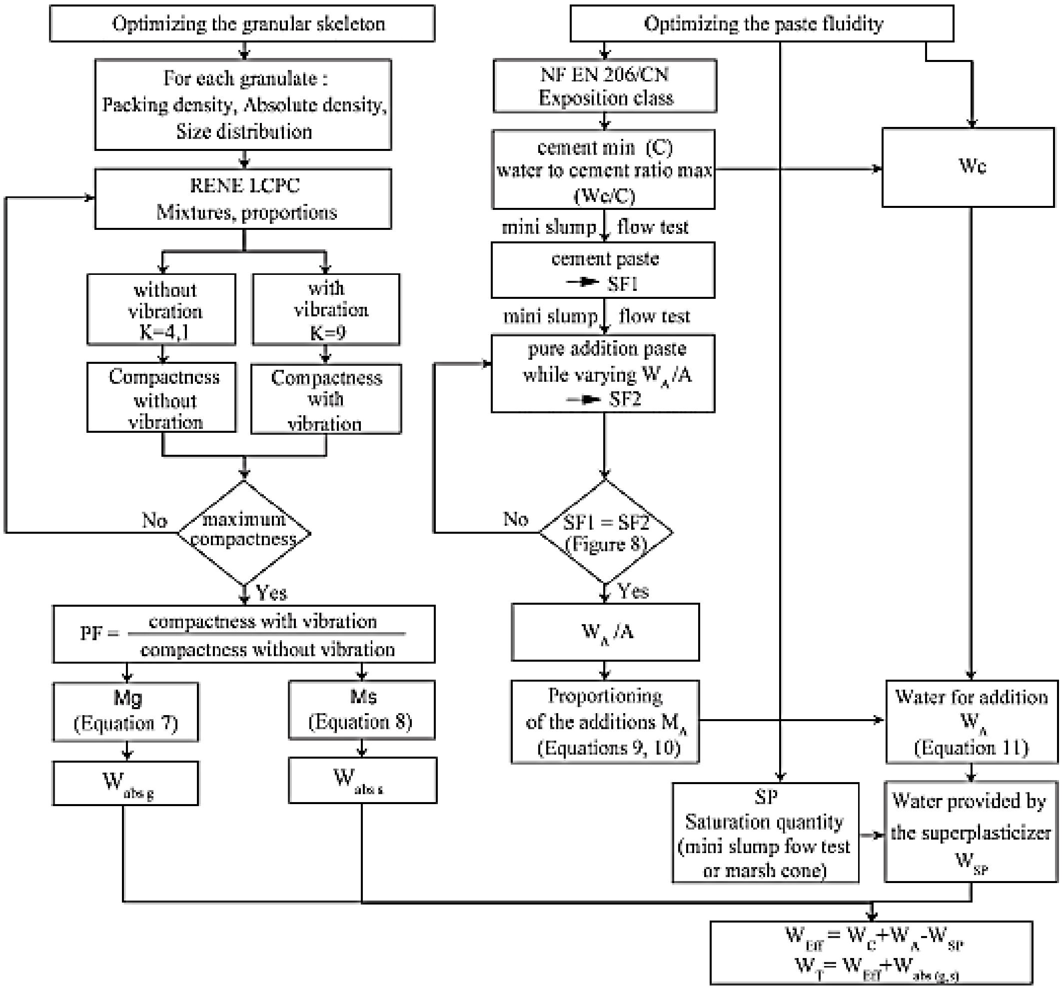

Figure IV.11: Mix design method for SCC [43]

GENERAL CONCLUSION

It is very unfortunate that due to the infamous pandemic, Covid-19, we did not have access to the laboratory hence did not manage to carry out the experimental part of our project. As far as practical work is concerned, we did characterisation of materials. Our work is based more on the research and experiments done by other different authors.

In this study, we were interested in the reinforcement of concrete with fibres. Our attention was focused on the formulation of fibre reinforced concrete, durability parameters, and the mechanical behaviour of the concrete. At the end of this research and on the basis of the analysis of the results obtained, we drew the following conclusions:

The study of the workability of fresh concrete reinforced with steel fibres, carried out beforehand, showed that it decreases when these fibres are incorporated into the concrete. Then the addition of superplasticizer is recommended to increase the workability of the concrete, but a high proportion of fibre leads to a rapid decrease in the latter because the incorporation of these fibres results in an increase in the surface area. Reinforcement of concrete with fibres can offer technical solutions for improving mechanical performance. These fibres guarantee improved behaviour thanks to better crack control which results in good ductility of the concrete. Compressive strength increases with increase in fibre dosage until optimum compressive strength was achieved after which it will decline. The influence and effectiveness of steel fibres in concrete are distinctively noticed at higher dosages of fibres. With high dosage of fibres significant improvement of ultimate flexural strength was attained. The post cracking tendency of the steel fibre reinforced concrete is affected by the fibre length as longer fibres show better post-cracking capability with strain hardening behaviour. A better distribution of steel fibres within the concrete as a result of adequate dosage of fibres provides an effective multi-directional reinforcement within the concrete matrix.

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