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Title

Study of mechanical behaviour and shrinkage of mortars reinforced by micro and macro synthetic fibres

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Dedications

I dedicate this modest work to:

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Abstract

Shrinkage is a very important phenomenon that affects all concrete structures. If it is not controlled, its effects will be detrimental to the sustainability of the construction.

The first objective of this work is to study the mechanical and physical characteristics of the mortar reinforced by synthetic fibres. The second objective is to see if using synthetic fibres reinforcement, playing on their diameter, can improve the mechanical strength and reduce the risk of free shrinkage of these materials. The work is carried out on mortars, with limestone crushing sand, composite cement and synthetic fibres. The fibres used as reinforcement of these mortars are synthetic fibres of polypropylene coming from industrial wastes; macro fibres with a diameter of 0.45 mm produced by PLAST BROS factory of Bordj Bou Arreridj (Algeria) and micro fibres of a diameter of 0.25 mm obtained from the market. The used fibres have the same length of 30 mm.

The addition of fibres has a negative effect on the workability of the mixture especially micro fibres. However, the mechanical properties of mortars have been enhanced. Mortar M100/0 gives the highest compressive strength while mortar M25/75 shows the most important flexural strength. The total shrinkage is decreased with the use of macro and micro fibres, nevertheless endogenous shrinkage is reduced only by macro fibres. The weight loss is close in all mortars.

Key words: fibre mortar, mechanical behaviour, total shrinkage, endogenous shrinkage, synthetic fibres, micro fibre, macro fibre.

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General introduction

General introduction

Concrete is the most used material in the world after water. It is a durable material, it has a good compressive strength and stiffness and it can be moldable into complicated shapes. However, it has a low tensile strength and a low ductility **(Manaswini, 2015)**. To improve this weakness, many techniques are proposed; among them the introduction of fibres in its mass.

Cracks often occur in the concrete due to rapid drying and shrinkage. They generally increase in the time and thus gradually propagate the concrete volume. Aggressive agents can easily enter into concrete through these cracks and then negatively affect its mechanical strengths and its service-life. To reduce all above mentioned phenomena, the utilisation of fibres seems to be an effective possibility to control creation, development and width of cracks. During the mixing process, fibres are distributed throughout the concrete in all directions. Consequently, the fresh concrete is thus protected against excessive formation of plastic shrinkage cracks; concrete tensile strength as well as modulus of elasticity are thus increased. In the hardened concrete, the fibres prevent the evolution of cracks.

The problem of the addition of fibres to concrete is the decrease of it workability, thus for improving this property, mixing water volume should be increased or water reducing super plasticizers will be added to the mixture.

In construction, there are several types of fibres used for the reinforcement of concrete, as metallic, synthetic, mineral or vegetable fibres. It has been established that the addition of metallic or polypropylene fibres to cement based materials can increase their fracture toughness, ductility and their impact resistance **(Vasudeva, 1991)**.

In order to reduce the air, water and ground pollution, synthetic fibres are used in concrete. These fibres are non-biodegradable and their presence in the nature cause environmental pollution. Synthetic fibres of polypropylene or polypropylene-based are often preferred over steel fibres due to theirs lower production cost. They have a low weight and a high deformation and do not absorb water or react chemically with cement; their use represents an economic gain in the field of civil engineering. Polypropylene fibres have the ability to disperse easily in the concrete and they are effective in controlling cracks of plastic shrinkage

(Banthia and Gupta, 2006). They have also a good resistance to degradation and sufficient mechanical properties, such as tensile strength and toughness **(Banthia and Gupta, 2006)**. Moreover, synthetic fibres provide an increase of fire resistance for the structure due to their low melting point of the polymers and inferential formation of water vapour capillaries in the structure of concrete **(Antoš et al, 2017)**. It was observed that the presence of synthetic fibres waste in concrete decreases its workability and improves efficiently its mechanical strengths **(Antoš et al, 2017)**. Polypropylene fibres can significantly affect the lifespan of the structure by reducing the permeability, the amount of shrinkage and the expansion of concrete **(Antoš et al, 2017)**.

Sand is the essential aggregate used in the composition of the mortar. The river sand is the most commonly used for construction in Algeria. The excessive extractions of this sand have contributed significantly to the depletion of resources and have caused adverse effects on the environment. Many parts of the world are experiencing this situation and must now look for alternative materials to meet the growing demand for concrete and mortar aggregates. Crushing sands are very often the only alternative. However, they must meet their own quality criteria and be available in sufficient quantities at reasonable prices. The use of crushing sands was granted by the Ministry of Housing and Urban Planning of Algeria, by the law of 14 June 2005 **(Benyahia and Benkhennouche, 2016)**.

In this experimental work, crushing limestone sand produced by Ouazzane station (situated in the north of Laghouat city) is used for preparing the test's mortars. The fibres used as reinforcement of these mortars are synthetic fibres of polypropylene coming from industrial wastes; macro fibres with a diameter of 0.45 mm produced by PLAST BROS factory of Bordj Bou Arreridj (Algeria) and micro fibres with a diameter of 0.25 mm obtained from the market. The used fibres have the same length of 30 mm. The valorization of these materials as aggregate and reinforcement seems to be a good solution for the economic, environmental and technical problems of concrete constructions.

The present investigation is carried out to study the effect of the diameter of polypropylene synthetic fibres on the shrinkage (total and endogenous) and the mechanical behaviour of mortars prepared with crushing limestone sand. This work contains three chapters, starting with literature review in chapter one, chapter two characterise the used materials and finally results and discussions in chapter three.

Chapter I: Literature review

I.1. Introduction

In the past, most of the structures were made either in masonry, steel or timber depending upon the availability of the materials and the nature of the structure. Very recently concrete as building material, has come into being. In a very short period, concrete has gained so much importance that today more than 65 per cent of the structures coming up in the world are constructed with concrete. Concrete is very strong in compression but extremely weak in tension and is a brittle substance **(Syal and Goel, 2008)**. Due to its lack of tensile strength, it is reinforced with reinforcement bars or mesh in structures, but this kind of reinforcement is crude and ineffective for crack control. Also this reinforcement gets decayed and corroded in abusive environments. Concrete technology now includes reinforcement in the form of polymeric fibres, steel or glass fibres. Fibre reinforcement is not used for structural strengthening; rather it improves the durability by delaying the crack propagation (**Manaswini, 2015)**.

I.2. Fibre concrete

Concrete is composed of aggregates such as gravel and sand, cementing materials as Portland cement and water. It can take any shape such as beams, slabs or columns. Cement and water react chemically to bind sand (known as fine aggregate) and gravel. When the constituent materials are mixed together, they get hardened after a few hours and a hard stone-like product is obtained; this is called “concrete” **(Syal and Goel, 2008)**.The inherent weakness of concrete is its less tensile strength. To improve this inherent weakness it can be associated to other materials, as fibres, then we obtained a composite material.

The need for materials with properties not found in conventional materials, combines with advances in technology, has resulted in combining two or more materials to form what are called composite materials. These materials usually combine the best properties of their constituents and frequently exhibit qualities that do not even exist in their constituents. Strength, stiffness, specific weight, fracture resistance, corrosion resistance, wear resistance, attractiveness, fatigue life, temperature susceptibility, thermal insulation, and acoustical insulation, can all be improved by composite materials. Of course, not all these properties are improved in the same composite, but typically a few of these properties are improved **(Mamlouk and Zaniewski, 2011)**.A composite material is constituted in the most general case of one or more discontinuous phases distributed in a continuous phase. The discontinuous phase, called reinforcing material, is usually harder with mechanical properties superior to those of the continuous phase, called matrix. Indeed, since a long time the fibres are used as reinforcement of several building materials in order to increase their mechanical resistance and improve their stability.

Fibre reinforced concrete is a composite material that has been used by civil engineers in various structural applications. Different types of fibres are used to reinforce the concrete; they are mixed with the fresh concrete in a random order.

It was in 1960 that the first research work on fibre concretes was realised in the United States. Since then, the use of fibres in concrete has become increasingly common practice and applications are developed.

I.3. Fibre types

Over the years, fibres of all kinds have been tested to reinforce concretes and mortars. Fibres need to have certain qualities as the chemical compatibility with the cement and the mechanical characteristics. Several types of fibres have been proven in reinforcing concrete and can be distinguished mainly those mentioned below **(Larrad, 2002)**.

- **Glass fibres**

For years, the glass fibres have shown their effectiveness thanks to their mechanical properties, especially their rigidity. These fibres must be subjected to a preliminary treatment before introducing into the concrete. It is either to treat them by sizing, or be protected at the time of their use by addition to the mix of polymers, or be made with a zirconium glass; this last solution being the most practical. The glass fibres have excellent characteristics, their tensile strength is greater than that of steel and their coefficient of expansion is substantially equal to that of the cement paste. Their applications are essentially in the fabrication of very thin panels, less than 20 mm thick, sanitation pipes, decorative elements.

- **Carbon fibres**

Carbon fibres, also called graphite fibres (this one corresponds to a very precise crystallographic structure), are the more resistant as the graphite planes are oriented parallel to the axis of the fibre. They are more expensive than glass fibres and their use is almost limited to the reinforcement of materials consisting of binder of synthetic origin little used in construction.

- **Steel fibres**

Metal fibres, especially steel, have been the subject of much researches in concrete. They have a very good compatibility with cement. They give the concrete a high resistance to traction and bending. Metallic fibre concretes are used in pavements and industrial floors (on the ground or on piles), for the manufacture of tunnel segments, shells or the construction of piles or to produce sprayed concrete (for construction or repair tunnel and tunnel coverings and the reinforcement of concrete retaining walls); for the production of numerous prefabricated products as well as for the manufacture of repair or sealing mortar. These fibres are used to improve the mechanical behaviour of concrete structures. Indeed, they contribute to the reduction of crack width in the concrete matrix.

- **Synthetic fibres**

Synthetic fibre groups nylon, polypropylene, acryl, polyester ... etc. They appeared at the end of the 3rd century under the name of rayon. They are derived from natural cellulose. Today, most synthetic fibres come from products derived from oil and polymers whose structure resembles that of plastics. The first plastic fibre successfully marketed, nylon, dates from 1938. Since then, synthetic materials, including acrylic fibres, aramid, olefin and polystyrene appeared. These fibres have also been studied for very precise industrial processes, such as the manufacture of insulation materials, bulletproof, fuselages and airplane wings **(Djebali, 2013)**.

The polypropylene (PP) fibres are the most used synthetic fibres in the concrete. They braided in a loose pattern, which facilitates their dispersion in the concrete. These fibres have the ability to improve the cohesion and to sew cracks in fresh concrete. Their incorporation into the concrete is an effective way to limit the bursting of concrete surface subjected to fire. Indeed, the heat melts them, and the space, which they occupied, constitutes then a network of drains allowing the free water of the concrete to escape in the form of vapour. Their main advantage could lie in their insensitivity to corrosion. Since polypropylene fibres are made of a material with a comparatively low modulus of elasticity, they do not have much effect on the properties of the concrete until cracking. However, they do have a substantial impact on the concrete behaviour during curing, while the concrete is still weak **(Myers, 2006)**.

The recycling of polypropylene fibres is more economical and easier than the other types of plastics.

- **Hybrids**

Hybrids are the combination of two or more fibres under the same matrix. This procedure allows increasing the range of properties that can be achieved by composites. Design specifications can thus be met at a higher cost as high-performance composites or conventional composites. Combinations of fibres of different characteristics are beginning to be used. **Banthia** and **Gupta (2004)** show that the combination of synthetic and metallic fibres can give a material more ductile than in the case of concretes fibre reinforced only with metallic fibres.

Some authors **(Kawamata et al., 2003)** have used a combination of long and short fibres in self-compacting concretes. According to these authors, the short fibres prevent the formation of small cracks, thus delaying the formation of macro cracks, which will in turn be taken up by the longest fibres and require greater energy dissipation to break; by this, the ductility of the material would be increased.

The most common hybrid found in rebar is carbon-glass. If mechanical properties a little lower than carbon can be used, a user can greatly benefit from the cost of it by adding glass. If on the other hand for a given use the glass shows too great an arrow, high modulus of elasticity carbon fibres can be combined with the glass. Carbon fibres will also increase fatigue strength, torsional stiffness and add to its conductive effect.

I.4. Different civil engineering utilisations of fibres

To make a good choice of fibre to use, we must look for the type that offers an excellent price/performance ratio. However, the fibre must be mechanically, chemically and physically compatible with the constituents of the matrix (concrete) and in particular with the cement. It must maintain its properties over time and be at an acceptable cost (available on the market).

The selection of any fibre depends on the nature of the work to be done, the possibilities of implementation, physico-chemical stresses to which the element is subjected. Given their desired properties, fibres find many applications wherever there is a need to reduce the risk of cracking, space shrinkage joints, increase impact resistance and improve tensile strength, **(Stéphane, 2003)**.

Table (I.1) summarizes some examples of the application of fibres in Civil Engineering **(Absi, 1994)**.

Table.I. 1 Applications of fibres in Civil Engineering

Nature of the fibre	Essential benefit to concrete	Main applications
Glass	- Tensile strength - Lightening thanks to the decrease in thickness.	-Various panels: sandwiches, dressing, decorative - Industrial cladding - Sanitation - Mortars of plaster or repair
Steel	- Tensile and flexural strength - Resistance to shocks, wear - Spacing of joints	- Paving: parking, industrial floors, pavements - Prefabricated elements: pipes, gutters, shelters, garages - Concretes projected in gallery: tunnels, embankments - Silos: tanks
Synthetic fibre	- Limitation of shrinkage - Impact resistance	- Decorative prefabricated panels - Thin shells

I.5. Effect of physical and geometric properties of fibre on concrete's characteristics

The mechanical performance of concrete is affected by fibres properties (Fig.I.1). Each type of fibre has its own characteristics and properties: dimensions (diameter and length), shapes (smooth, corrugated, etc.), mechanical strength (tensile strength) and durability in the cement matrix.

To improve the mechanical performance of concrete, fibres must have a good deformation capacity, so a modulus of elasticity higher than the concrete matrix. They must be relatively long and thin, flexible without being fragile to prevent theirs destruction during mixing, easy to incorporate and safe for the workforce. Their shape or surface condition should facilitate the attachment to adhere well to the cement paste. Tensile strength is among the main features improved. This improvement depends on the adhesion of fibres in the direction of the stresses. Shape of the fibre and its surface condition are responsible for the quality of the adhesion. The dosage, the dispersion of fibres, random or oriented in a preferred direction, determine the ability of the concrete to withstand well-defined efforts **(Stéphane, 2003)**.

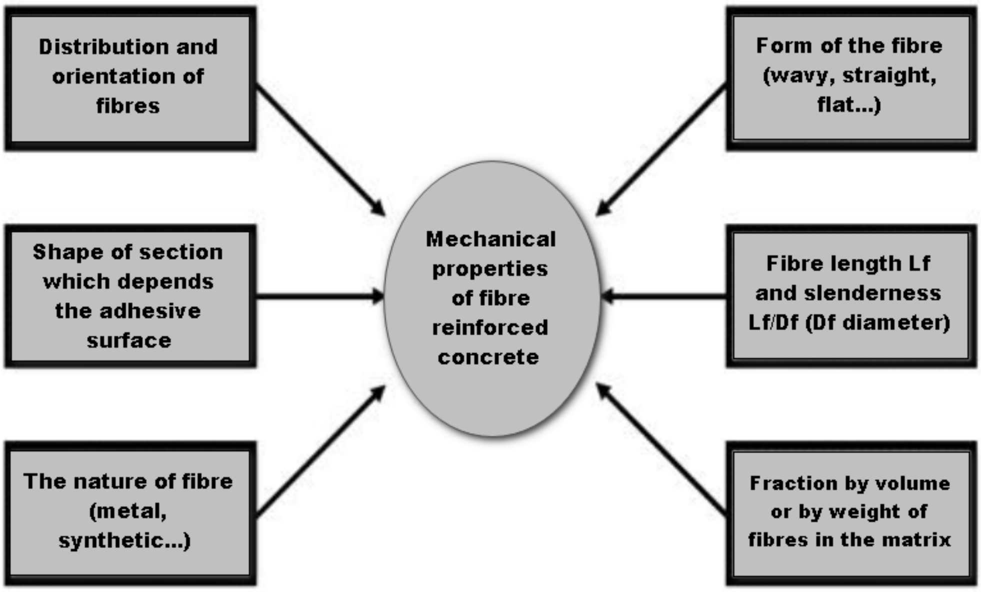


Fig.I. 1 Different factors affecting the mechanical behaviour of fibre reinforced concrete.

Macro and micro fibres were found to have different impacts on concrete behaviour, with different optimal dosage rates. Micro fibres greatly dried out the concrete mixture, hindering workability. However, the micro fibres substantially reduced plastic shrinkage and improved concrete strength at early age. Macro fibres, while not hindering workability, did not provide benefits as great as the micro fibres to the concrete strength **(Myers, 2006)**. Swamy and Mangat have shown a linear relation between the flow time V.B and the (l/d) ratio of steel fibres, which represents the ratio of the fibre length to its diameter **(Swamy and Mangat, 1974)**. According to these authors, the formation of balls is encountered in the case of slenderness greater than 100, where a difficulty of implementation of composite will take place. For cylindrical fibres, the ratio (l/d) plays an important role in the rheological properties of the mixtures, as well as in the fibre spacing coefficient.

Bentur and Mindesssee found that the length of fibres must remain greater than twice the size of the largest granulate ($l_f > 2\ D_g$), and this to make possible their mechanical action at the micro cracks **(Bentur and Mindess, 2007)**.While Absi recommend that $l_f > 4\ D_g$ (for D = 8 to 15 mm) **(Absi, 1974)**.

I.6. Properties of fibre concrete

I.6.1. Workability

The workability of fibre reinforced concrete is a major issue. The primary factors deciding the level of workability are the paste volume fraction, the fibre dosage rate, and the fibre aspect ratio. Typically, fibres decrease slump, but this does not necessarily make fibre mixes harder to compact with vibration. Fibres do make mixes somewhat drier due to their high specific surface area. Other researchers have shown that the fibre input decreases the precision of the workability index provided by the self-placing concrete spreading test, and the workability seems to be less good when the volume of fibres exceeds the 1 % of the mixing volume **(Myers, 2006)**.

I.6.2. Free shrinkage

The plastic shrinkage, which occurs at early age before the concrete, has hardened depends on two primary factors: the rate at which surface water forms (bleeding) and the evaporation rate of the surface water **(Wang et al., 2001)**. When the evaporation rate from the top surface of the concrete exceeds the bleed rate at which water rises from the concrete, the top surface dries out. At this point, the free water surface in the concrete drops within the concrete, yielding menisci between the particles. These menisci exert a tensile force due to surface tension on the particles, a suction of sorts. This and a low concrete strength due to top surface desiccation cause cracking **(Mindess and Young, 1981; Cheng and Johnston, 1985; Holt, 2001; Brown et al., 2001)**. Since this type of cracking occurs because of forces near the surface of the concrete, the cracks are typically shallow in depth and originate from the top surface. These cracks, however, are sufficient to assist water and chloride penetration, and to provide stress concentration points for long-term shrinkage cracking. Plastic shrinkage does not require external restraint on the member to create stresses, as the majority of the member is not shrinking, and it is solely the surface that shrinks. Thus, the surface alone will crack. Theoretically, fibres should have a more significant effect on shrinkage at early age, due to their relatively higher modulus of elasticity (**Zhang and Li, 2001).** Fibres were found to greatly reduce early age shrinkage, with the effect increasing with increasing dosage levels. Long term shrinkage is not affected by the addition of polymer fibres **(Myers, 2006)**.

Kao (2005) investigated the early age shrinkage properties of polymer fibre reinforced concrete extensively. He found that the early age shrinkage (at less than 24 hours) was greatly reduced by the addition of fibres. Each fibre described a curve: the shrinkage decreased with increasing dosage of fibres up to a point, and then increased as more fibres were added. The optimum dosage varied, but with all fibres, reduction of at least 50 % of the early age shrinkage was realised. However, a slight increase in shrinkage is observed with the addition of fibres; the result seems to be based upon a test normalized at 12 hours, so the earliest shrinkage behaviour is omitted; this could cause the discrepancy **(Altoubat and Lange, 2002)**.

Polymer fibres decrease early age unrestrained shrinkage **(Ramseyer, 1999)**, but the magnitude and effectiveness of shrinkage reduction is poorly understood. A reduction of about 20 % (from 2700 to 2000 microstrain) in early age shrinkage is found in 0.2 % polypropylene fibre mix **(Filho and Sanjuan, 1999)**.

Drying shrinkage is the most significant type of shrinkage in most concrete mixes, and has been called the most deleterious property of Portland cement composites **(Zhang and Li, 2001)**. The mechanisms are similar to those of plastic shrinkage, but occur after the concrete has hardened. Drying shrinkage comes from the transfer of water from the concrete to the surrounding environment, thus increasing the surface tension in the pores. Eventually, the concrete will come to complete equilibrium with the surrounding environment. At that point the movement associated with moisture will simply follow the environmental conditions if wet, then the concrete swells, if dry, it shrinks **(Mindess and Young, 1981)**.

In a study of high-performance cements, the addition of a polyethylene fibre had absolutely no effect on the free shrinkage behaviour **(Lim et al., 1999)**. The polypropylene fibre increased the shrinkage somewhat; they theorized that this was because the fibre prevented micro cracking at the surface from relaxing the stress **(Altoubat and Lange, 2002)**.

The long term shrinkage behaviour is analysed of a variety of fibres and dosage rates **(Kao, 2005)**. He found a slight decrease in the unrestrained shrinkage with the addition of fibres, but the dosage rate did not matter much. Based on this result, it can be concluded that high modulus fibres, such as steel and carbon fibres, are more effective than low modulus fibres, such as polypropylene and polyvinyl alcohol fibres, in reducing the matrix shrinkage under the same fibre content and fibre geometry.

In addition, fibres in immature cementitious matrix are more effective on the restraint to the matrix shrinkage than that in the matured matrix due to the difference in the matrix elastic modulus **(Zhang and Li, 2001)**.

I.6.3. Endogenous shrinkage

Endogenous shrinkage is defined as the macroscopic volume change occurring with no moisture transferred to the exterior surrounding environment, and thus is related to the actual chemical reactions of the concrete. Endogenous shrinkage occurs even when the concrete is completely submersed in water, thus having 100 % humidity on the surface. It also occurs even when the surface is made completely air and water proof with some curing agent. Thus its mechanism is not related to surface tension of water at the surface, but rather to the surface tension in pores, a reduction in relative humidity as the pore water is chemically consumed, and the actual volume change from the reactants to the products **(Holt, 2001; Brown et al., 2001; Xi et al., 2003; Lura, 2003)**. The higher performance concretes move the reaction more in favour of lower volume products, increasing the importance of the last mechanism mentioned.

Endogenous shrinkage is usually insignificant compared with plastic and drying shrinkage, but for high-strength concretes with low water to cement ratios, it has been shown that endogenous shrinkage becomes important.

I.6.4. Flexural strength

In general, fibres increase the tensile and flexure strength of concrete so that a more efficient structural member can be designed **(Mamlouk and Zaniewski, 2011)**. As well as the fracture energy of the composite and it gives a better resistance to cracking, to the propagation of the crack, whatever either the origin of this cracking (shrinkage, thermal stresses, external loads ...) and a clear improvement of post-cracking behaviour with the prolonged maintenance of a lift under increase of the deflection **(Swamy and Managat, 1974)**.

Some authors **(Soroushian et al., 1992)** studied the flexural strength of fibre reinforced mixes. They found a moderate increase in the flexural strength with the addition of fibres, increasing with higher dosage rates of fibres. The plain concrete mixes had strength of about 4.27 MPa, while the highest dosage of fibres yielded strength of about 5.10 MPa in flexure. A moderate improvement in flexural strength is noted with the addition of fibres, but stated that the major difference was in the behaviour after reaching the ultimate load **(Li, 2002)**. Instead of brittle failure, the fibre mix showed somewhat ductile behaviour, with ultimate deflection four times that of the plain concrete.

Early age concrete strength is improved with the addition of fibres, but long term strength is sometimes reduced with high dosages of fibres **(Myers, 2006)**.

The flexural strength is not substantially affected by the addition of polymer fibres. This is again primarily due to the low modulus of elasticity of the fibres. However, after cracking, the fibres come into play, and permit a greatly increased ultimate strain, though the load carrying capacity is decreased. Some research has shown that glass fibre reinforced concrete offers two to three times the flexural strength of unreinforced concrete.

The strength did not change appreciably after the testing of the modulus of rupture of fibre reinforced samples **(Balaguru and Khajuria, 1996)**.

The addition of polymer fibres has little effect upon the overall modulus since the polymer fibres have a lower modulus of elasticity than the concrete matrix itself. This assumption has been experimentally confirmed by Aulia that found no significant variation in the modulus of elasticity of the concrete with the addition of fibres **(Aulia, 2002)**.

I.6.5. Compressive strength

The compression strength of concrete has been shown to be only slightly affected by the addition of fibres, except at very early age, under 24 hours. This is due to the fact that polymer fibres have a lower modulus of elasticity than does concrete once the concrete cures. Thus, the fibres do not take load until the concrete cracks. However, at early age, the concrete has a lower modulus of elasticity, and the fibres take load.

The use of 0.2 % by volume of polypropylene fibres alone resulted in the low influence on both the compressive strength and modulus of elasticity of concrete **(Aulia, 2002)**; there was no difference between the compressive strength with and without fibres.

With the addition of more fibres, the compressive strength significantly decreased; the plain concrete had strength of about 46.19 MPa, while the average strength with fibres decreased with higher dosage rates to about 35.85 MPa at a 0.1 % by volume dosage **(Soroushian et al., 1992)**. It must be noted that a small amount of superplasticizer is added after the incorporation of fibres. A slight decrease in compressive strength at 28 days is also found **(Kao, 2005)**. However, at 1 day, the strength of the fibre reinforced concrete was usually equal to or higher than the plain concrete control.

I.6.6. Failure mode and cracking

The main role of fibres in a material may be related to two essential points:

- Controlling the propagation of a crack in a material in service condition by reducing the opening of cracks.
- Transformation of the brittle behaviour of a material into a ductile behaviour that increases security during ultimate loading states.

Fibres affect the mechanical performance of concretes in all modes of rupture, **(Gopalaratnam, 1987)**. It is extremely difficult to generalize the exact contribution of the fibres compared to ordinary concrete because there are numerous parameters influencing its behaviour. If the modulus of elasticity of the fibre is high compared to the modulus of elasticity of the concrete or mortar, the fibres take up part of the loads, thus increasing the tensile strength of the material. Increasing the length / diameter ratio of the fibres usually increases the flexural strength and toughness of the concrete. The values l/d of this ratio are generally between 100 and 200, because fibres of too great length tend to form balls in the mixture, thus creating problems of workability. As the fibres are scattered randomly in the concrete; however, if the fibres are aligned in the direction of the stresses, better tensile and flexural strengths are obtained.

Moreover, the material under increasing load does not fail abruptly, but yields gradually (Fig.I.2). This gradual yielding occurs, because fibres are stronger than the matrix and, therefore, arrests cracks. Instead of a worsening of the first crack that occurs in the concrete, more cracks are developed elsewhere, and failure finally occurs when fibres pull out or break **(Mamlouk and Zaniewski, 2011)**.

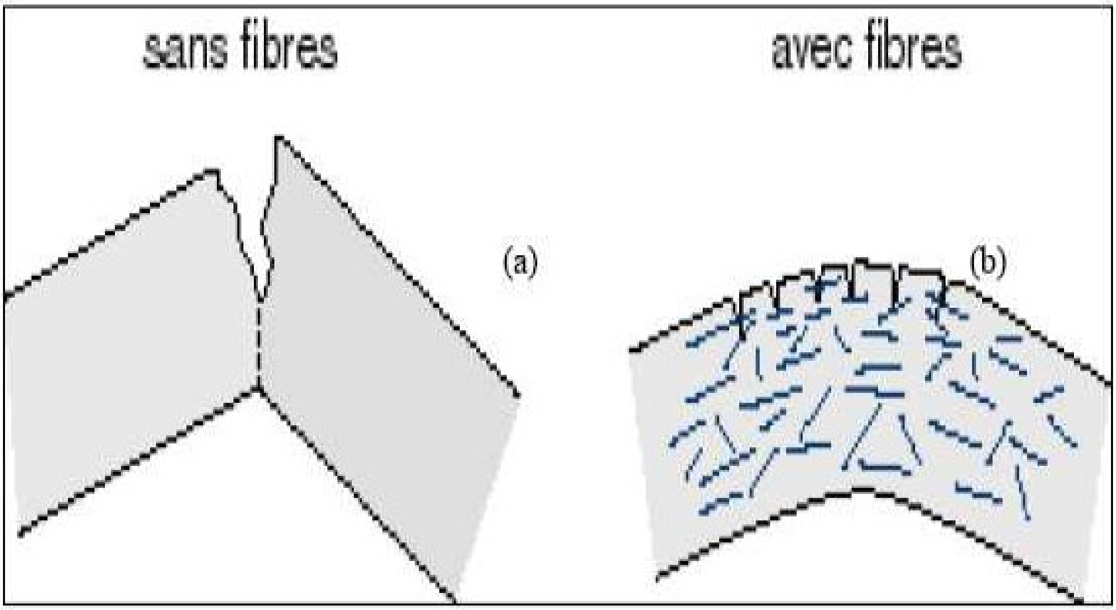


Fig.I. 2 Cracking of concrete (a) without fibre, (b) with fibre

In general, the role of a fibre appears clearly in the case of the ruin of a composite due to the propagation of a crack (Fig.I.3).

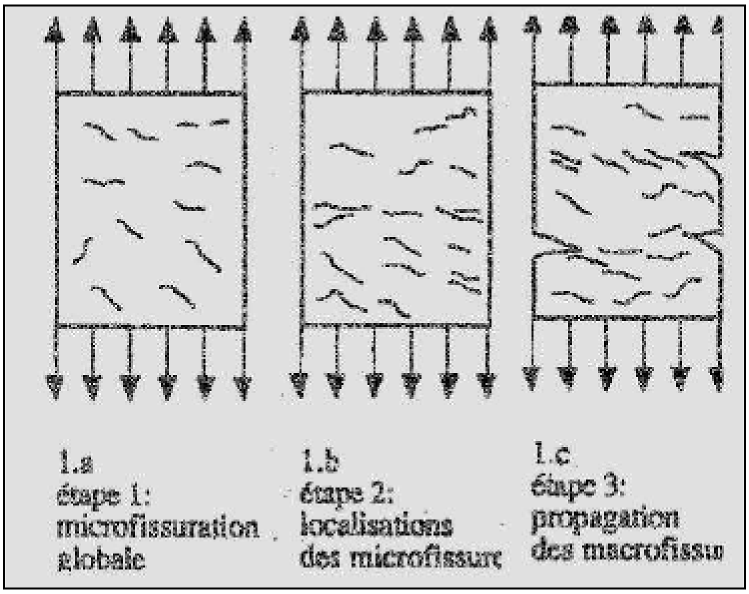


Fig.I. 3 Propagation of micro cracks in a concrete subjected to traction

The use of the scanning microscope on samples of a fibre composite (Fig.I.4) short report allowed us to report that the stress increase at the front of a crack in growth leads to overload and fracture of the reinforcing fibres (a), pulls the fibres out of the matrix (b) or separates the matrix of the fibres (c). When the crack spreads between fibres, it gradually forces the matrix to deform and yield (d).

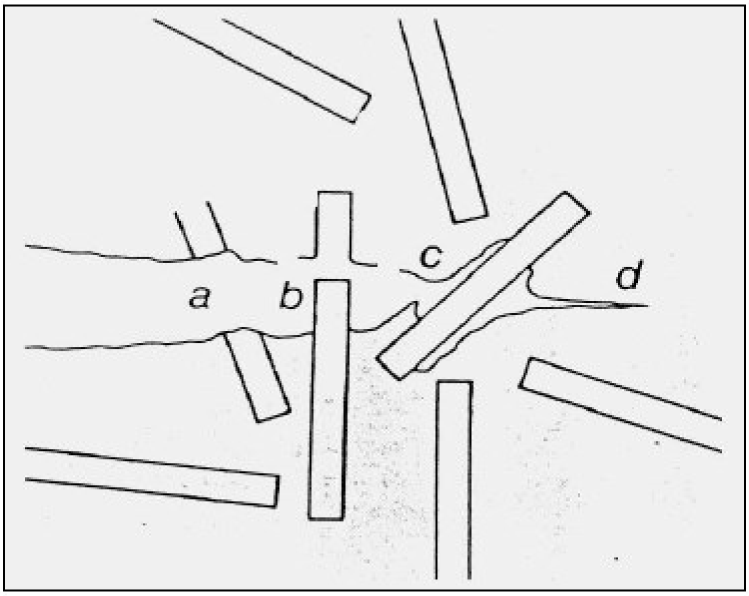


Fig.I. 4 Ruin of a composite

Therefore, the more fibres there are, the better they are anchored in the concrete, the greater will be their effectiveness. A good anchorage can be obtained with fibres as long as possible or having improved adhesion. The number of fibres per unit weight increases in reducing their diameter.

In summary, it is necessary to say that fibres play the main role of modifying the distribution of cracks, to sew them, therefore to make the material less fragile and therefore more ductile **(Benali, 2010).** By the change in deformability of the concrete before breaking, makes it possible to achieve a deformation of the order of 1 % for fibre concretes, whereas it hardly exceeds 1 ‰ for concretes without fibres **(Stéphane, 2003)**.

I.7. Bibliographic synthesis

This literature search allowed us to make the following conclusions:

- Each type of fibre has its own characteristics and properties: dimensions (diameter and length), shapes (smooth, corrugated, etc.), mechanical strength (tensile strength) and durability in the cement matrix.
- The addition of fibres decreases the workability of concrete. The primary factors deciding the level of workability are the paste volume fraction, the fibre dosage rate, and the fibre aspect ratio.
- The mechanical behaviour is generally improved with the addition of fibres.
- Endogenous shrinkage is usually insignificant compared with plastic and drying shrinkage.

Chapter II: Materials and experimental programme

II.1. Introduction

Fibre mortar is a mixture composed of fine aggregates (sand), cement, water and fibres. Thereby, the characteristics of these constituents directly affect the properties and the quality of fibre mortar.

In the present chapter, a physical, chemical and mechanical characterisation is given for all materials used in the composition of fibre mortar, such us: specific gravity, grains size analysis, sand equivalent, absorption...etc. Different experimental methods used in this experimental investigation are also presented in this second chapter.

II.2. Materials

II.2.1. Sand

Limestone crushed sand is used as fine aggregate in the mortar composition. It is a crushing residue obtained from the fabrication of limestone gravel in Ouazzane station in the north of Laghouat. The sand (Fig.II.1) has a particle size ranging between 0 and 3.15 mm. This fraction is abandoned in nature without any use, especially in construction.

Fig.II. 1 Limestone crushed sand

a. Specific gravity

The specific gravity of fine aggregates **ρ**

The specific gravity of fine aggregates ρ_s (Fig.II.2) is determined with a pycnometer according to **EN 1097-6** by the following relation:

$$\rho_s = \frac{Ws}{Ws-(W3-W2)} \times 1000 \qquad \text{(II.1)}$$

Where:

W_s: dry weight (g)

W_2: weight of the pycnometer filled with water (g)

W_3: weight of the pycnometer filled with sand and water (g)

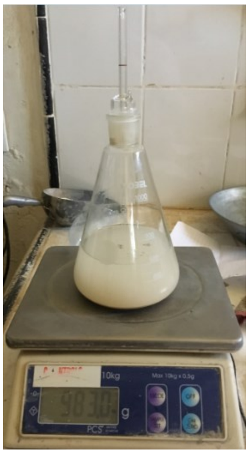


Fig.II. 2 Specific gravity

b. Bulk density

According to **NF P18-555**, the bulk unit weight of fine aggregate ρ is determined as:

$$\rho = \frac{Ws}{V} \qquad \text{(II.2)}$$

Where:

W$_s$: weight of aggregate (g)

V: volume of the container (cm^3)

c. Absorption

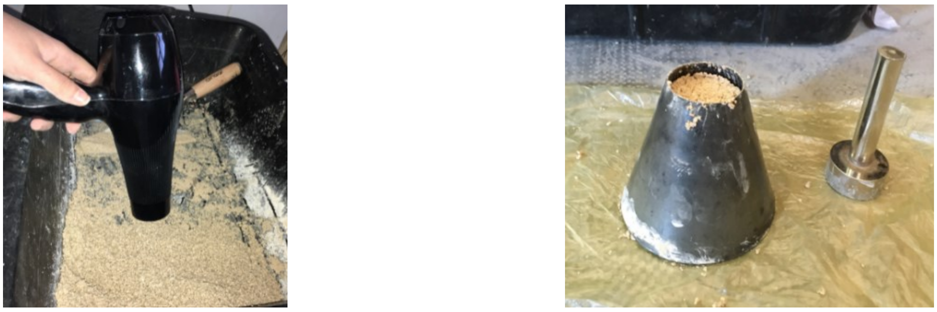
According to **NF P18-555**, the absorption **Ab** of fine aggregates (Fig.II.3) is defined as:

$$Ab\ (\%) = \frac{Wa - Ws}{Ws} \times 100 \qquad \text{(II.3)}$$

Where:

W$_s$: dry weight after passing to the oven at 105^{o}C (g)

W$_a$: saturated weight with dry surface (g)



Stream of lime air

Used materials

Fig.II. 3 Absorption test

d. Sand equivalent

The sand equivalent **Es** of fine aggregate (Fig.II.4) is determined according to **EN 933-8** by:

$$Es = \frac{h2}{h1} \times 100 \qquad (II.4)$$

Where:

h1: height of sand plus clay (cm)

h2: height of sand (cm) measured visually or with a piston (Fig.II.5):

Esv: visually sand equivalent **Esp:** piston sand equivalent

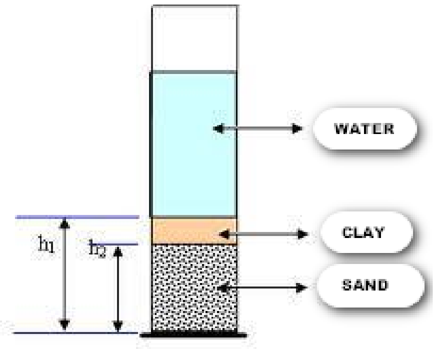


Fig.II. 4 Sand equivalent

a. Visually

b. with a piston

Fig.II. 5 Sand equivalent

e. Methylene blue test

According to standard NF 18-592, the methylene blue test **V_B** (Fig.II.6) is realised at the biology's laboratory of the Laghouat University and determined as follows:

$$S_{st} = 21V_B \qquad \text{(II.5)}$$

$$V_B = \frac{volumeofmethylenebluesolution}{weightofthesample\ (g)} \qquad \text{(II.6)}$$

Where:

V_B: blue value of the end phase

S_{st}: total surface area (m^2/g)

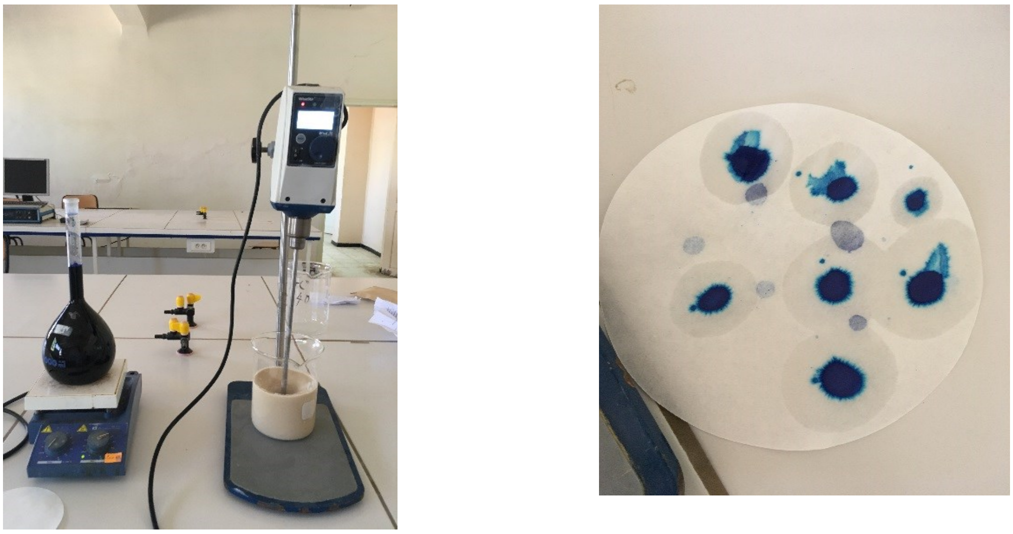


Fig.II. 6 Methylene blue test

f. Sieve Analysis

The sieve analysis realized on fine aggregate (Fig.II.7) is determined according to **NF EN 12620**. Figure (II.8) gives the size graduation of the used sand.

Fig.II. 7 Sieve analysis

Table.II. 1 The particle size distribution of limestone sand

AFNOR	Sieve size (mm)	Amount retained (g)	Cumulative amount retained (g)	Cumulative percent retained (%)	Percent passing (%)
36	3.15	00	00	00	100
35	2.5	50	50	3.85	96.15
34	2.0	116	166	12.77	87.23
33	1.6	122	288	22.15	77.85
32	1.25	108	396	30.46	69.54
31	1.0	102	498	38.31	61.69
30	0.8	70	568	43.69	56.31
29	0.63	98	666	51.23	48.77
27	0.4	88	754	58.00	42.00
25	0.250	102	856	65.85	34.15
23	0.125	104	960	73.85	26.15
21	0.1	34	994	76.46	23.54
20	0.08	26	1020	78.46	21.54
Pan		130	1150	88.46	11.54
Total		1286	1286	98.90	01.10

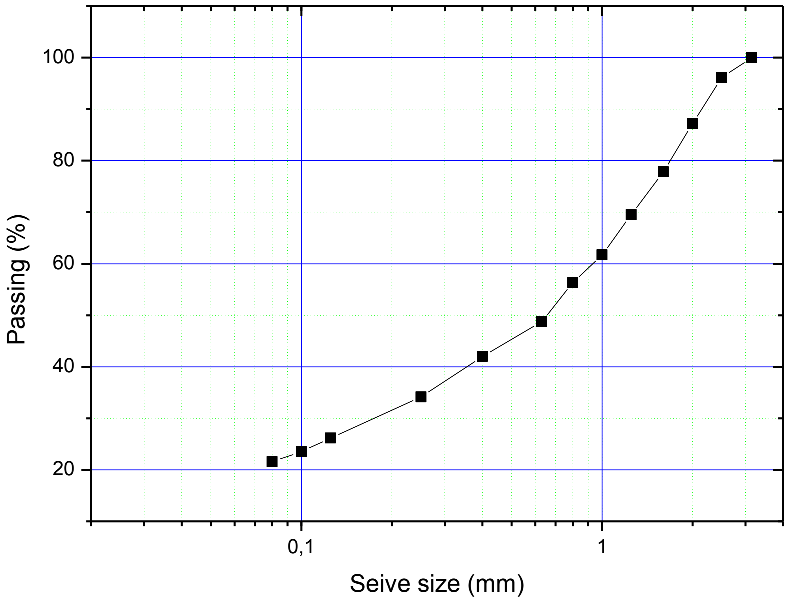


Fig.II. 8 Size graduation of limestone sand

The content of fines less than 80 µm of the used sand is 21.54 %. This percentage is slightly higher than that obtained in previous works.

- **Fineness Modulus**

The fineness modulus **FM** is an index number representing the grain size of fine aggregate. It is equal to one-hundredth of the sum of the cumulative percentage weight retained on standards sieves: 0.125, 0.25, 0.5, 1, 2 and 4 mm **(NF EN 12620)**, according to the following relation:

$$FM = \frac{\sum \textit{cumulative percent retained}}{100} \qquad \text{(II.7)}$$

g. Chemical analysis

A summary chemical analysis is carried out on the sand at Ghardaïa's laboratory ***LTPS.*** The results revealed the presence of 90 % of $CaCO_3$, 0.51 % of $SO_3^{-\ 2}$ and 6.80 % of insoluble materials **(Bendjillali, 2015)**.

h. Mineralogical analysis

The mineralogical composition of the sand is identified by X-ray diffraction. The analysis is realised by an X'PERT diffractometer, coupled to a computer system at the diffractometer laboratory in Laghouat University **(Bendjillali, 2015)**. The result is presented in the following figure:

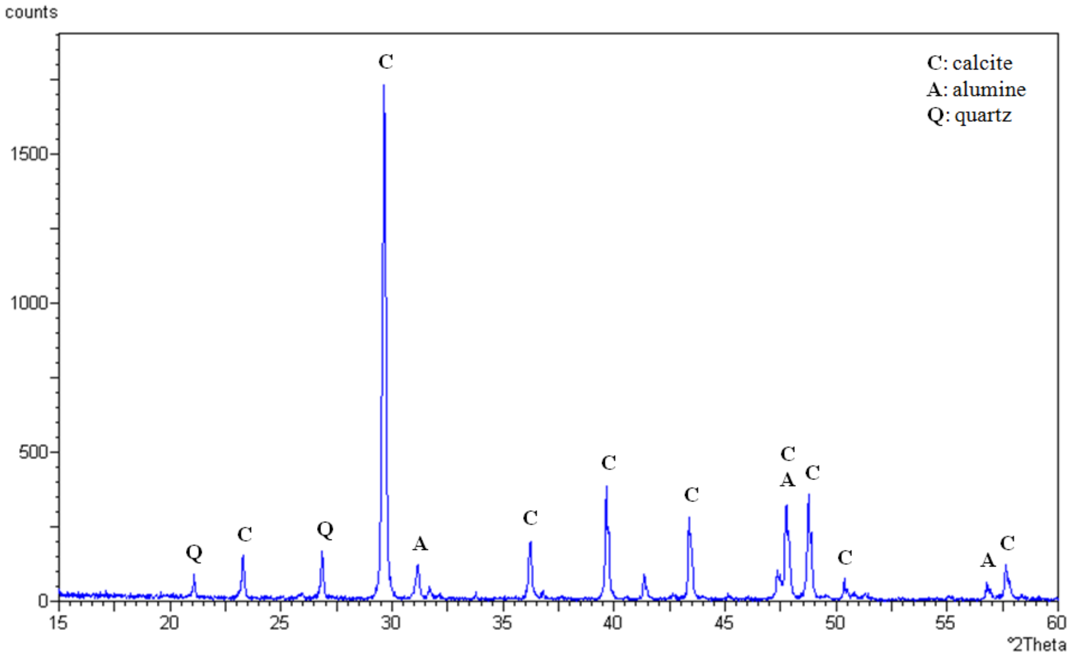


Fig.II. 9 Mineralogical composition of limestone sand

All obtained results are presented in the following table:

Table.II. 2 Sand characterisation results

Properties	Results	Interpretations
Specific gravity	**2.60 g/cm^3**	Current aggregates **(Neville, 2002)**
Bulk density	**1.49 g/cm^3**	Current aggregates **(Neville, 2002)**
Fineness modulus	**2.45**	$2.2 < 2.45 < 2.8$ Medium sand **(Festa and Dreux, 2006)**
Absorption	**6.23 %**	6.23 % superior to 5 %. Slightly a high absorption, which can lead to a firm mixture.
Esv / Esp	**64 % / 59 %**	64 < 65 % / 59 < 60 % Satisfactory sand **(Festa and Dreux, 2006)**
V_B	**0.14**	$0.14 < 1$ Sand insensitive to water **(Festa and Dreux, 2006)**

II.2.2. Cement

The cement used in this study is a Portland cement CEM II/B-L 42.5 N (Fig.II.10). It is produced by M'sila cement factory (Algerian company). Table (II.3) gives the different properties of the used cement.

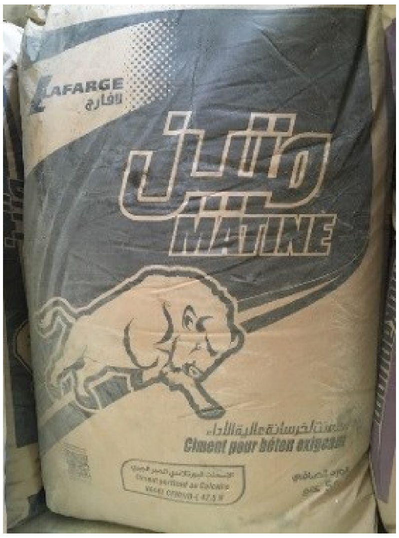


Fig.II. 10 Used cement

Table.II. 3 Cement characterisation results

Properties	Standards	Results
Specific gravity	NF P18-555	**3.1 g/m^3**
Bulk density	NF P18-555	**1.13 g/m^3**
Fineness	EN 196-6	**3700 cm²/g**
Consistency	EN 196-3	**26.5 ± 2.0 %**
Cement setting	EN 196-3	**150 ± 30 min**
7th compressive strength	NF EN 197-1	**37.89 ± 1.88 MPa**
7th flexural strength	NF EN 197-1	**6.45 ± 0.44 MPa**

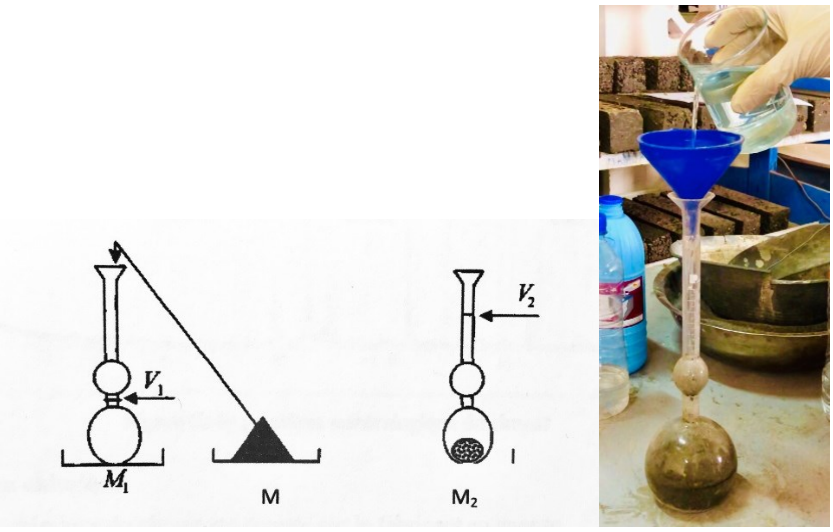


Fig.II. 11 Chatelier Flask method

The chemical (table II.4) and the mineralogical (table II.5) analysis of used cement are carried out at M'sila factory.

Table.II.4 Chemical analysis

SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	SO_3	K_2O	Na_2O
17.07	**3.96**	**2.65**	**61.91**	**1.37**	**2.76**	**0.56**	**0.14**

Table.II. 5 Mineralogical analysis

R_wp	Alite_sum	Belite_beta	Alum_cubic	Alum_ortho	Alum_sum
6.76	**51.52**	**7.68**	**2.8**	**1.05**	**3.85**
Portlandite	FCaO_XRD	Periclase	Quartz	Arcanite	Langbeinite
1.57	**1.29**	**0.22**	**0.19**	**0.19**	**0**
Hemi_hydrat	Anhydrite	Calcite	Dolomite	SO3_XRD	BFS_amorph
0.55	**0**	**19.14**	**0.27**	**1.84**	**3.59**
Ferrite	lime	Aphthitalite	Gyppsum	BFSlag_total	Gypsum_XRD
8.03	**0.11**	**0.29**	**2.81**	**3.59**	**3.63**

II.2.3. Fibres

a. Geometric properties

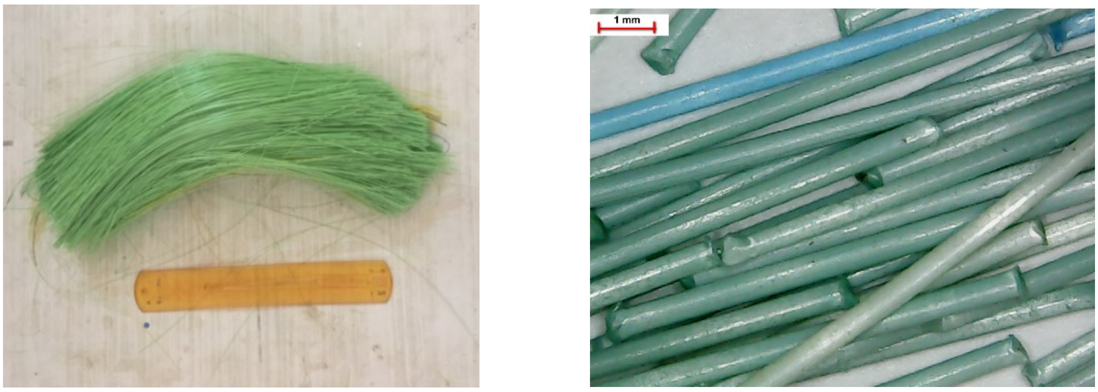
The fibres used in this work are synthetic fibres of polypropylene (PP) with two different diameter, macro (Fig.II.12.a) and micro fibres (Fig.II.12.b).

Macro fibres are produced by PLAST BROS factory of Bordj Bou Arreridj (Algeria).

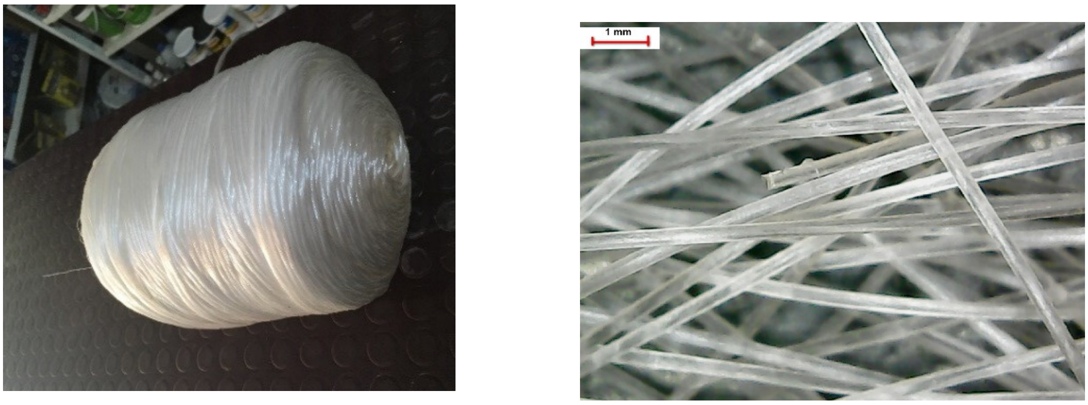
Micro fibres are obtained from the market. Geometric characteristics are illustrated in table (II.6).

Table.II. 6 Geometric properties

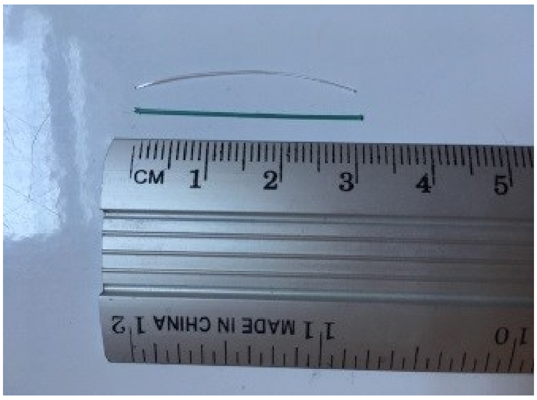
Properties	Macro fibres	Micro fibres
Nature	**Thermoplastic**	**Thermoplastic**
Surface	**Smooth**	**Smooth**
Cross-section	**Circular**	**Circular**
Diameter (mm)	**0.45**	**0.25**
Length (mm) (Fig.II.12.c)	**30**	**30**



a. Macro fibre



b. Micro fibre



c. Length of fibres

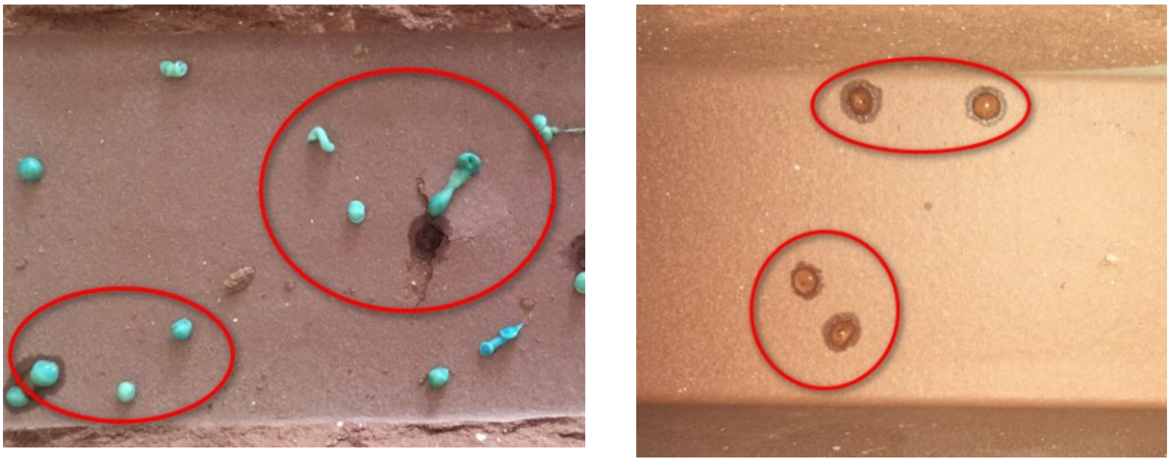
Fig.II. 12 Used polypropylene fibres

b. Physico-chemical and thermal properties

These tests are realised in the civil laboratory at the University of Laghouat, the results are given in table (II.7).

Table.II. 7 Characteristics of fibres

Characteristics	Macro fibres	Micro fibres
Specific gravity	**0.99**	**0.99**
Absorption to water	**None**	**None**
Melting temperature (°C) (Fig.II.13)	**280 – 300**	**180 – 260**



a. Macro fibre b. Micro fibre

Fig.II. 13 Melting point test of fibre

c. Mechanical properties of fibres

Fibre tensile test is carried out in the mechanical laboratory at the University of Laghouat, using a MTS traction device (GB / T 14344-2008) for the traction of synthetic or artificial filament yarns (Fig.II.14). The results of the mechanical characteristics of fibres are shown in table (II.8).

Figures (II.15) and (II.16) give the diagram force-elongation of macro and micro fibre respectively.

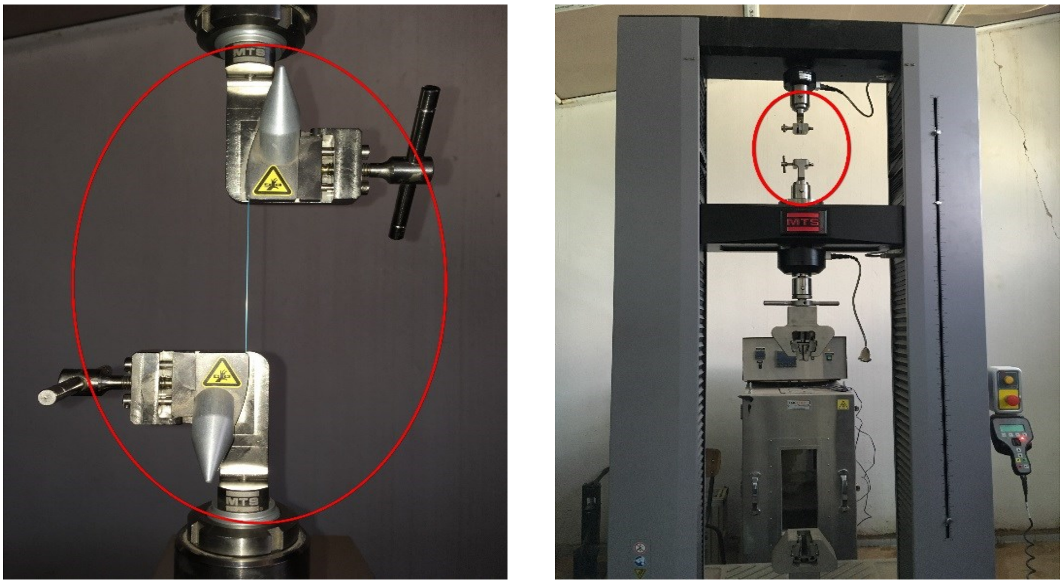


Fig.II. 14 Fibre tensile test

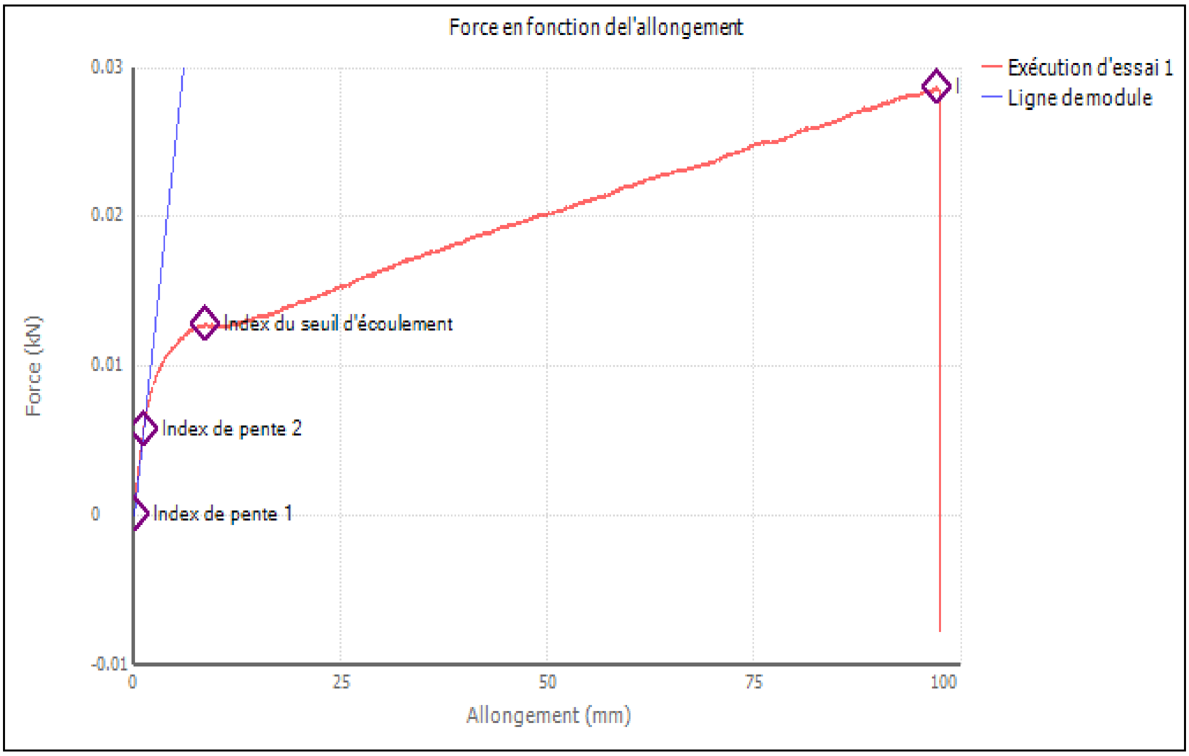


Fig.II. 15 Diagram force-elongation of fibre

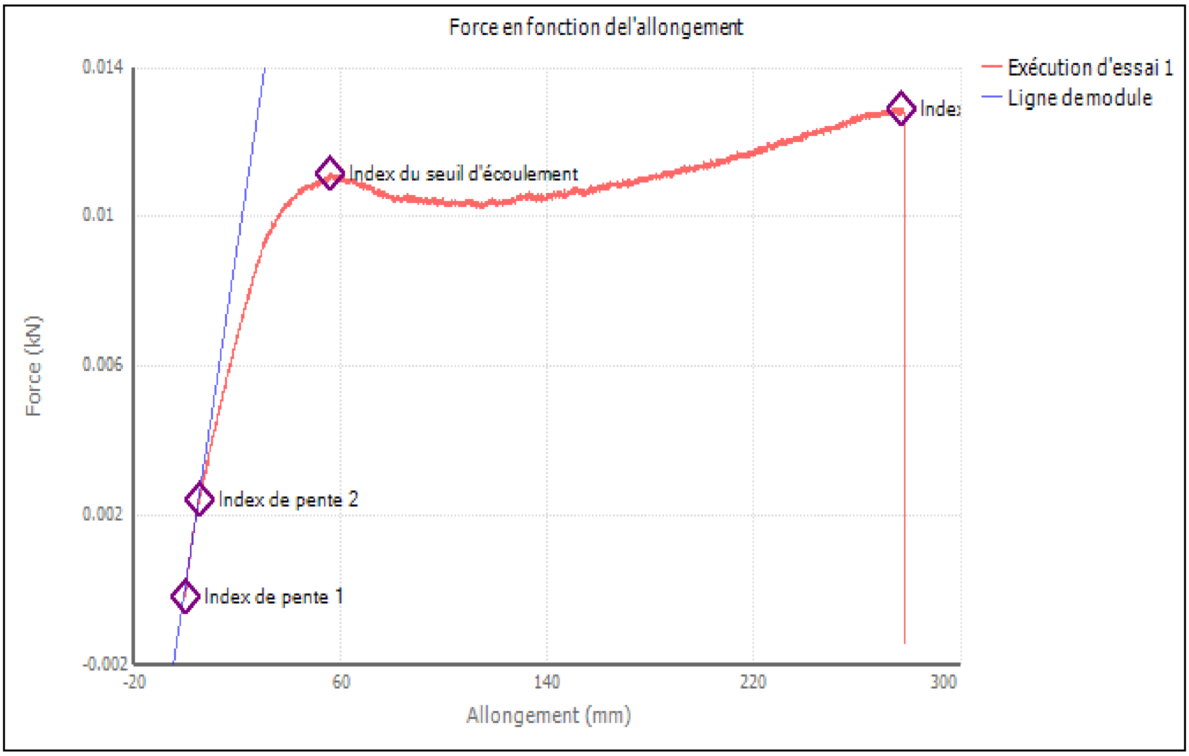


Fig.II. 16 Diagram force-elongation of fibre

Table.II. 8 Mechanical characteristics of fibre

Characteristics	Macro fibres	Micro fibres
Tensile strength (MPa)	**204**	**235**
Elasticity modulus (kN/mm²)	**1.8**	**0.5**
Elongation (cm)	**4**	**14**

II.2.4. Water

The water used for mixing is potable water. The results of the chemical analysis are given in the following table **(Bendjillali, 2015)**.

Table.II. 9 Chemical analysis of water

<table>
<tr><td colspan="3">Nature of the water point</td><td colspan="8">Valve</td></tr>
<tr><td colspan="3">Ca^{+2} in mg/l</td><td colspan="2">119,04</td><td colspan="4">Balance</td><td colspan="2">5,94</td></tr>
<tr><td colspan="3">Mg^{+2} in mg/l</td><td colspan="2">32,93</td><td colspan="4">Cations</td><td colspan="2">2,71</td></tr>
<tr><td colspan="3">Na^{+} in mg/l</td><td colspan="2">144,90</td><td colspan="4">m.éq/l</td><td colspan="2">6,30</td></tr>
<tr><td colspan="3">K^{+} in mg/l</td><td colspan="2">5,69</td><td colspan="4">15,10</td><td colspan="2">0,14</td></tr>
<tr><td colspan="3">Cl^{-} in mg/l</td><td colspan="2">169,96</td><td colspan="4">Balance</td><td colspan="2">4,79</td></tr>
<tr><td colspan="3">SO_4^{-2} in mg/l</td><td colspan="2">420</td><td colspan="4">Anions</td><td colspan="2">8,75</td></tr>
<tr><td colspan="3">HCO_3^{-} in mg/l</td><td colspan="2">153,80</td><td colspan="4">m.eq/l</td><td colspan="2">2,52</td></tr>
<tr><td colspan="3">NO_3^{-}in mg/l</td><td colspan="2">11,07</td><td colspan="4">16,24</td><td colspan="2">0,18</td></tr>
<tr><td colspan="2">Dry residue at110°C
1172 mg/l</td><td colspan="2">PH
7,77</td><td colspan="5">Conductivity in1/10 mm at 25°C
16,30</td><td colspan="2">Total hardness
43,25</td></tr>
<tr><td colspan="6">Chlorine test (ml of bleach at 15 ° / m3)
0,30 ml/</td><td colspan="2">T.A.C
12,60</td><td colspan="2">S.A.F
67,70</td><td>I.S
45,05</td></tr>
<tr><td colspan="2">Mineralisation
1010,60</td><td colspan="5">M.O an acidic environment in O_2
8,53</td><td colspan="2">SiO_2
4,45mg/l</td><td colspan="2">Sum of ions
1057,40</td></tr>
<tr><td>Cations</td><td colspan="3">Ca^{+2} = 39,34%</td><td>Mg^{+2} = 18%</td><td colspan="6">Na^{+} + K^{+} = 43,01%</td></tr>
<tr><td>Anions</td><td colspan="3">HCO_3^{-} = 15,5%</td><td>SO_4^{-2} = 53,8%</td><td colspan="6">Cl^{-} + NO_3^{-} = 30,6%</td></tr>
</table>

II.2.5. Superplasticizer

SIKA VISCORETE TEMPO 12 (Fig.II.17) is used in this study as superplasticizer, it is a high water reducer based on acrylic copolymer, and its properties are given in the annex.

Fig.II. 17 Used superplasticizer

II.3. Formulation

36 mixes are prepared by varying the water to cement ratio (W/C) and the percentage of superplasticizer (Sp); the detail is given in annex. A fibre dosage of 1 % by weight, which is previously fixed **(Bendjillali, 2015)** is used in this work. Mixtures are prepared as follows:

- Fix sand to cement ratio (S/C) equal to 1/3, with C = 450 g.
- Vary the W/C ratio to achieve a desirable workability, without the use of admixture.
- Find out the percentage of superplasticizer, which gives the desirable workability of mortars for a given W/C ratio.
- Find out the percentage of superplasticizer (Sp) which gives the desirable workability of fibre mortar, for a given W/C and a percentage of fibres of 1 % (micro **mf**, macro **MF** or cocktail).

Table (II.10) gives the different mixtures tested in this investigation.

Table.II. 10 Mortar mixes

Mixes	**C (g)**	**S (g)**	**W (g)**	**mf (g)**	**MF (g)**
MC	450	1350	247.5	00	00
$M_{100/0}$	450	1350	247.5	20.5	00
$M_{75/25}$	450	1350	247.5	15.4	5.1
$M_{25/50}$	450	1350	247.5	5.1	15.4
$M_{50/50}$	450	1350	247.5	10.3	10.3
$M_{0/100}$	450	1350	247.5	00	20.5

$M_{75/25}$: mortar with 75 % of micro fibres **mf** and 25 % of macro fibres **MF**.

a. Mixing method

Mixing process is carried out with a mortar mixer (Fig.II.18) as below:

- Cement and sand are mixed for 60 sec,
- 70 % of water is added; the wet mixing is kept for 30 sec,
- The rest of water (30 %) is added with the superplasticizer; mixing is kept for another 30 sec,
- Fibres are added to the wet mortar and mixed for 90 sec.

During the first 210 sec, the mixing is realised with a slow speed and then with a fast speed during another 30sec to ensure that the fibres can evenly disperse throughout the mortar. After, the mixture is relaxed for 90 sec and then remixed for 60 sec with a fast speed.

Fig.II. 18 Mortar mixer

b. Measure of workability

The workability of mortars is measured according to **NFP18-452** by a **Maniabilimeter B** (Fig.II.19).

Fig.II. 19 Maniabilimeter B

c. Preparing and curing of specimens

The fresh mortar was filled in prismatic moulds (40×40×160) mm (Fig.II.20.a), which are covered with a plastic film (Fig.II.20.b). Specimens are demoulded after 24 h and curing as below:

- Specimens used for mechanical tests are conserved in controlled chamber (T = 22 ◦C, RH = 92 %),
- Specimens used for free shrinkage tests are conserved in uncontrolled chamber (T = 20 ± 5◦ C, RH = 20 ± 5 %) (Fig.II.21.a),
- Specimens used for endogenous shrinkage tests are covered with aluminium and conserved in uncontrolled chamber (T = 15 ± 5◦ C, RH = 20 ± 5 %) (Fig.II.21.b).

a. Moulding mortar b. Curing under a plastic cover

Fig.II. 20 Moulding and curing

a. Specimens for free shrinkage b. Specimens for endogenous shrinkage

Fig.II. 21 Shrinkage specimens

d. Mechanical properties

According to **EN 196-1**, compressive and flexural strength are measured after 7, 28 and 90 days of age on prismatic specimens (40×40×160) mm using “CONTROLS” testing machine (Fig.II.22.), with a maximum charge load of 100 kN.

Fig.II. 22 Testing machine

- **Flexural strength**

The flexural test is conducted using test beam under third-point loading (Fig.II.23), with a charging speed of 5 kN/s. The flexural strength σ_f is calculated as follows:

$$\sigma_f = \frac{3F\,l}{2b^3} \qquad \text{(II.9)}$$

Where:

σ_f: flexural strength (N/mm^2)

F: maximum load (N)

l: distance between the two supports on the tension surface of the beam (l = 100 mm)

b: width of the beam (b = 40 mm)

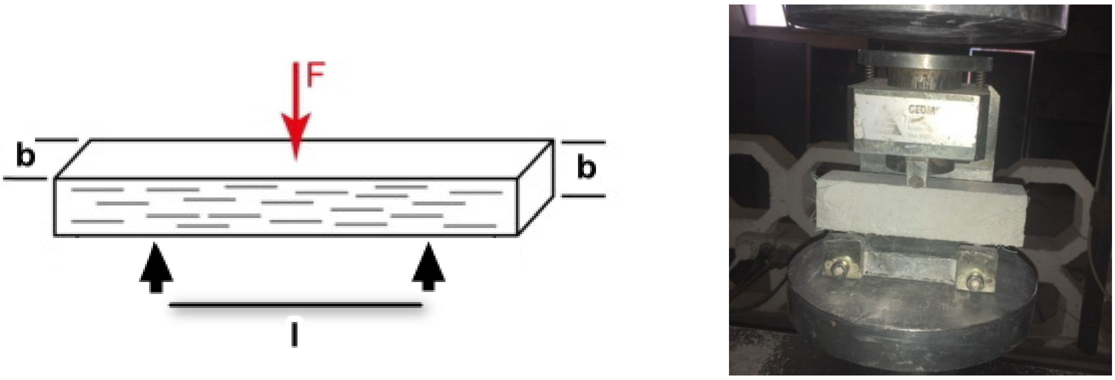


Fig.II. 23 Third point flexural test

- **Compressive strength**

The compressive test is carried out on the half-prisms (Fig.II.24) resulting from the bending test with a charging speed of 240 kN/s. The compressive strength σ_c is calculated as follows:

$$\sigma_c = \frac{Fc}{S} \qquad \text{(II.10)}$$

Where:

σ_c: compressive strength (N/mm^2)

F_c: maximum compressive load (N)

S: cross section of the beam (S = b × b) (mm^2)

Fig.II. 24 Compressive test

e. Total and endogenous shrinkage

In this study, total and endogenous shrinkage are measured on prismatic specimens (40×40×160) mm with studs at the ends (Fig.II.25) using digital drying shrinkage (Fig.II.26), from the first day, just after demoulding, until 90 days of age. Measures are taken as following:

The variation temperature and moisture of the external environment are measured and presented in table (II.11).

Table.II. 11 Variation of temperature and moisture during measurements

Age (days)	1-3	7-11	16-18	21-23	25-27	30-34	36-39	42-46	51-58	65-90
T (C°)	**10-12**	**18-25**	**19-20**	**18-18.5**	**16-17**	**16.8/9**	**16-17**	**17.6-19**	**19-22**	**21-24**
RH (%)	**20**	**20**	**20**	**20**	**20-23**	**23-41**	**22-25**	**20**	**20**	**20**

Fig.II. 25 Moulds for shrinkage test

a. Total shrinkage measure b. Endogenous shrinkage measure

Fig.II. 26 Shrinkage test

II.4. Conclusion

Basing on the characterisation results of all the materials, the following conclusions are made:

- The used limestone sand has generally acceptable properties, and then it can be used for concretes and mortars with a good mechanical behaviour.
- The cement used meets the specifications of current cements.
- The potable water is acceptable for mixing concrete.
- The use of a superplasticizer is an obligation to have flowable mortars, especially after the introduction of fibres.

Chapter III: Results and discussions

III.1. Introduction

After the physical, chemical and mechanical characterisation of all materials used as constituents of mortars presented in the previous chapter, the present chapter consists of characterising the different mortars prepared according to the formulation showed in chapter 2. A presentation of the test results concerning workability, mechanical properties, free and endogenous shrinkage of different mortars is given accompanied to a discussion and an interpretation with regard to literature results.

III.2. Formulation of mortars without fibres

III.2.1. Optimisation of water of mortars without fibres

For a mortar prepared by 450 g and 1350 g of sand, numerous water dosages are used until obtaining of a good workability, which corresponding to a flow time of 16 ± 4 seconds. The experimental results of this test are shown in table (III.1).

Table.III. 1 Flow time of mortar with W/C ratio

Mixes	**C (g)**	**S (g)**	**W (g)**	**W/C**	**Flow time (s)**	**Visual observations**
M_0	450	1350	270	0.6	45	Very dry mix
M_1	450	1350	292.5	0.65	30	Dry mix
M_2	450	1350	301.5	0.67	10	Wet mix
M_3	450	1350	310.5	0.69	5.88	Self-levelling mix

Figure (III.1) illustrates the variation of flow time of mortars with regard to W/C ratio.

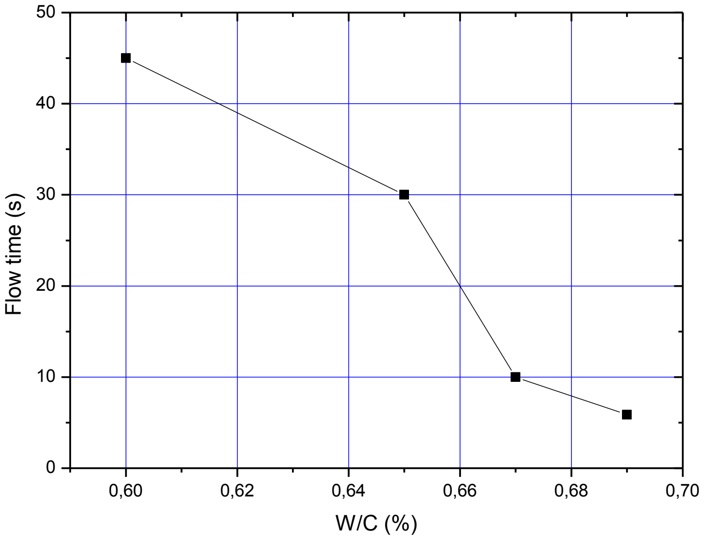


Fig.III. 1 Variation of flow time with W/C ratio

The figure (III.1) confirms the practical reality that the flow time decreases with the addition of water. To reach a good workability, mixtures need a high W/C ratio compared to the standards that recommend for a good concrete, a ratio between 0.50 and 0.55. The high W/C ratio is due to the important absorption of the used sand (= 6.23 %).

III.2.2. Optimisation of superplasticizer dosage of mortars without fibres

For respecting the recommendations of standards and norms, the W/C ratio is reduced to 0.50 and then to 0.55. For each W/C ratio, the percentage of superplasticizer, which gives the desirable workability, is measured. The test results are presented in the following table:

Table.III. 2 Flow time of mortars with superplasticizer dosage

Mixes	**C (g)**	**S (g)**	**W (g)**	**W/C**	**Sp (%)**	**Flow time (s)**	**Visual observation**
M1	450	1350	225	0.50	1	28	Very dry mix
M2	450	1350	225	0.50	1.2	15.69	Plastic mix
M3	450	1350	225	0.50	1.3	8.86	Wet mix
M4	450	1350	247.5	0.55	0.6	35	Very dry mix
M5	450	1350	247.5	0.55	0.8	30	Very dry mix
M6	450	1350	247.5	0.55	0.9	25.18	Dry mix
M7	450	1350	247.5	0.55	0.93	14.42	Plastic mix
M8	450	1350	247.5	0.55	0.95	9.41	Wet mix
M9	450	1350	247.5	0.55	1	7.15	Wet mix
M10	450	1350	247.5	0.55	2	1	Self-levelling mix

According to the table (III.2), the mixes M2 and M7 give the good workability.

Figure (III.2) illustrates the variation of the flow time with the percentage of superplasticizer. The figure confirmed the role of the used superplasticizer, which is a water-reducer to reduce the water dosage. This conclusion is in accord with another study especially established on the effect of the superplasticizer on the rheological properties of concrete **(Kheribet et al., 2011)**. The viscosity of the mixture decreases that means that the utilisation of superplasticizer reduces water requirement to have a workable mixture, this can be explained by the dispersing effect of the superplasticizer, which, causes a steric repulsion between the cement particles, reducing their agglomeration **(Kheribet et al., 2011).**

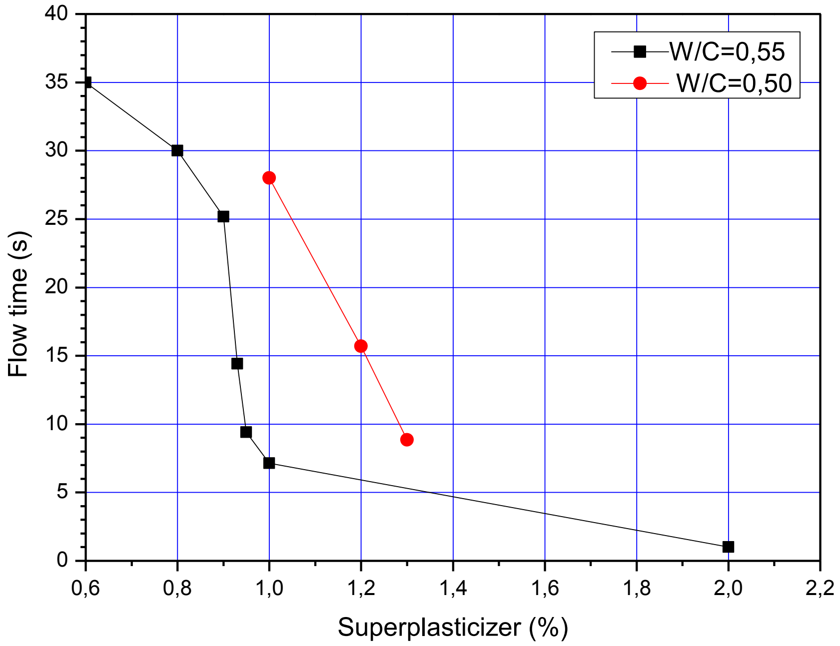


Fig.III. 2 Variation of the flow time with the superplasticizer percentage

III.2.3.Composition of control mortar

The mixture M7 is chosen as control mortar **MC**, because it requires an acceptable water dosage and a superplasticizer percentage (= 0.93 %) lower than that required by M2 (= 1.2). Since the superplasticizer is a commercial material, it is very important to use lowest dosages for not increasing the mortar cost. The table (III.3) gives the final formulation of control mortar.

Table.III. 3 Formulation of control mortar

	C (g)	**S (g)**	**W (g)**	**W/C**	**Sp (%)**
MC	450	1350	247.5	0.55	0.93

III.3. Mechanical characterisation of control mortar

The results of the flexural and the compressive tests realised on control mortar are presented in the table (III.4). The variation of mechanical strength of control mortar is given in function with age in figure (III.3). We note that the highest resistance in compressive and flexural strength is achieved at the 28th day.

Table.III. 4 Mechanical strengths of control mortar

Age (days)	**7**	**28**	**90**
Flexural strength **(MPa)**	5.41 ± 0.26	9.36 ± 0.62	7.87 ± 0.02
Compressive strength **(MPa)**	33.21 ± 2.15	43.83 ± 2.10	38.07 ± 2.62

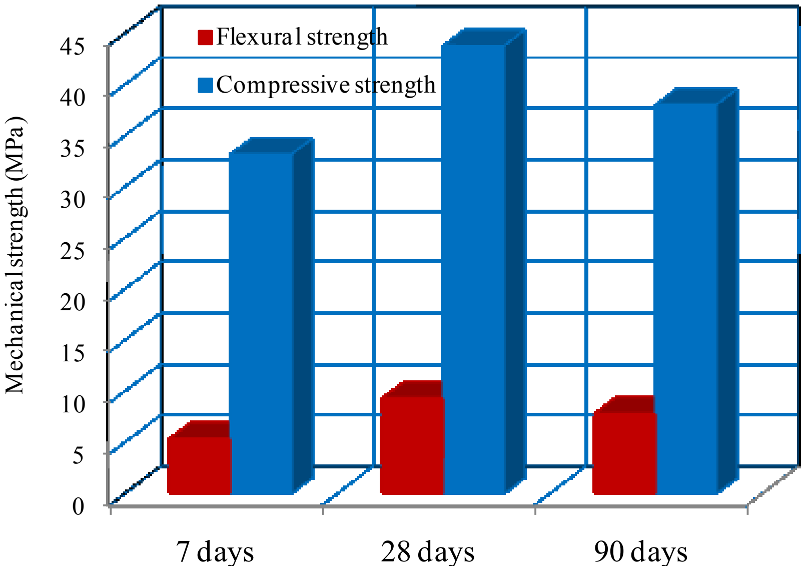


Fig.III. 3 Mechanical strength of control mortar

III.4. Formulation of fibres mortars

With the same composition of control mortar (C = 450 g, S = 1350 g and W/C = 0.55), fibre mortars are prepared with a new optimisation of superplasticizer. For each mixture, numerous tests are conducted to look for the superplasticizer dosages **Sp**, which give the desirable workability. All the results realised in this investigation are presented in annex and in the table (III.5), we illustrate only the composition of the workable mixtures.

Table.III. 5 Composition of fibres mortars

Mixes	**C (g)**	**S (g)**	**W (g)**	**W/C**	**mf (g)**	**MF (g)**	**Sp (%)**	**Flow time (s)**
MC	450	1350	247.5	0.55	00	00	0.93	14.42
$M_{100/0}$	450	1350	247.5	0.55	20.5	00	1.60	18.95
$M_{75/25}$	450	1350	247.5	0.55	15.4	5.1	1.44	20.00
$M_{25/75}$	450	1350	247.5	0.55	5.1	15.4	1.30	11.52
$M_{50/50}$	450	1350	247.5	0.55	10.3	10.3	1.35	17.70
$M_{0/100}$	450	1350	247.5	0.55	00	20.5	1.28	14.35

III.5. Workability of fibres mortars

Figure (III.4) presents the variation of superplasticizer dosage of fibres mortars. It is remarked that fibres mortars need higher dosage of superplasticizer compared to control mortar, while mortars with high percentage of micro fibres require the most important dosage compared to other mixes this could be due to their high specific surface as reported by Myers **(Myers, 2006)**. The majority of the literature studies confirmed that the addition of fibres to concretes and mortars negatively affect their workability and increase their viscosity **(Sebaibi et al., 2014; Söylev and Özturan, 2014; Manaswini and Deva, 2015; Bendjillali and Chemrouk, 2017)**.

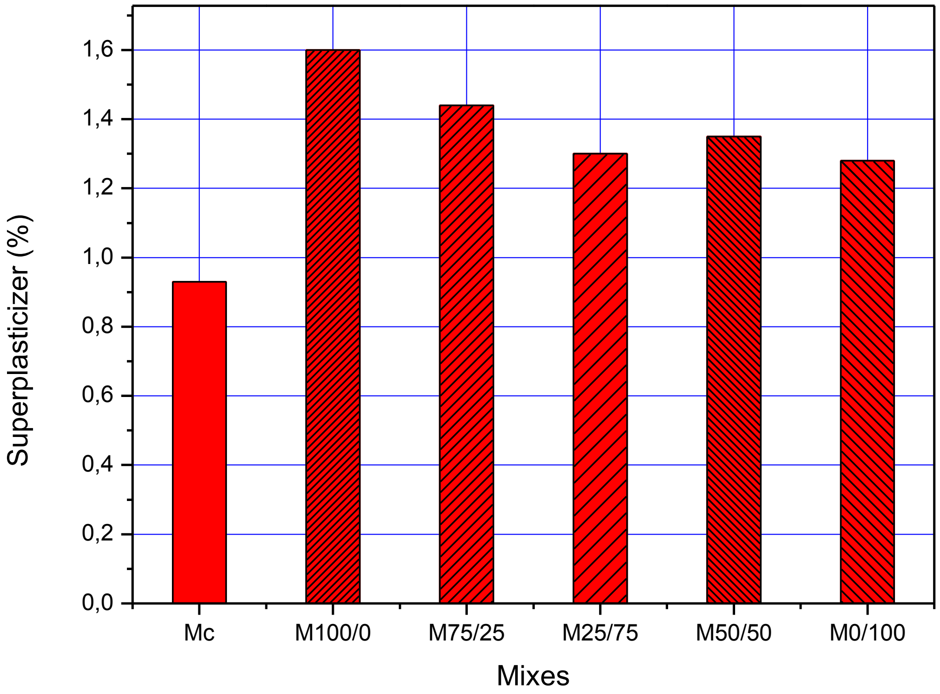


Fig.III. 4 Variation of superplasticizer dosage of fibres mortars

III.6. Mechanical characterisation of fibres mortars

The results of the flexural and the compressive tests are presented in the table (III.6) below:

Table.III. 6 Mechanical strength of fibres mortars

Age (days)		**7**	**28**	**90**
Flexural strength **(MPa)**	**MC**	5.41 ± 0.26	9.36 ± 0.62	7.87 ± 0.02
	$M_{100/0}$	15.63 ± 0.13	18.33 ± 0.87	12.39 ± 0.01
	$M_{75/25}$	16.83 ± 0.30	16.69 ± 0.17	14.69 ± 0.98
	$M_{25/75}$	12.73 ± 0.16	22.54 ± 1.2	13.87 ± 0.62
	$M_{50/50}$	15.72 ± 1.10	20.55 ± 1.44	11.70 ± 0.82
	$M_{0/100}$	16.04 ± 0.77	19.09 ± 0.09	11.50 ± 0.81
Compressive strength **(MPa)**	**MC**	33.21 ± 2.15	43.83 ± 2.10	38.07 ± 2.62
	$M_{100/0}$	47.47 ± 2.37	46.10 ± 1.65	46.94 ± 3.16
	$M_{75/25}$	45.57 ± 2.31	43.33 ± 3.04	39.06 ± 2.55
	$M_{25/75}$	38.85 ± 1.17	45.24 ± 2.04	40.81 ± 2.44
	$M_{50/50}$	42.86 ± 2.8	43.35 ± 2.89	40.27 ± 0.95
	$M_{0/100}$	45.01 ± 2.21	45.57 ± 1.55	38.86 ± 1.55

a. Flexural strength

The flexural strength of all mortars is schematised in the figure (III.5). For a good discussion, the strength gain of the flexural strength of fibres mortars (Fig.III.6) is calculated compared to control mortar as following:

$$\Delta Rf = \frac{Rf - Rf0}{Rf0} 100 \qquad \text{(III.1)}$$

With:

ΔRf: strength gain of the flexural strength (%)

Rf: flexion strength of fibre mortar (MPa)

Rf0: flexion strength of control mortar (MPa)

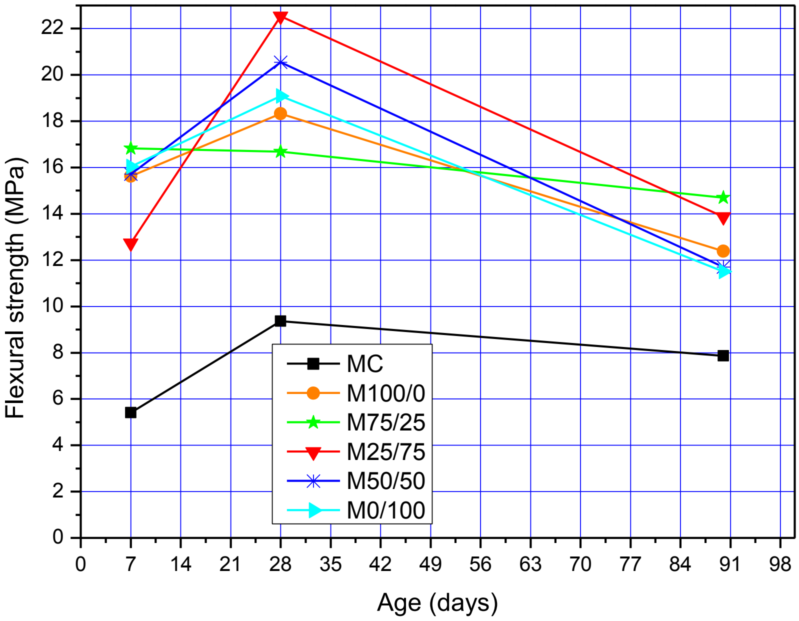


Fig.III. 5 Flexural strength of mortars

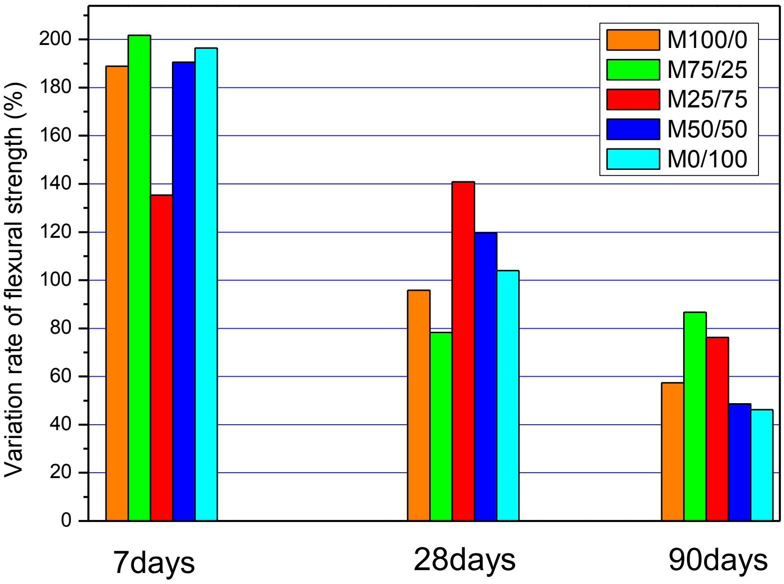


Fig.III. 6 Strength gain of the flexural strength

Figure (III.5) shows an increase of the flexural strength of mortars with age until the 28th days, and then the strength becomes lower. Generally, the highest flexural strength is reached at the 28th day of age for all mixtures, when the maximum strength value (22.54 MPa) is obtained in M25/75 mortar and the minimum in M75/25 (16.69 MPa). At 90 days, the flexural strength values are close in all fibres mortars.

It is very important to note that fibres mortars produce higher flexural strengths compared to the control mortar that means that the addition of polypropylene fibres to mortar enhances its flexural behaviour. This result is found in the most of the literature studies **(Langlois et al., 2007; Mamlouk and Zaniewski, 2011; Pereira de Oliveira et al., 2011)**. This increase in flexural strength is due to the fibre bridging properties, as reported by some authors (**Hasan et al., 2011)**. According to the same authors, under flexural test, the load is transferred to the fibres when the matrix began to crack. Fibres with high tensile strength transfer higher tensile stresses from a cracked matrix to the fibres **(Song et al., 2005)**.

Its remarked through the figure (III.6) that the highest strength gain are recorded at early age (7 days) for all fibres mortars, compared to control mortar, which means that the effect of polypropylene fibres is more important in this state more than at longer time. The values of this gain varies between a minimum of 135 % in M25/75 mortar and a maximum of 202 % in M75/25 mortar at 7 days. It seems that the mix M25/75 gives the best flexural behaviour at 28 days. The good dispersion of fibres in the matrix can affect positively the mechanical performance of the materials as reported by other studies **(Akkaya et al., 2001; Ozyurt et al., 2007)**.

b. Compressive strength

The variation of the compressive strength of mortars is given, in function with age in figure (III.7). In figure (III.8), the strength gain of the compressive strength of fibres mortars is presented. This strength gain is calculated by comparison to control mortar with the following relation:

$$\Delta Rc = \frac{Rc - Rc0}{Rc0} 100 \qquad \text{(III.2)}$$

With:

ΔRc: strength gain of the compressive strength (%)

Rc: compressive strength of fibre mortar (MPa)

Rc0: compressive strength of control mortar (MPa)

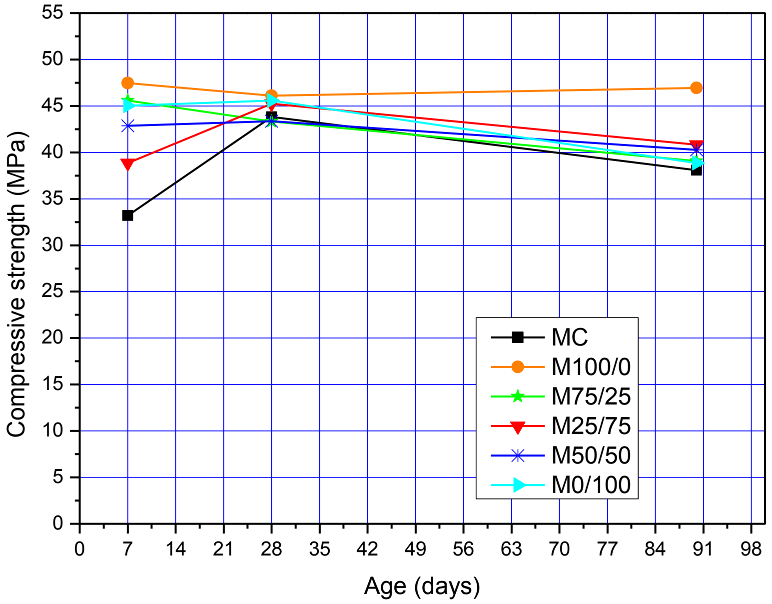


Fig.III. 7 Compressive strength of mortars

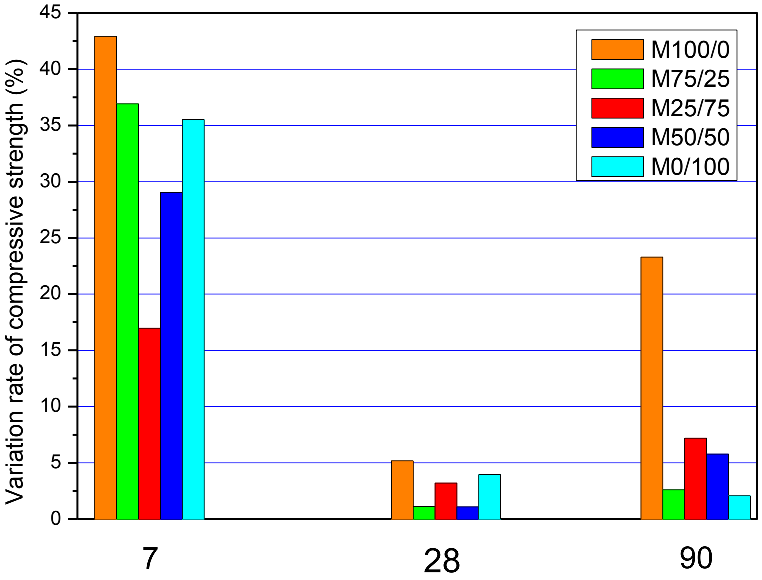


Fig.III. 8 Strength gain of the compressive strength

As in flexural strength, until the 28th days, the compressive strength of mortars increases with time and after that, it decreases, except the strength of mortar M75/25 that slightly decreases from the 7th day, however the strength of mortar M100/0 remains almost constant which means that the micro fibres do not negatively affect the porosity of the materials. Typically, it is observed that all mortars showed a good mechanical behaviour.

It is very important to note that generally the highest compressive strengths of mortars are reached at 28 days of age, the same result is found in a previous study **(Manaswini, 2015).** The maximum values of the compressive strength are recorded in M100/0, at any age. By comparison with control mortar, the M100/0 shows amelioration between 43 and 23 % at 7 and 90 days respectively (Fig.III.8).

The highest compressive strengths are produced in polypropylene fibres mortars, as in flexural strength, which shows the positive effect of the addition of polypropylene fibres to mortar. Some researchers **(Hasan et al., 2011; Alengaram et al., 2013; Bendjillali et al., 2016; Sohaib et al., 2018)** have reported a compared conclusion.

In general, the effect of fibres is negligible on the 28th day in compressive strengths (Fig.III.8).

The addition of PP fibres improved the post-failure toughness in compressive strength as it is reported by **(Alengaram et al., 2013)**.

III.7. Shrinkage

a. Total shrinkage

The results of total shrinkage are illustrated in figure (III.9) and in figure (III.10), the comparison of total shrinkage between fibre's mortar and control mortar is presented. This comparison is calculated with the following relation:

$$\Delta TS = \frac{TSi - TS0}{TS0} 100 \qquad \text{(III.3)}$$

With:

ΔTS: shrinkage variation percentage (%)

TSi: total shrinkage of fibre mortar (μm/m)

TS0: total shrinkage of control mortar (μm/m)

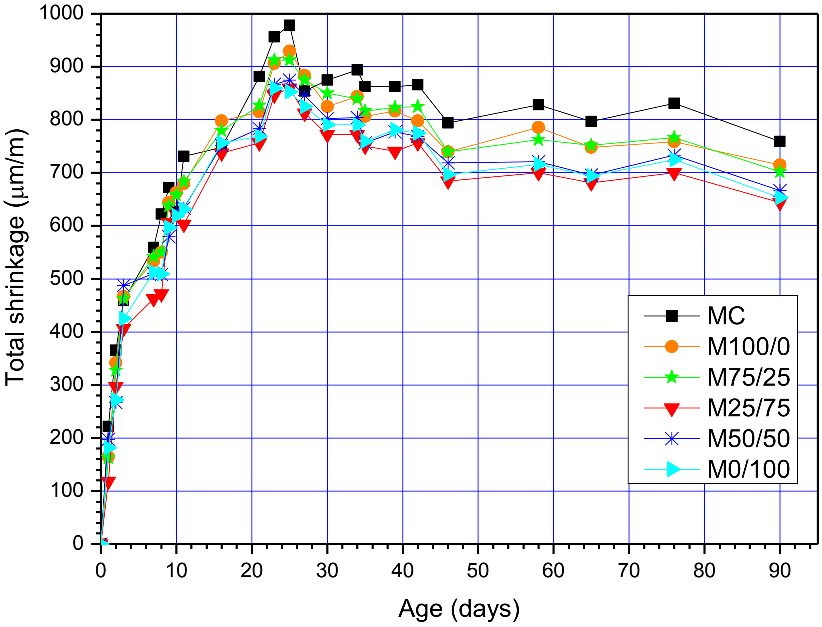


Fig.III. 9 Variation of total shrinkage with age

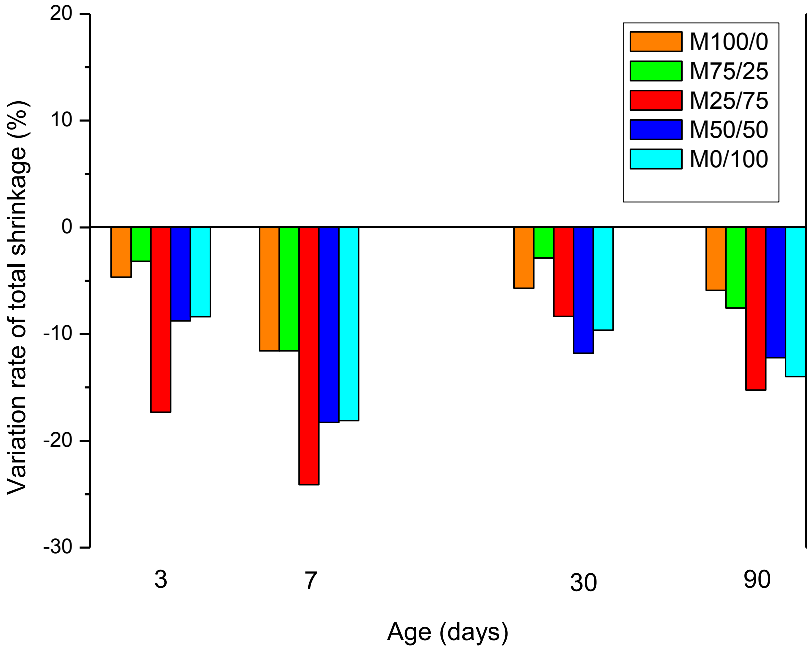


Fig.III. 10 Comparison of total shrinkage between fibre mortar and control mortar

The total shrinkage evolves very rapidly for all mixes during the first 4 days, due to the important variation of humidity between the mortar mass and the conservation chamber.

The conservation conditions (T = 15 ± 5 ◦C, RH = 20 ± 5 %) favourite the premature desiccation of mortars, which leads to a high risk of shrinkage. Then a continuous increase of shrinkage is observed on all mortars to a maximum around 900 µm/m at 25 days, after that it decreases until the stabilisation nearly to 700 µm/m.

Control mortar have the highest shrinkage however, mortars M50/50, M0/100 and M25/75 gives the lowest shrinkage compared to other mixes, this could be explained that the present of macro fibres with a high percentage leads to evolve the positive effect of fibres on shrinkage.

Based on the experimental results, the introduction of synthetic fibres to mortars reduces considerably theirs total shrinkage, as find by other authors **(Ma et al., 2002; Bendjillali et al., 2016; 2017)**. According to some researchers **(Zhu et al., 2004)**, fibres decreases the number of larger cracks and increases the number of finer cracks; by creating obstacles to shrinking movement. In other work **(Branch et al., 2002)**, it is reported that the introduction of any type of fibres into ordinary concrete can reduce the shrinkage by 40 to 85 %. The reduction of total shrinkage achieves 24 %, at 7 day aging in M25/75 mortar, which is the highest reduction ratio.

The geometry of the fibre (circular cross-section) can also affect the shrinkage by reducing its values **(Ma et al., 2002)**.

b. Endogenous shrinkage

The figure (III.11) shows the variation of endogenous shrinkage of all materials with age. The comparison of the endogenous shrinkage of fibre’s mortar with control mortar is calculated with the relation below and the results are illustrated graphically in figure (III.12).

$$\Delta ES = \frac{ESi - ES0}{ES0} 100 \qquad \text{(III.4)}$$

With:

ΔES: shrinkage variation percentage (%)

ESi: endogenous shrinkage of fibre mortar (µm/m)

ES0: endogenous shrinkage of control mortar (µm/m)

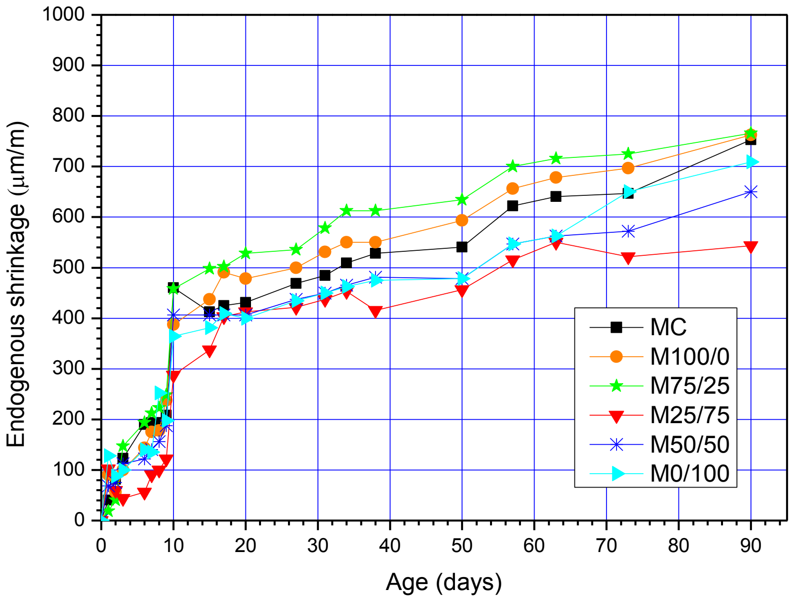


Fig.III. 11 Variation of endogenous shrinkage with age

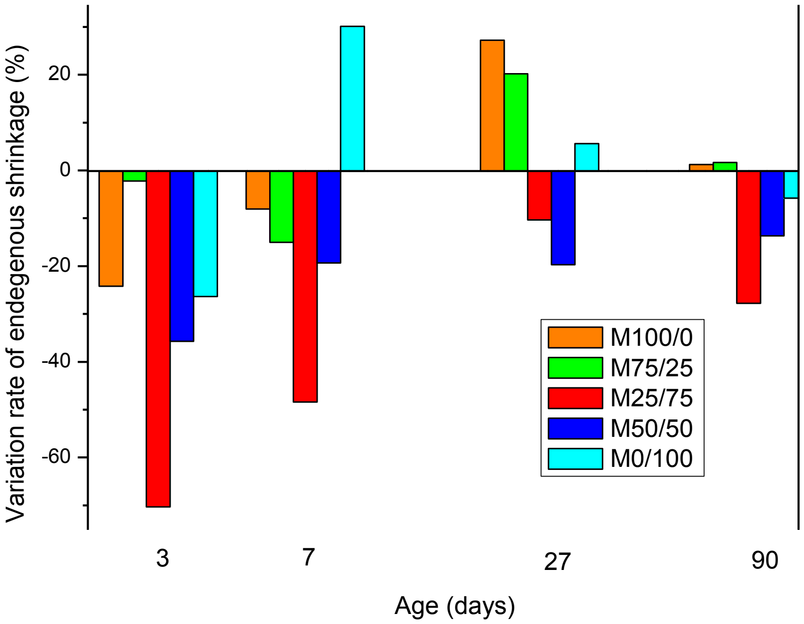


Fig.III. 12 Comparison of endogenous shrinkage between fibre mortar and control mortar

It is observed that generally synthetic fibres reduce the endogenous shrinkage as it is found in previous study **(Bendjillali et al., 2017)**. According to figure (III.11), mortar M25/75 generates the lowest endogenous shrinkage as with the total shrinkage and M75/25 the highest one. In M100/0 and M75/25, the endogenous shrinkage is increased by 27 % and 20 % respectively at 27 days, compared to control mortar. We can conclude that the high percentage of macro fibres mitigates also the endogenous shrinkage as in the total shrinkage; a reduction about 75 % at early age (after 3 days aging), and around 30 % at long term (after 90 days aging) in M25/75 mortar.

The effect of macro fibres on endogenous shrinkage is more important than that of micro fibres, as found in the total shrinkage.

A good dispersion of fibres in the matrix improves the shrinkage control and as indicated by other authors **(Kawashima and Shah, 2011)** it is in correlation with the endogenous shrinkage results.

III.8. Weight loss

Figure (III.13) presents the variation of weight loss with time. It can be remarked that the weight loss develops rapidly with age, especially during the first two weeks from around 2 % to 7 %; then it continuous to evolve slowly until the stabilisation nearly to 7.5 %. In general, the weight loss measurements are close during all tests. That means that scattered fibres in the matrix did not affect negatively the size of pores (increase) in the material as well as theirs volume, by increasing the capillary intensity, and obstructing the evaporation of water contrary to what other authors found **(Mesbah and Buyle-Bodin, 1999)**.

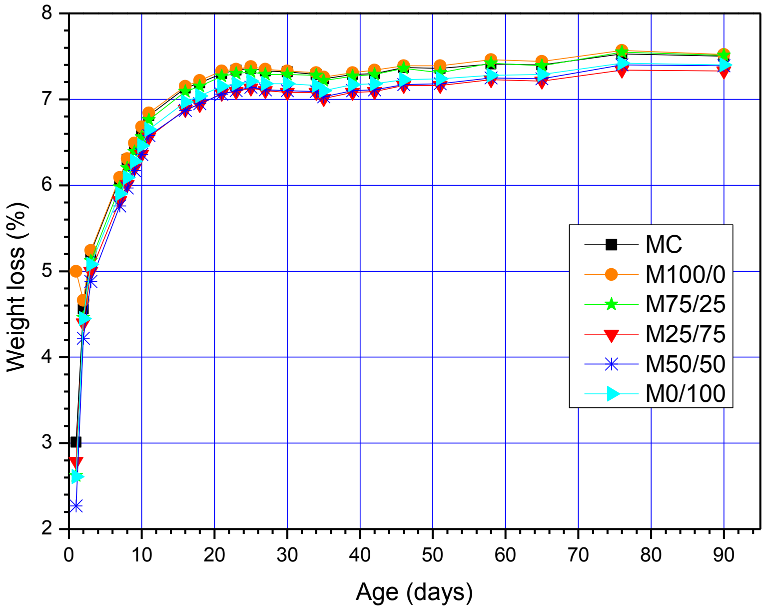


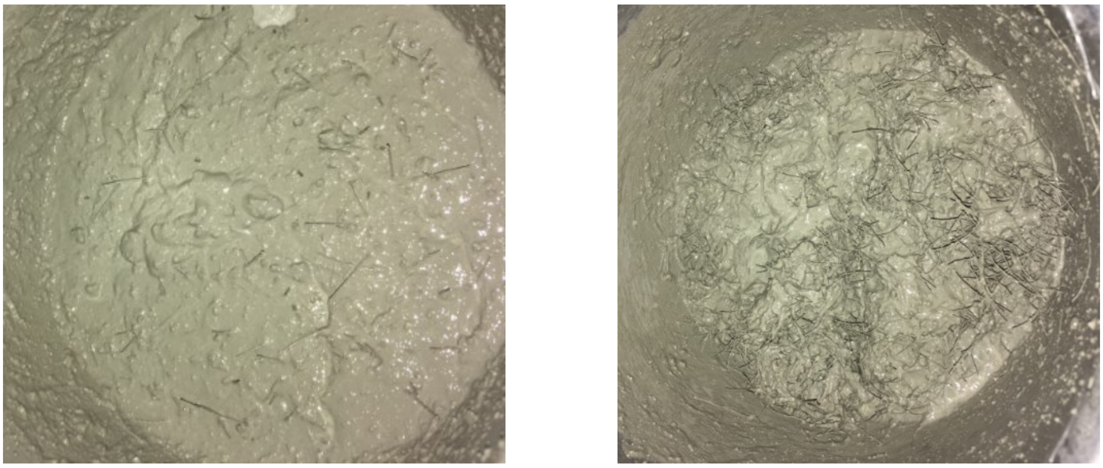
Fig.III. 13 Variation of weight loss

III.9. Visual observations

- The addition of PP fibres affects negatively the workability of the mixture that means that the use of a superplasticizer is an obligation to facilitate the placement of concrete in the construction site (Fig.III.14). This effect is more observed in the micro fibres mixtures.

a. Dry mix

b. Very dry mix



c. Very wet mix

d. Wet mix

Fig.III. 14 Fresh fibre mortars

- No fibres balls are created in the material during the mixing processes (introduction by hand), certainly thanks to the mixing method.

- No pullout problem is observed during the flexural test in all mortars. It is can be due to the sufficient fibre length used in this work, which have ensured a best cohesion between fibre and matrix (Fig.III.15).

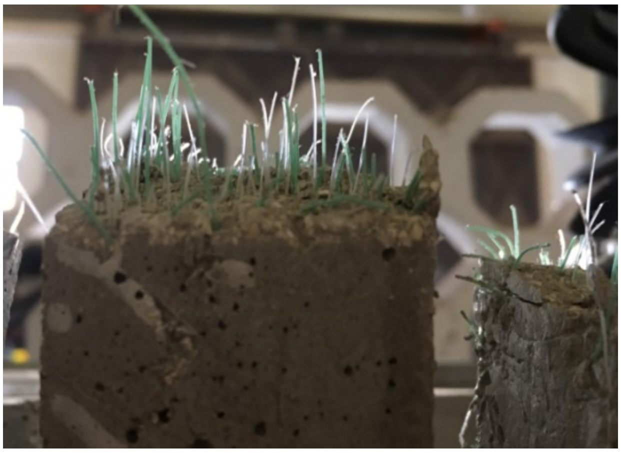


Fig.III. 15 Specimen’s surface after flexural test

- A good distribution of fibres is observed in the matrix (Fig.III.16).

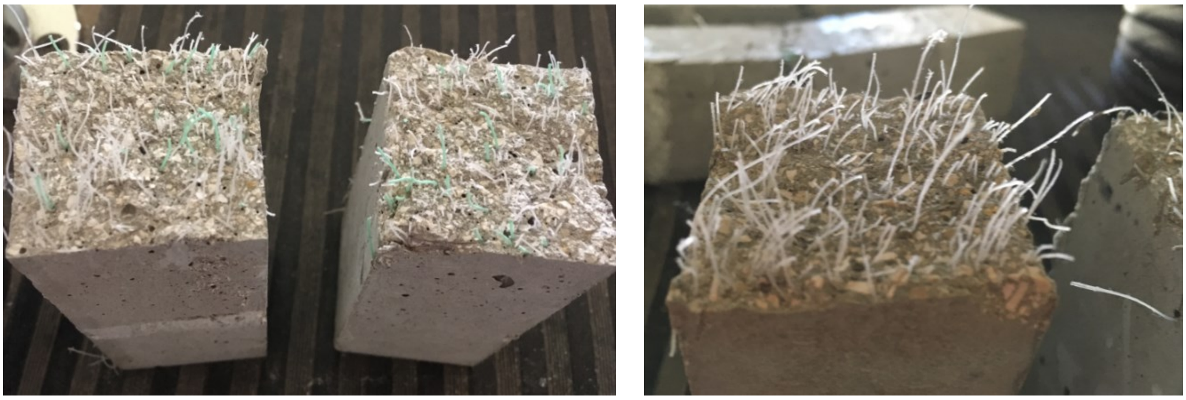


Fig.III. 16 Good dispersion of fibre within the matrix

- Used fibres have assured a good control of the propagation of cracks in the mortar during flexural test, probably thanks to their high elasticity and elongation (Fig.III.17). Adding supplementary material to the concrete mix can significantly improve the ductile behaviour and reduce crack propagation **(Hamoush et al. 2010)**.

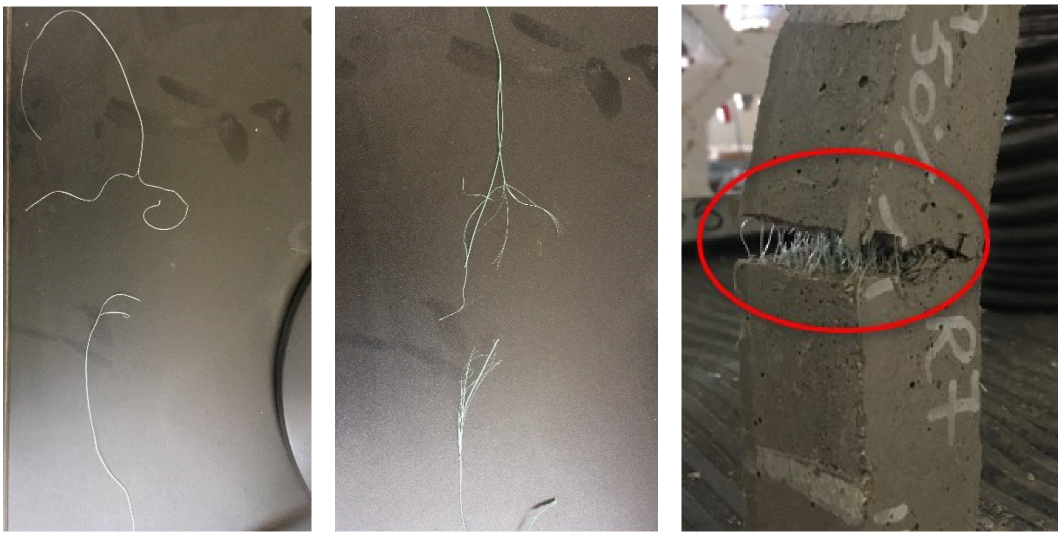


Fig.III. 17 Control of the propagation of cracks

- It is remarked that the control mortar containing no fibres failed suddenly, while the fibres reinforced mortar exhibited cracks but did not fully separate (Fig.III.18, III.19). By using high percentage of PP fibre in the reinforced concrete beam, the ductility can be improved by 160 % **(Ghosni et al, 2013)**.

a. Control mortar

b. Fibre mortar

Fig.III. 18 Failure mode in flexural test

a. Control mortar

b. Fibre mortar

Fig.III. 19 Failure mode in compressive test

III.10. Conclusion

Based on the experimental results, these conclusions are made:

- The workability of limestone mortars is negatively affected by the addition of synthetic fibres.
- The mechanical behaviour of limestone mortars is enhanced with the incorporation of macro and micro fibres compared to control mortar.
- The highest flexural and compressive strengths are reached at the 28th day of age for all mixtures.
- The mix M25/75 gives the best flexural behaviour at 28 days.
- The maximum values of the compressive strength are recorded in M100/0, at any age; by comparison with control mortar, the M100/0 shows amelioration between 43 and 23 % at 7 and 90 days respectively.
- The reduction of total shrinkage achieves 24 %, at 7 day aging in M25/75 mortar, which is the highest reduction ratio.
- In M100/0 and M75/25 mortars, the endogenous shrinkage is increased by 27 % and 20 % respectively at 27 days, compared to control mortar.
- In general, the weight loss measurements are close during all tests.

General conclusion

General conclusion

This paper has been concerned with the investigation of mechanical behaviour, total shrinkage and endogenous shrinkage of mortar reinforced with macro and micro synthetic fibres. Hence, the conclusions summarized as:

- The used VISCOCRETE TEMPO 12 improves the workability.
- The workability of mortars is reduced by the addition of polypropylene fibres.
- The addition of PP enhanced the mechanical properties of mortar. The enhancement is mainly attributed to the fibre bridging process that allowed additional stress to develop for the cracks to propagate.
- Mortar M100/0 gives the highest compressive strength.
- Mortar M25/75 gives the highest flexural strength at 28 days.
- Mortar M75/25 gives the most important variation rate of the flexural strength about 200 % and compressive variation rate approximately 34% at the 7^{th} day compared to control mortar.
- Mortar M100/0 gives variation rate of the flexural strength about 187 % and the most important variation rate of compressive strength nearly to 43 % at the 7^{th} day compared to control mortar.
- The visual observation showed that the fracture in fibre reinforced mortar is slower compared to control mortar.
- The used fibres have a benefice role in the material by delaying the appearance of micro cracks; also, they have such an important role in the sewing of these cracks after the rupture of the matrix.
- The presence of fibres in the matrix offers to the mortar a very good ductility and a good distribution of cracks in the fractured area.
- The addition of PP fibres improved the post-failure toughness in terms of post-failure compressive and flexural strength.
- The fibre reinforced mortar has the ability to hold on the crack of the mortar and resist the mortar specimen from falling apart.
- Macro fibres, micro fibres and the cocktail behave differently on the mechanical properties, total shrinkage and endogenous shrinkage of mortar.

- The addition of micro and macro synthetic fibres leads to decrease the total shrinkage compared to control mortar.
- The presence of high percentage of macro fibres reduces the endogenous shrinkage, while the high percentage of micro fibres improves it.
- Macro fibres are found to be the most effective. These findings are in agreement with the effect of these fibres on endogenous shrinkage.
- The weight loss is very close in all mortars until the age of 90 days.

As the concrete is a fundamental material in the field of construction engineering, the improvement of its mechanical properties by the addition of this fibre will certainly increase the use of this composite material, which will offer more strong and durable structures in the future and will open a new area in the field of construction materials.

Recommendations

- Study of the durability of mortars reinforced with micro and macro synthetic fibres.
- Study of the mechanical behaviour of mortars with a cocktail of micro short fibres and long macro fibres.
- Use other dosage of fibres.
- The use of the same cocktail as reinforcement of concrete with gravel 3/8 mm.

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Annexes

Annexes

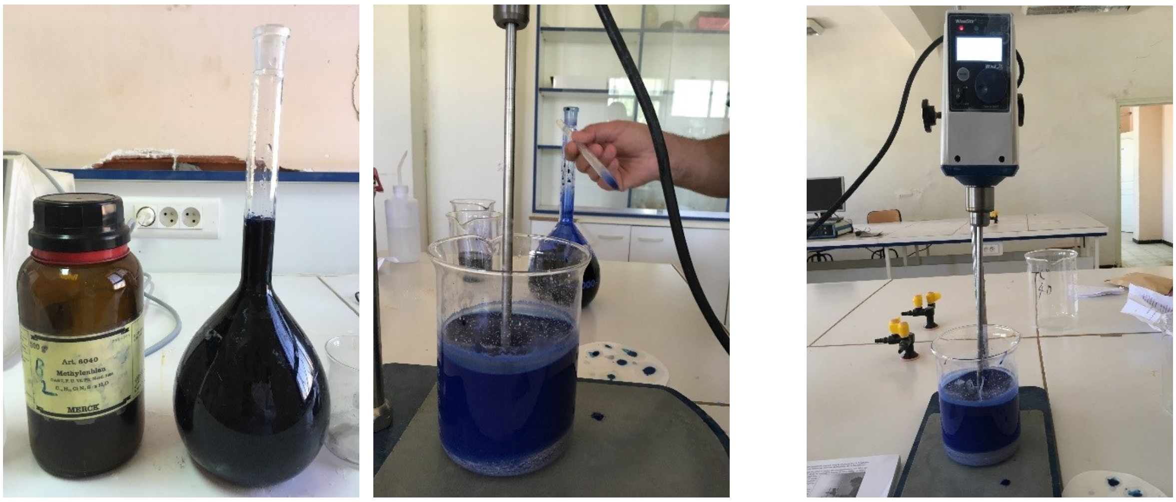


Fig.1. Blue methylene test of sand

Fig.2. Melting temperature test of fibres

Fig.3. Used micro and macro fibres

Fig.4. Moulding

Fig.5. Specimens conserved in controlled chamber

Fig.6. Measurement of temperature and moisture conservation

Fig.7. Specimens after flexural test

M100/0

M0/100

M50/50

Fig.8. Photos of fibre mortar taken by digital microscope

Formulations of mortars with and without fibres

Mixes	C (g)	S (g)	W (g)	W/C	mf (g)	Mf (g)	Sp (%)	t (s)	Visual observations
MC$_1$	450	1350	270	0.60	00	00	00	45	Very dry
MC$_2$	450	1350	292.5	0.65	00	00	00	30	Very dry
MC$_3$	450	1350	301.5	0.67	00	00	00	10	Wet
MC$_4$	450	1350	310.5	0.69	00	00	00	5.88	Very Wet
MC$_5$	450	1350	225	0.50	00	00	0.6	35	Very dry
MC$_6$	450	1350	225	0.50	00	00	01	30	Very dry
MC$_7$	450	1350	247.5	0.55	00	00	0.8	28	Very dry
MC$_8$	450	1350	247.5	0.55	00	00	0.9	25.18	Dry
MC$_9$	450	1350	225	0.50	00	00	1.2	15.69	Plastic
MC$_{10}$	450	1350	247.5	0.55	00	00	0.93	14.42	Plastic
MC$_{11}$	450	1350	247.5	0.55	00	00	0.95	9.41	Wet
MC$_{12}$	450	1350	225	0.50	00	00	1.3	8.86	Wet
MC$_{13}$	450	1350	247.5	0.55	00	00	01	7.15	Wet
MC$_{14}$	450	1350	247.5	0.55	00	00	02	01	Very Wet
M$_{100/0}$	450	1350	225	0.50	20.5	00	02	50	Very dry
M$_{100/0}$	450	1350	247.5	0.55	20.5	00	1.6	18.95	Plastic
M$_{100/0}$	450	1350	247.5	0.55	20.5	00	02	08	Wet
M$_{100/0}$	450	1350	247.5	0.55	20.5	00	1.8	5.75	Very wet
M$_{100/0}$	450	1350	247.5	0.55	20.5	00	2.1	05	Very wet
M$_{100/0}$	450	1350	247.5	0.55	20.5	00	2.2	05	Very wet
M$_{100/0}$	450	1350	247.5	0.55	20.5	00	2.5	03	Very wet
M$_{75/25}$	450	1350	247.5	0.55	15.37	5.125	1.4	22.10	Dry
M$_{75/25}$	450	1350	247.5	0.55	15.37	5.125	1.44	20	Plastic
M$_{75/25}$	450	1350	247.5	0.55	15.37	5.125	1.47	20	Plastic
M$_{75/25}$	450	1350	247.5	0.55	15.37	5.125	1.52	7.13	Wet
M$_{75/25}$	450	1350	247.5	0.55	15.37	5.125	1.49	7.05	Wet
M$_{25/75}$	450	1350	247.5	0.55	5.125	15.37	1.28	30	Very dry
M$_{25/75}$	450	1350	247.5	0.55	5.125	15.37	1.30	11.52	Plastic
M$_{25/75}$	450	1350	247.5	0.55	5.125	15.37	1.36	5.13	Very wet
M$_{50/50}$	450	1350	247.5	0.55	10.25	10.25	1.35	17.70	Plastic
M$_{50/50}$	450	1350	247.5	0.55	10.25	10.25	1.44	09	Wet
M$_{0/100}$	450	1350	247.5	0.55	00	20.5	1.1	40	Very dry
M$_{0/100}$	450	1350	247.5	0.55	00	20.5	1.2	25	Dry
M$_{0/100}$	450	1350	247.5	0.55	00	20.5	1.28	14.35	Plastic
M$_{0/100}$	450	1350	247.5	0.55	00	20.5	1.3	6.15	Wet
M$_{0/100}$	450	1350	247.5	0.55	00	20.5	1.6	01	Very wet

Construction

Notice technique
Edition juin 2017
Numéro 1.20
Version n°106. 2017
SIKA® VISCOCRETE® TEMPO 12

SIKA® VISCOCRETE® TEMPO 12

Superplastifiant/Haut Réducteur d'eau polyvalent pour bétons prêts à l'emploi.

Conforme à la norme NF EN 934-2 Tab. 1, 3.1 et 3.2.

Présentation

SIKA VISCOCRETE TEMPO 12 est un superplastifiant/haut réducteur d'eau polyvalent de nouvelle génération non chloré à base de copolymère acrylique.

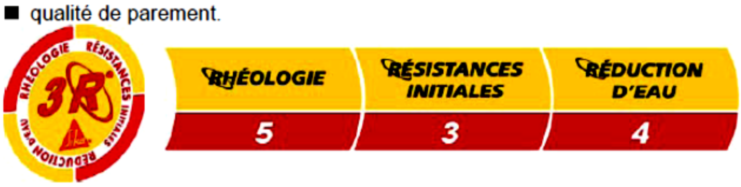
Domaines d'application

- SIKA VISCOCRETE TEMPO 12 permet la fabrication de bétons plastiques à autoplaçants transportés sur de longues distances et pompés.
- Dans les bétons autoplaçants, SIKA VISCOCRETE TEMPO 12 améliore la stabilité, limite la ségrégation du béton et rend les formules moins susceptibles aux variations d'eau et des constituants.

Caractères généraux

SIKA VISCOCRETE TEMPO 12 est un superplastifiant puissant qui confère aux bétons les propriétés suivantes :

- longue rhéologie (>2h),
- robustesse à la ségrégation,
- qualité de parement.



Agréments, essais de laboratoire

- PV CNERIB : DTEM : 108/2017.

Caractéristiques

Aspect

Liquide brun clair

Conditionnement

- Fûts de 230 kg
- CP de 1000 L
- Vrac

Stockage

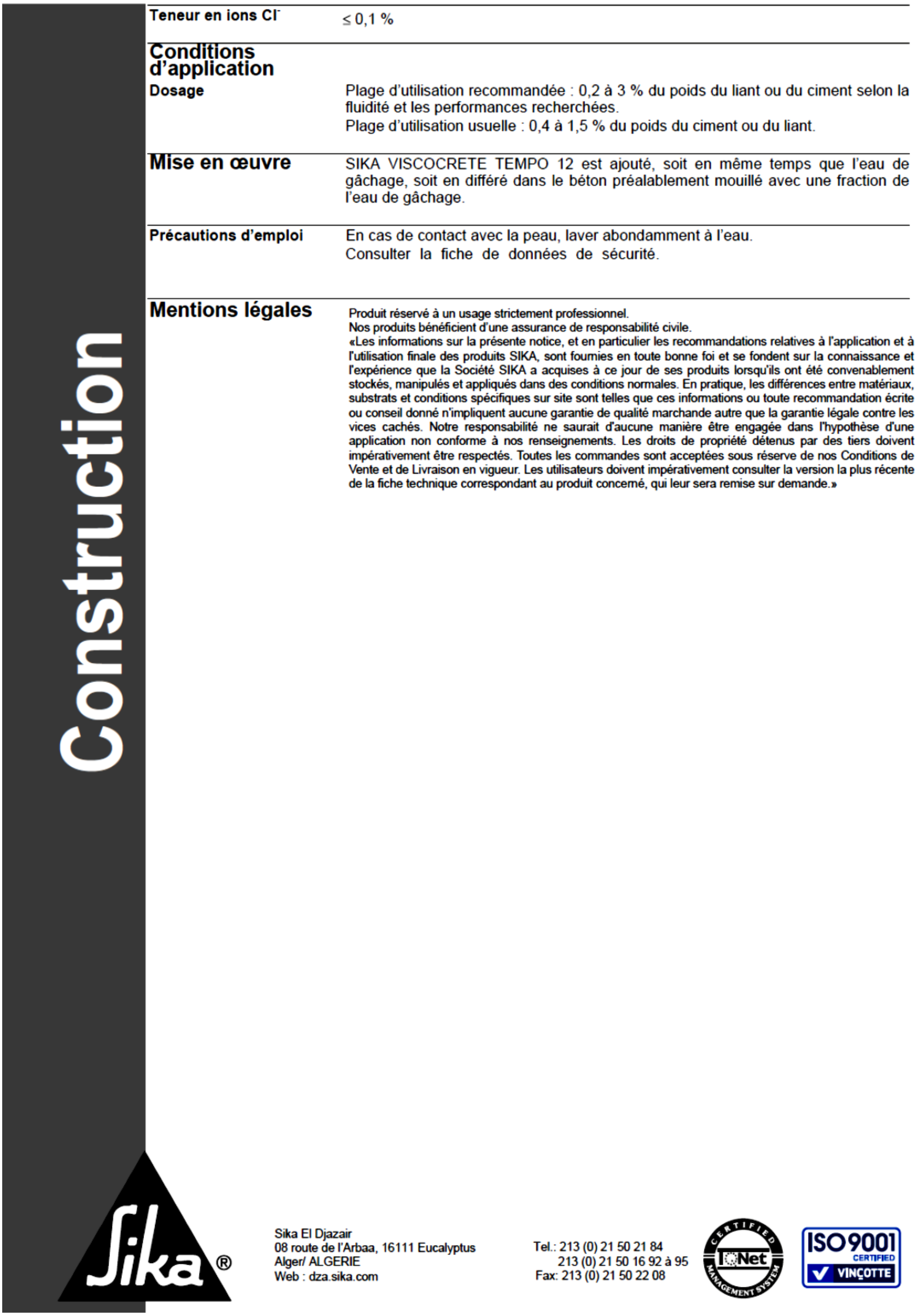
Dans un local fermé, à l'abri de l'ensoleillement direct et du gel, entre 5 et 30 °C.
SIKA VISCOCRETE TEMPO 12 peut geler, mais, une fois dégelé lentement et réhomogénéisé, il retrouve ses qualités d'origine.
En cas de gel prolongé et intense, vérifier qu'il n'a pas été déstabilisé.

Conservation

1 an en emballage intact

Données techniques

densité	1,06 ± 0,01
pH	6 ± 1
Teneur en Na_2O Eq.	$\leq$ 1 %
Extrait sec	30,2 ± 1,3 %



Teneur en ions Cl^-	≤ 0,1 %

Conditions d'application

Dosage	Plage d'utilisation recommandée : 0,2 à 3 % du poids du liant ou du ciment selon la fluidité et les performances recherchées. Plage d'utilisation usuelle : 0,4 à 1,5 % du poids du ciment ou du liant.

Mise en œuvre

SIKA VISCOCRETE TEMPO 12 est ajouté, soit en même temps que l'eau de gâchage, soit en différé dans le béton préalablement mouillé avec une fraction de l'eau de gâchage.

Précautions d'emploi	En cas de contact avec la peau, laver abondamment à l'eau. Consulter la fiche de données de sécurité.

Mentions légales

Produit réservé à un usage strictement professionnel.
Nos produits bénéficient d'une assurance de responsabilité civile.
«Les informations sur la présente notice, et en particulier les recommandations relatives à l'application et à l'utilisation finale des produits SIKA, sont fournies en toute bonne foi et se fondent sur la connaissance et l'expérience que la Société SIKA a acquises à ce jour de ses produits lorsqu'ils ont été convenablement stockés, manipulés et appliqués dans des conditions normales. En pratique, les différences entre matériaux, substrats et conditions spécifiques sur site sont telles que ces informations ou toute recommandation écrite ou conseil donné n'impliquent aucune garantie de qualité marchande autre que la garantie légale contre les vices cachés. Notre responsabilité ne saurait d'aucune manière être engagée dans l'hypothèse d'une application non conforme à nos renseignements. Les droits de propriété détenus par des tiers doivent impérativement être respectés. Toutes les commandes sont acceptées sous réserve de nos Conditions de Vente et de Livraison en vigueur. Les utilisateurs doivent impérativement consulter la version la plus récente de la fiche technique correspondant au produit concerné, qui leur sera remise sur demande.»

Construction

Sika El Djazair
08 route de l'Arbaa, 16111 Eucalyptus
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عنوان المذكرة: **دراسة السلوك الميكانيكي وانكماش الملاط المقوى بالألياف الصناعية ذات القطر الكبير والصغير.**

اللقب: بن جيلالي **الاسم: فتيحة** **المؤطر: بن جيلالي خضرة و قربة بن حرزالله**

ملخص: الانكماش ظاهرة مهمة للغاية تؤثر على جميع الهياكل الخرسانية، له اثار ضارة على ديمومة البناء إذا لم يتم التحكم فيه.

الهدف الأول من هذا العمل هو تحديد الخصائص الميكانيكية والفيزيائية لعينات الملاط المقواة بالألياف الاصطناعية. الهدف الثاني هو معرفة ما إذا كان استخدام الألياف الاصطناعية بتغيير قطرها يمكن ان يحسن من الخصائص الميكانيكية ويقلل من خطر الانكماش الحر لهذه المواد. تم تنفيذ العمل على عينات من الملاط باستخدام الرمل الجيري، اسمنت مركب وألياف اصطناعية. الألياف المستخدمة كتعزيز لهذه الملاط هي ألياف تركيبية من مادة البولي بروبيلين مستخرجة من النفايات الصناعية، حيث ان الألياف الكبيرة يبلغ قطرها 0.45 مم يتم انتاجها في مصنع PLAST BROS ببرج بوعريريج (الجزائر) والألياف ذات القطر الأصغر 0.25 مم تم اقتناؤها من المتجر. كما ان للألياف المستخدمة نفس الطول 30 مم. إضافة الألياف لها تأثير سلبي على قابلية الخليط للتشغيل وخاصة الألياف ذات القطر الأصغر. غير أنه يمكنها تحسين الخواص الميكانيكية للخليط. الخليط M100/0 له أكبر قوة ضغط بينما الخليط M25/75 له أكبر قوة انثناء. يتم تقليل الانكماش الكلي بوجود الألياف الكبيرة والصغيرة، كما يمكن تقليل الانكماش الداخلي بوجود الألياف الكبيرة فقط. اما فقدان الوزن فهو متقارب في جميع العينات.

كلمات مفتاحية: الملاط المقوى بالألياف، السلوك الميكانيكي، الانكماش الكلي، الانكماش الداخلي، الألياف الاصطناعية، الألياف الكبيرة، الألياف ذات القطر الأصغر.

Titre du mémoire: Etude du comportement mécanique et retrait des mortiers renforcés par un mélange des micro et macro fibres synthétiques

Nom: Bendjilali **Prénom: Fatiha** **Encadreur: Mme Bendjillali Khadra et Mr Krobba Benharzallah**

Résumé: Le retrait est un phénomène très important qui touche toutes les structures en béton. S’il n’est pas contrôlé, ses effets seront néfastes sur la durabilité de la construction. Le premier objectif de ce travail est d’étudier les caractéristiques mécaniques et physiques des mortiers renforcés par des fibres synthétiques. Le deuxième objectif est de voir si en utilisant un renforcement fibreux synthétique, en jouant sur leur diamètre, nous pouvons améliorer la résistance mécanique et réduire le risque du retrait libre de ces matériaux. Le travail est réalisé sur des mortiers, avec un sable calcaire de concassage, un ciment composé et des fibres synthétiques. Les fibres utilisées comme renfort de ces mortiers sont des fibres synthétiques de polypropylène provenant de déchets industriels; macro fibres de diamètre de 0,45 mm produites par l'usine PLAST BROS de Bordj Bou Arreridj (Algérie) et micro fibres de diamètre de 0,25 mm disponibles sur le marché. Les fibres utilisées ont une même longueur de 30 mm. L'ajout de fibres a un effet négatif sur l'ouvrabilité du mélange, en particulier les microfibres. Cependant, les propriétés mécaniques des mortiers ont été améliorées. Le mortier M100/0 offre la résistance à la compression la plus élevée, tandis que le mortier M25/75 présente la résistance à la flexion la plus importante. Le retrait total est réduit avec l’utilisation de macro et micro fibres. Le retrait endogène n’est réduit que par les macro fibres. La perte en masse dans tous les mortiers est très comparable.

Mots Clés: mortier de fibre, comportement mécanique, retrait libre, retrait endogène, fibres synthétiques, micro fibre, macro fibre.