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# IMPACT OF ELEVATED TEMPERATURE ON THE PROPERTIES OF CONCRETES REINFORCED WITH ALFA FIBER

Imane MIHOUB[1], Mohammed Rissel KHELIFA[2], Samy MEZHOUD[3*]
[1]Laboratory of Soil Mechanics and structures (LMSS), Dept. of Civil Engineering,
Faculty of Science and Technology, University of Mentouri Brothers Constantine 1,
Constantine, Algeria
[2] Department of Civil Engineering, Faculty of Technology, University of Batna 2, Batna,
Algeria
[3] Department of Geography and Land Sciences, University of Mentouri Brothers
Constantine1, Constantine, Algeria

## Abstract

Alfa fiber reinforced concretes are not used to their full potential due to the limited information on their properties, especially in more severe environments. In this study, the effects of elevated temperature on the properties of concretes reinforced with Alfa fiber were analyzed. The influence of fiber length on reinforced concretes is mainly investigated. For this purpose, five types of structural concretes were formulated; two types of concrete reinforced with 1% Alfa fiber volume using two different fiber lengths of 20 mm and 30 mm (AC-20, and AC-30), and three control concretes, two polypropylene fiber reinforced concretes (PC) using the same fiber length (PC-20, PC-30), and one ordinary concrete (OC). The results showed that with the increase of temperature, the mechanical performance decreased and the porosity rose continually for all mixtures. However, the use of Alfa fiber with a length of 20 mm showed the optimal results in terms of compressive and tensile strength, even at temperatures of 600°C. This finding suggests that Alfa vegetable fiber can be used to produce more sustainable concretes with acceptable mechanical properties compared to the use of polypropylene fiber, even under severe conditions of elevated temperature.

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[*] Corresponding author : mezhoud.sami@umc.edu.dz

Keywords: reinforced concretes, Alfa fiber, polypropylene fiber, elevated temperature, sustainability, fiber length

## 1. INTRODUCTION

The current study is oriented towards ensuring the sustainability of concrete technology and the development of conventional concrete, for the benefit of green concrete with new raw materials. Recently, this research field has been interested in the reinforcement of structural concrete by bio-source fibers such as: coconut [1, 38], Bamboo [39, 2], Sisal [7, 38], Diss [35], Date Palm [18], Flax [29], Hemp [13, 34], and Alfa [3, 15, 16]. These fibers would seem to be an alternative with less environmental impact compared to synthetic fibers made from petroleum derivatives. Their low cost and low density as well as their specific properties make them very competitive.

In the last years, a considerable focus has been oriented toward the use of Alfa natural fibers (AF), taking into account their availability. This kind of fiber is used widely to make ropes, wickerwork, paper, and, currently, to reinforce concrete. These fibers are harvested in the arid regions of the Mediterranean basin, and in Algeria, from Hodna, El-Oued, and Djelfa. They are in the form of tufts of grass, consisting of cylindrical stems at a height of about 1 m [32]. The AF fiber has a specific surface area of $3m^2/g$ and is mainly composed 45% of cellulose, 24% of hemicelluloses, 24% of lignin, 5% of pectin, and 2% of wax [6]. According to Bahloul [2] and Khelifa [15, 16] untreated AF have been used in the manufacture of cementitious mortars and concretes with different volume percentages. The results obtained showed that the optimal percentage of fibers to be incorporated either in the mortar or in the concrete is between 1% and 1.5%. These studies show that the incorporation of these fibers with a rate greater than 1.5% leads to a decrease in mechanical performance.

In term of durability of concrete reinforced with natural fiber, the ability to resist temperature action is considered as a key factor. In the case of fire in tunnels or buildings, the concrete is subjected to high temperatures which leads to deterioration of the materials [4]. Fire is considered as a dangerous threat because of its disastrous consequences, therefore, it is very important to take precautions to reduce the associated damage. In addition, when concrete is exposed to fire, the temperature increases gradually over 1000°C, leading to an increase in the temperature of the interior of the concrete up to 700°C [17]. During this heating period, several physical and chemical phenomena are produced and will lead to the modification of the composite microstructure, affecting the thermal, hydric, and mechanical properties of concrete [17, 19]. Several research studies have presented these physical and chemical transformations of the cementitious matrix under the effect of rising temperature [31, 40, 26, 45, 46]. These studies show that the impact of temperature increase on the concrete structure manifest in the dehydration of the cement paste, the increase of the porosity, the development of cracks, and a sudden drop in the mechanical performance.

Numerous research studies have been conducted to manage high temperatures to evaluate the residual performance of concrete under these high temperatures. The results indicate that adding fiber to the cement mixture will improve the concrete properties by increasing the toughness, tensile and flexural strengths, and other physical properties. Accordingly, the literature reveals that the addition of polypropylene fibers is the most effective for improving the behavior of concrete subjected to high temperature [30, 27, 11]. Serrano et al.[36] stated that steel or polypropylene fibers could be used to enhancing the resistance of reinforced concrete structures at elevated temperatures, they concluded that incorporating polypropylene fibers (PP) is a good alternative to traditional concrete because it improves its resistance and the behavior in case of fire. Furthermore, the addition of steel fibers presents advantages compared to traditional concrete, although steel fibers cannot compare to the performance obtained when adding polypropylene fibers. The addition of polypropylene fibers and steel has been recommended also by [30, 43] for improving both the initial and residual strength, and for decreasing concrete spalling at high temperatures.

Current research focuses on replacing polypropylene fibers with vegetable fibers. Among these investigations, Page [29] carried out tests on concrete reinforced with flax fibers under high temperature, noting a significant decrease in the mechanical properties of bio-concrete. This reduction can be explained by the thermal decomposition of the flax fibers at temperature of 250°C. The results showed that when the flax fibers degraded thermally, the porosity of the concrete was greatly increased, thus generating significant reductions of the mechanical resistance.

In the case of AF fibers, several researchers [15, 16, 44] have recommended the addition of Alfa fibers to concrete for possible improvement of the resistance of concrete. However, the behavior under elevated temperature has not been properly studied as yet. Therefore, the main purpose of this study is to evaluate the properties of concretes reinforced with Alfa fiber under elevated temperature and thereby to assess the effect of Alfa fiber length on the performance of the reinforced concrete. The work has focused on comparing mechanical and physical behavior of AF concrete with concrete reinforced with polypropylene fibers or conventional concrete without fibers, when they are exposed to elevated temperatures.

# 2. MATERIAL AND METHODS

## 2.1. Materials

### 2.1.1. Cement, Aggregates, and Superplasticizer

The cement used is type CEM II / A 42.5; it complies with EN 197-1 Standard. The chemical composition and physical properties of the cement are shown in Table 1.

Table 1. Chemical composition and physical properties of the cement used

| Component | Value |
|---|---|
| **CaO (%)** | 61,69 |
| **$Al_2O_3$ (%)** | 5,37 |
| **Si $O_2$ (%)** | 19.34 |
| **$Fe_2O_3$ (%)** | 3,00 |
| **MgO (%)** | 1,80 |
| **$Na_2O$ (%)** | 0,14 |
| **$K_2O$ (%)** | 0,76 |
| **$SO_3$ (%)** | 2,20 |
| **Absolute density (g/cm$^3$)** | 3,150 |
| **Apparent density (g/cm$^3$)** | 1,215 |
| **The finesse (cm$^2$/g)** | 3371 |

The aggregates used are calcareous with multiple gradations. The granular class range for the sand is 0/3 and the specific gravity is 2.5 t/m$^3$. The coarse aggregates (3/8 mm and 8/16 mm) have a specific gravity of 2.67 t/m$^3$ and 2.6 t/m$^3$, respectively. The grain-size curves for all the aggregates used are presented in °C 1.

In this study, a superplasticizer based on modified polycarboxylates (SP) has been used. It has a specific gravity of 1080 kg/m$^3$ and a dry content of 28%. It was added to the concrete mixtures to maintain the desired workability.

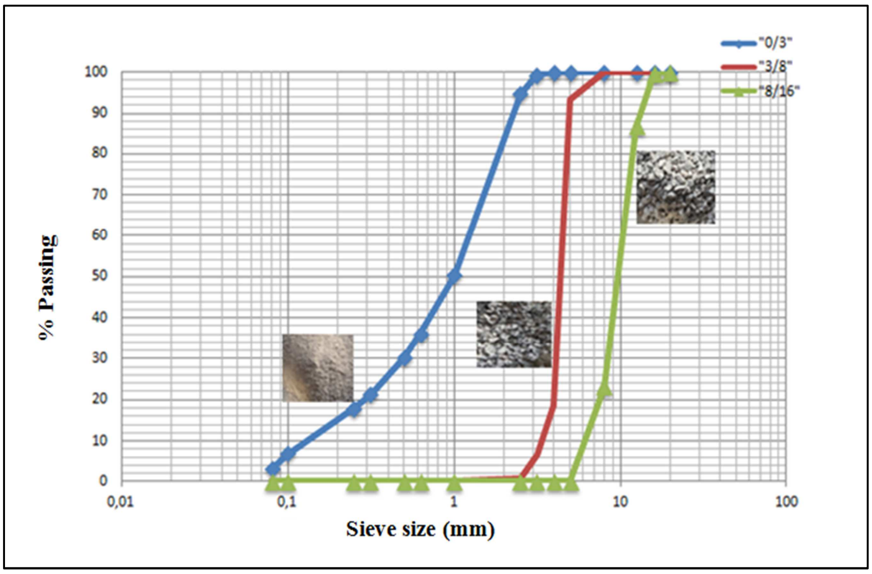
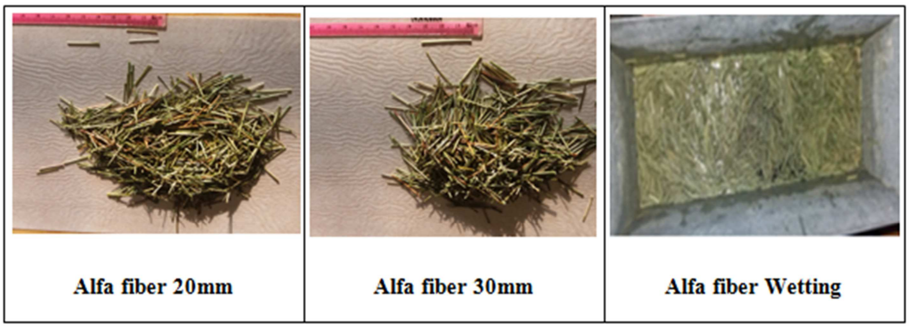


Fig. 1. The grain size curves of the aggregate used

### 2.1.2. The Alfa fibers (StipaTenacissima)

The AF used is from the Ain-Touta region (Algeria), the fibers were dried at 50°C until their weight stabilized, and then cut into two different lengths; 20 mm and 30 mm. They were soaked for 2 hours [15, 16] before being incorporated into the concrete to prevent them from absorbing the mixing water (Figure 2).
The wetting time was estimated from the drying curve of Alfa fibers (Figure 3).



**Alfa fiber 20mm** **Alfa fiber 30mm** **Alfa fiber Wetting**

Fig. 2. Alfa (StipaTenacissima) fiber

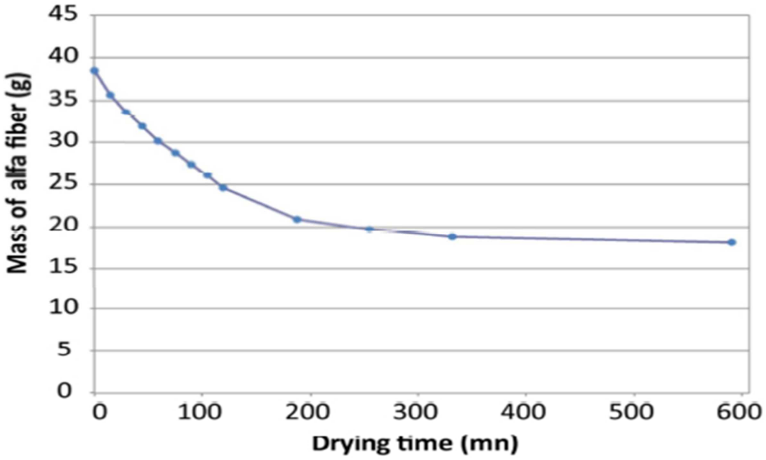


Fig. 3.The drying curve of Alfa fibers [16]

The physical properties and mechanical tensile properties of Alfa are presented in Tables 2 and 3. Figure 4 shows thermogravimetric analysis (TGA) which measures mass loss during heating and the differential thermal analysis (DTA) which measures the relative changes in sample temperature during heating on Alfa fiber. A variety of information can be extracted from this data; the TGA diagram shows that with increasing temperature the alfa fiber loses mass until a temperature of 600°C is reached, at which point the mass loss is completed. In addition, the DTA diagram shows that the alfa fiber is exothermic. The following phases can be distinguished:

Table 2. The physical properties of alfa fiber [6]

| Fiber | Cellulose (%) | Diameter(µm) | Length(mm) | L / d ratio |
|---|---|---|---|---|
| Alfa | 45 | 5-95 | 5-50 | 1964 |

Table 3. The mechanical tensile properties of alfa fiber [5]

| Fiber | E (GPa) | All (%) | σ (MPa) | specific gravity |
|---|---|---|---|---|
| Alfa | 13-17.8 | 1.5-2.4 | 134-220 | 1.4 |

<u>Phase I (from 25 to 180°C):</u> this represents low mass loss, which is estimated at 4.48%. This loss is due to evaporation of the absorbed water and occurs between 0 and 100°C. After 100°C, the evolution of this loss is practically nil, the mass varies little at a temperature between 100 and 180°C and no exothermic or endothermic reaction is observed in DTA, which indicates that alfa fibers are stable at these temperatures.

<u>Phase II (from 180 to 420°C):</u> above 180°C, there is a loss of mass corresponding to the thermal decomposition of the compositions of the alfa, however, in this phase, a significant loss of mass of about 66.45% is noted.

There are changes of slope in the TGA curve beyond 240°C, which can be explained by the degradation of hemicelluloses and pectin (some studies have shown that hemicelluloses and pectin will degrade between 250 and 320°C [42, 28, 23, 14]). Beyond 303.8°C, there is an inflection in the DTA curve and we also recorded a change of slope in the TGA curve which can be explained by the degradation of cellulose at 317.1°C, while some research shows that the cellulose would degrade between 300 and 420°C [42, 23] .

The loss of mass recorded after 320°C can be interpreted as lignin decomposition not yet complete because it is slower and degrades over a wider temperature range, from 160 to 900°C [42, 8], than other compositions.

<u>Phase III (beyond 420°C)</u>: in the last phase, a decrease in the speed of loss of mass is noted; there is a variation in the loss of about 5% which corresponds to the thermal degradation of lignin and the residues resulting from the decomposition of the principal components during the previous phase.

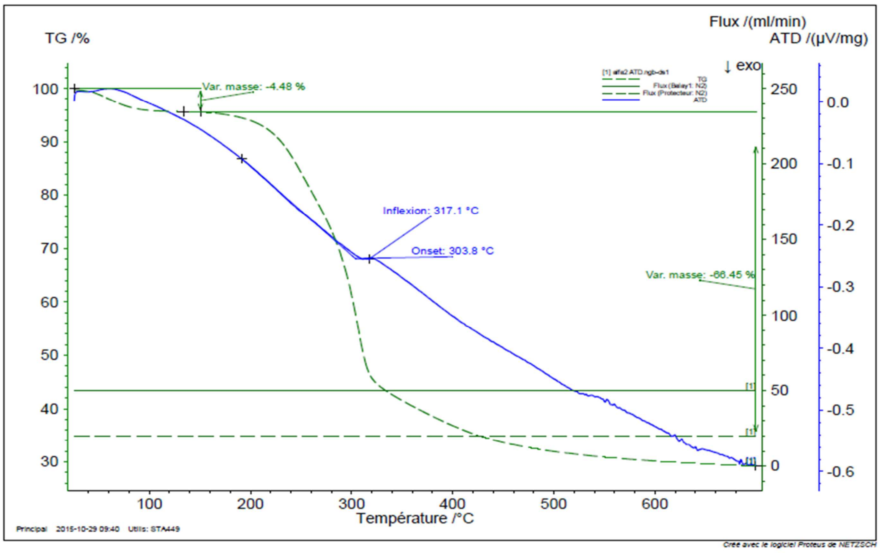


Fig. 4. Thermogravimetric analysis and differential thermal analysis on Alfa fiber

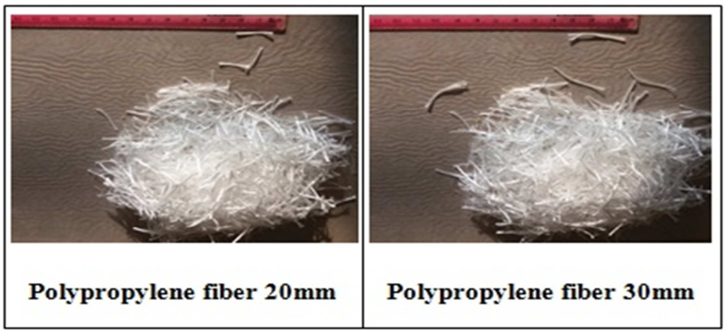
### 2.1.3. The Polypropylene fiber

The polypropylene fibers used in this study are TUF-STRAND MAXTEN fibers from Canada (Figure 5); they are a synthetic macrofiber. They were cut into two different lengths, being 20 and 30 mm, depending on their use.

The properties of the polypropylene fibers used are shown in Table 4. The amount of polypropylene fibers is incorporated according to the manufacturer's recommendations, which suggest a volume of 0.22%.

Table 4. The properties of the polypropylene fibers

| Property | Description |
|---|---|
| Specific Gravity | 0,91 |
| Tensile Strength (MPa) | 600 to 650 |
| Melt Point | 160°C |
| The recommended dosages (kg/m$^3$) | 1.8 to 3.0 |
| Thermal conductivity | low |



**Polypropylene fiber 20mm** **Polypropylene fiber 30mm**

Fig. 5. Polypropylene fibers used in the mixture

## 2.2. Mix proportions

The objective of this study is to make a class C25/30 of fiber reinforced concrete with a ratio W/C = 0.5 and cement dosage of 350 Kg / m$^3$. For this purpose, five different types of concrete were formulated according to the Dreux-Gorisse method [9]. Two concretes of Alfa fiber with the fiber dosage at 1% (the dosage of 1% was optimized to obtain good physical and mechanical properties) AC-20 and AC-30, and two concretes of polypropylene fiber PC-20 and PC-30 were made, the first reinforced with fibers of 20 mm in length and the second with fibers of 30 mm. Finally, one ordinary concrete (OC) without fibers, taken as the control concrete, was also made. The mixture proportions are given in Table 5. For Concretes reinforced with fibers, the percentage of fiber is estimated by volume and fibers were introduced into the concrete as an additional component and not as a substitute for any other component such as the sand or the gravel.

In the fresh state, the slump test was conducted according to standard NFP 18-451 to determine the consistency of the studied concretes and to measure their densities.

Table 5. The proportions of the mixture studied

| **Quantity** | **OC** | **AC-20** | **AC-30** | **PC-20** | **PC-30** |
|---|---|---|---|---|---|
| **Cement** (Kg/m$^3$) | 350 | 350 | 350 | 350 | 350 |
| **Water** ( Kg/m$^3$) | 175 | 175 | 175 | 175 | 175 |
| **Sand** ( Kg/m$^3$) | 727 | 727 | 727 | 727 | 727 |
| **Coarse aggregate (3/8)** (Kg/m$^3$) | 109 | 109 | 109 | 109 | 109 |
| **Coarse aggregates (8/15)** (Kg/m$^3$) | 897 | 897 | 897 | 897 | 897 |
| **Superplasticizer** ( Kg/m$^3$) | 2.31 | 2.31 | 2.31 | 2.31 | 2.31 |
| **AF fiber** (%) | - | 1 | 1 | - | - |
| **PP fiber** (%) | - | - | - | 0.22 | 0.22 |
| **The density** (t/m$^3$) | 2.38 | 2.34 | 2.32 | 2.30 | 2.29 |
| **Slump test** (mm) | 120 | 100 | 110 | 115 | 110 |

| **Quantity** | **OC** | **AC-20** | **AC-30** | **PC-20** | **PC-30** |
|---|---|---|---|---|---|
| **Cement** (Kg/m$^3$) | 350 | 350 | 350 | 350 | 350 |
| **Water** ( Kg/m$^3$) | 175 | 175 | 175 | 175 | 175 |
| **Sand** ( Kg/m$^3$) | 727 | 727 | 727 | 727 | 727 |
| **Coarse aggregate (3/8)** (Kg/m$^3$) | 109 | 109 | 109 | 109 | 109 |
| **Coarse aggregates (8/15)** (Kg/m$^3$) | 897 | 897 | 897 | 897 | 897 |
| **Superplasticizer** ( Kg/m$^3$) | 2.31 | 2.31 | 2.31 | 2.31 | 2.31 |
| **AF fiber** (%) | - | 1 | 1 | - | - |
| **PP fiber** (%) | - | - | - | 0.22 | 0.22 |
| **The density** (t/m$^3$) | 2.38 | 2.34 | 2.32 | 2.30 | 2.29 |
| **Slump test** (mm) | 120 | 100 | 110 | 115 | 110 |

To test the mechanical and physical properties, a total of 355 test pieces of 100x200 mm cylinders and 70x70x280 mm prisms were cast using the above mixture proportions. They were removed from the mold after 24 h and then placed in the laboratory's ambient air before measurement.

The deadlines of the mechanical measurements for all concretes are seven, 28, and 90 days.

### 2.3. Experimental methods

After 90 days, the samples were heated in an electric furnace with a rising temperature rate of 1°C / min (Figure 6). These samples were exposed to a high temperature of 180°C, 380°C, and 600°C, the exposure temperature was maintained for one hour and then cooling to room temperature occurred; the time-temperature curve of the furnace is shown in Figure 7. The cycles of 180°C and 380°C correspond respectively to the end of melting of the polypropylene and alfa fibers [15].

All the samples were weighed before and after each heat treatment to determine their mass loss. They were weighed directly to avoid rehydration with the surrounding environment. Then, samples were tested by two mechanical tests: a flexural tensile test and a uniaxial compression test. Several physical tests were performed on the different hardened concretes (Figure 8), such as porosity to water [24] and capillary absorption. The physical and mechanical properties of the concretes were measured in ambient temperature and after each heating-cooling cycle.

Fig. 6. Location of the concrete specimens in the furnace

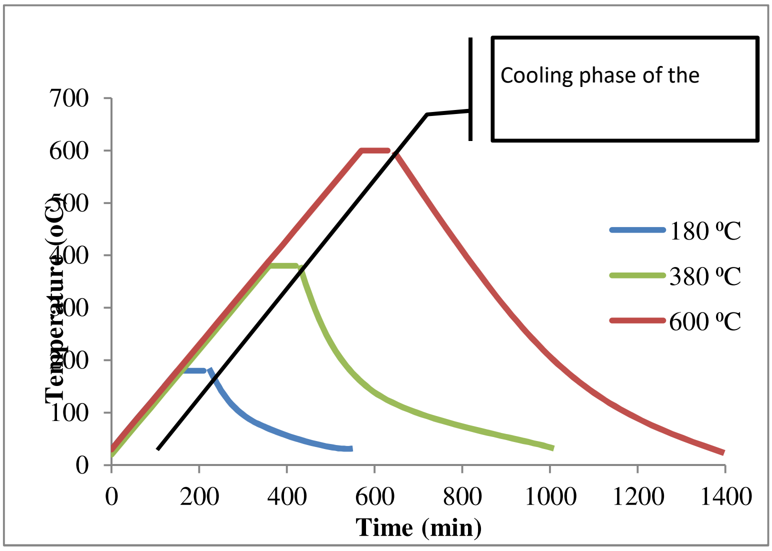


Fig. 7. The time-temperature curve of the different heating-cooling cycles

Fig. 8. Samples of dimensions 70x70x50 mm for the porosity accessible to water test and the capillary absorption test

## 3. RESULTS AND DISCUSSION

### 3.1. Characterization of fresh concrete:

Adding fibers to concrete impacts fresh concrete's workability and density. The effect depends on the type of added fiber. Regardless of the type of fibers, their incorporation into mixtures often improves cohesion and thus reduces workability [47].

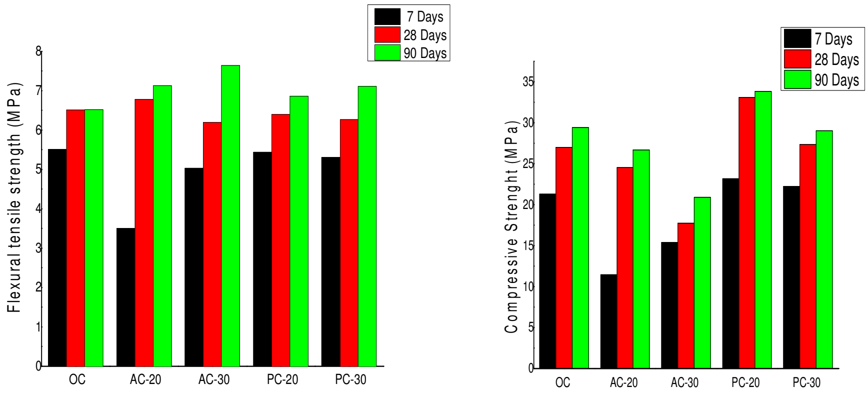
The above Table 5 also indicates the workability and density tests results of the various mixtures. The addition of AF fiber contributes to a decrease in the workability of the concrete, which can be explained by the high porosity of the AF fibers: given their impregnation in water before mixing, the AF fibers tend to absorb part of the free water available during mixing [3, 16]. This decrease is more apparent for AF fiber reinforced concrete with a fiber length of 20 mm than in the case of the fiber length of 30 mm.

The density results show that adding fibers to concrete affects their density, because the fiber reinforced concrete is lighter due to the volume of lighter fibers [43, 37, 16].

### 3.2. Characterization of hardened concrete

Figures 9a and 9b shows the evolution of the flexural tensile strength and the compressive strength of the various mixtures as a function of time. The analysis shows:

- The evolution of the compressive strength of the studied concrete rises gradually with age. The PP reinforced concrete has the greatest compressive strength compared to AF reinforced concrete. This result indicates that the introduction of vegetable fiber into the concrete decreases the compressive strength significantly. This decline is greater in the short term (7 days) due to the cellulose contained in Alfa, which disrupts the cement hydration [15, 16]. The highest compressive strength for PC is still observed after 28 days to 90 days and the reduction in strength by the addition of AF fibers was substantially reduced compared to the strength at 7 days, for AC2 and AC3 it is 10% and 20%, respectively, compared to OC concrete. Several researchers confirm these results [15, 16]. Khelifa et al. [16] have shown that the incorporation of AF fibers into the matrix does not improve the mechanical compressive strength of the concrete and despite these slight decreases for concretes with Alfa, the compressive strength remains within the acceptable range of structural concrete.
- The flexural tensile strength increases with the incorporation of AF fibers. In the long term, the best performance was obtained for AF fiber reinforced concrete with a fiber length of 30 mm. The flexural strength of AC-30 was 17% higher than OC.



(a) (b)

Fig. 9. The evolution of the mechanical properties of the different studied mixtures: (a) Flexural tensile strength; (b) Compressive strength

## 3.3. Durability of the concrete under high temperature

### 3.3.1. The physical properties

#### 3.3.1.1. Mass loss

For the mass loss assessment, the masses of the concrete specimens were measured before and after exposure to elevated temperatures. The loss in all the samples studied is expressed as a percentage of the mass at room temperature to the mass after exposure to a specific elevated temperature.

Several researchers reported that the loss of mass of the concrete under increased temperature could be attributed to the decomposition of calcareous aggregates, the release of carbon dioxide ($CO_2$), and spalling of the concrete surface, which therefore altered the mechanical properties of the concrete [10, 21].

All the data obtained on mass loss are illustrated in Figure.10.

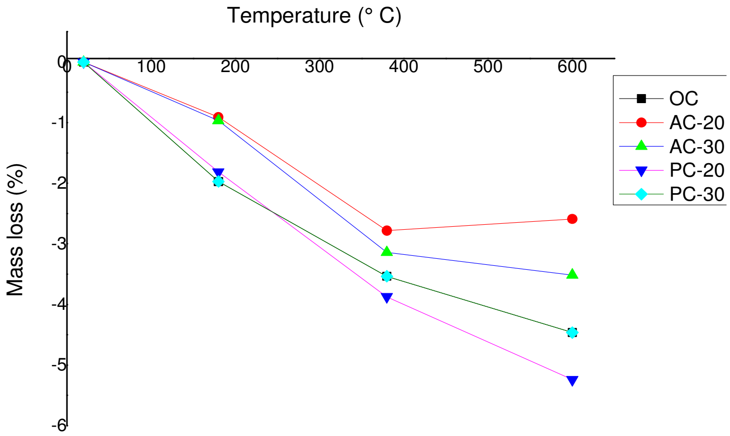


Fig. 10. Mass loss of different concrete mixtures at different temperatures

The results show that the mass of all concretes decreased according to the heating-cooling cycles, and the mass loss is related to the type of concrete. The AF concrete loses less mass than the other concretes. At 180°C, the mass loss of PC was greater than AF concretes. In addition, the free water content of the PC concrete (1.8%) was higher than that of AF concrete (0.9%). This observation can be explained by AF, which continues to absorb some of the mixing water during the preparation of the mixture, thereby reducing the quantity of free or adsorbed water. This is due to the high porosity of AF fibers, which is estimated at 67% [16, 22]. Beyond the temperature of 180°C, the concretes had the same loss of mass and there is always a less significant loss of mass for AC.

The mass loss in AC could be due to the fact that AF contains more water, which takes longer to evaporate [15]. After heating at 600°C, AC-20 concrete mass loss is less than AC-30 concrete. However, AC-20 loses 2.58% of its initial mass while AC-30 loses 3.51%. This change in mass loss can be a result of a change in the length of these fibers.

In the case of PC and OC concretes, the mass loss is similar, and is greater than AC concretes. Furthermore, after the heating-cooling cycle to 380°C and 600°C, the difference in the mass loss between the two concretes PC and OC is approximately 0.5%, this difference is explained by partial or total vaporization of the PP fibers. Similar results have been reported by Pliya [30], which show that the addition of PP fibers in concrete does not lead to a change in the kinetics of mass loss with temperature.

### 3.3.1.2. Porosity

The porosity was obtained by hydrostatic weighing for all concretes according to the procedure described in the NF P18-459 standard. Figure 11 shows the evolution of absolute porosity and Figure 12 shows the results of the relative porosity of the different concrete mixtures as a function of temperature. At 20°C, the porosity of the fiber concrete is slightly greater than that of concrete without fiber. This observation is due to the lightness of the fibers, and that adding them to concrete generates additional porosity in the matrix due to the creation of voids, followed by a decrease in density. These results are consistent with previous research studies described by [43, 37, 16].

With the increase of the temperature, the porosity of PC concrete and concrete without fiber grows more quickly than in AF concrete. For OC and PC concretes, a significant increase in porosity was noted at 180°C, while a lesser increase is seen in the case of AC concretes; this increase is noted beyond the temperature of 380°C. Between 180°C and 380°C, the increase in porosity is about 20% for PC and OC concrete, and 5% for AC concrete. Between 380°C and 600°C, the variation was 45% for AC concrete and 25% for OC and PC concrete. This difference in variation is due to the melting of the AF fibers and the formation of additional porosity in the concrete. The use of AF fibers affects the evolution of the porosity of concrete significantly better than PP fibers when exposed to high temperatures. The comparison of the results shows that the porosity of concrete with fibers 30 mm in length (PC3 and AC3) increases more than concrete with fibers of 20 mm in length (PC2 and AC2). This observation can be explained by the length of the fibers, which affected the porosity of the concrete at high temperatures.

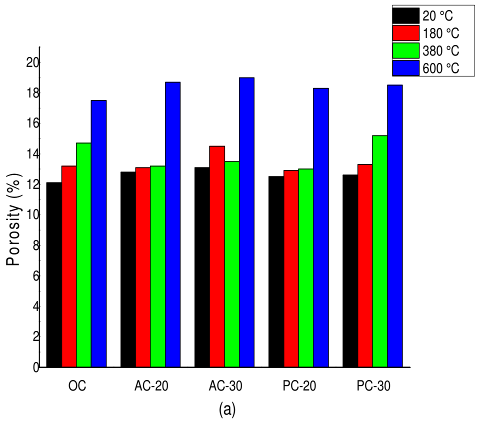


Fig. 11. Evolution of the absolute porosity of different concrete mixtures as a function of temperature

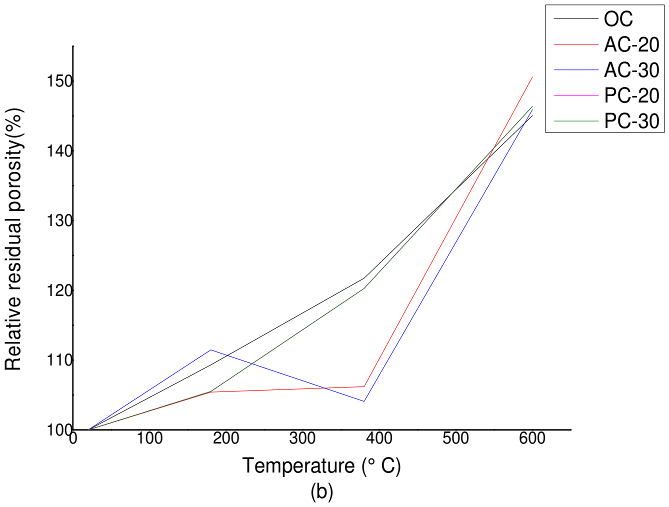


Fig. 12. Evolution of the relative porosity of different concrete mixtures as a function of temperature

Moreover, the porosity of the concrete is related to the length of the fibers, which could even create more different voids and reduce the pore pressure inside the concrete.

### 3.3.1.3. Capillary absorption

Figure 13, shows the water absorption by capillary of different concrete mixtures as a function of temperature, and figure 14 shows the absorption kinetics of different concrete mixtures as a function of temperature. At all temperature levels, the results show that the absorption kinetics and the capillary absorption increase significantly.

At 20°C, the absorption kinetics of AC concrete is higher than that of OC and PC concretes. As can be seen, the absorption of AC-20 was slightly higher than that of AC-30, being 0.0398 kg/(m².$s^{1/2}$) for AC-20 and 0.0339 kg/(m².$s^{1/2}$) for the AC-30. This difference is explained by the distribution of AF in the mixture.

The absorption kinetics of the AC and OC concrete do not change significantly after 180°C, being 0.042 kg/(m².$s^{1/2}$) and 0.032 kg/(m².$s^{1/2}$), respectively. The change of absorption is about 5.8% and 2.5%, respectively, for OC and AC concrete, while the PC concrete absorption increases more rapidly, about 73%. At a temperature level of 380°C, the absorption kinetics of AC concrete increase rapidly, about 45%. After heating at 600°C, the absorption kinetics are about 0.110, 0.116, 0.124, 0.129, and 0.131 kg/(m².$s^{1/2}$) for AC-30, AC-20, OC, PC-20, and PC-30. The incorporation of AF fibers in the concrete, when subjected to the elevated temperature, produces a positive influence on the absorption kinetics and also reduces cracking.

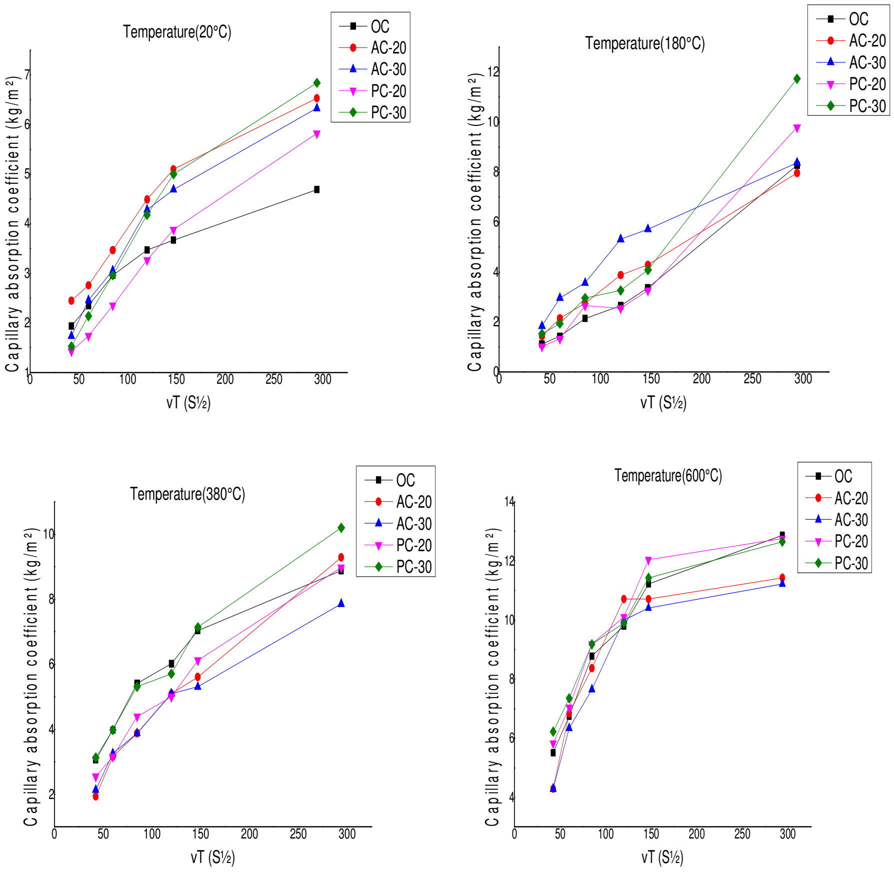


Fig. 13. Water absorption by capillary of different concrete mixtures as a function of temperature

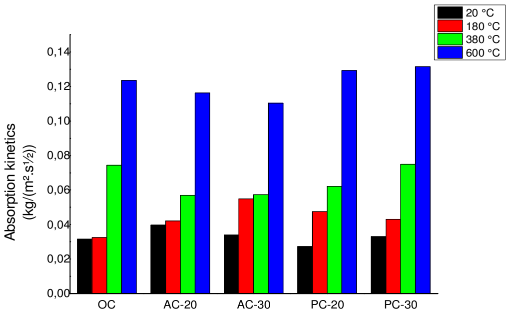


Fig. 14. Absorption kinetics of different concrete mixtures as a function of temperature

### 3.3.2. The Mechanical properties

Mechanical tests conducted on the heated samples after cooling allowed evaluation of the influence of the length and the additions of AF on the resistance and the behavior after exposure to high temperatures. Figure 15 shows the evolution of residual compressive strength of the concrete mixtures as a function of temperature, and Figure 16 indicates the evolution of residual flexural tensile strength of the concrete mixtures as a function of temperature.

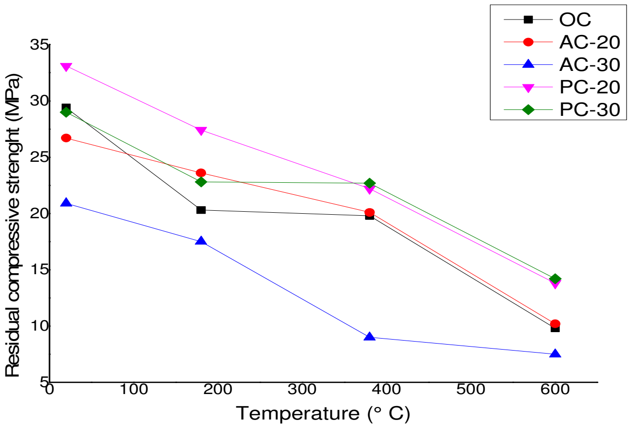


Fig. 15. Evolution of the residual compressive strength of the concrete mixtures as a function of temperature

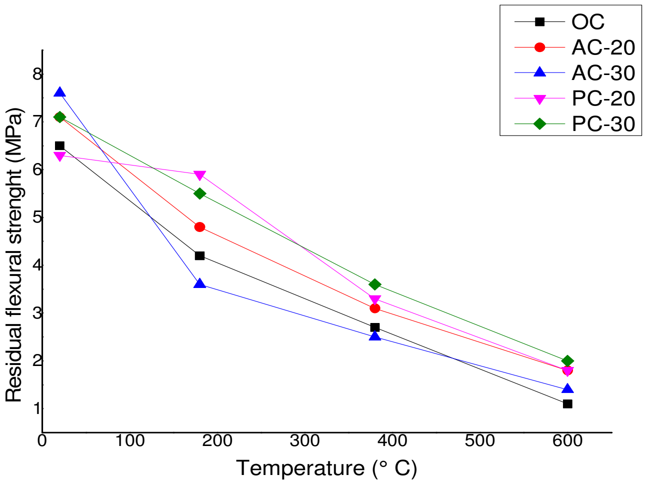


Fig. 16. Evolution of residual flexural tensile strength of the concrete mixtures as a function of temperature

Under the elevated temperature, a decrease of compressive and flexural tensile strength is noted, which is due to the radial cracks (Figure 17) at the paste-aggregate interface resulting from the thermal strain mismatch between aggregate (which expands) and paste (which shrinks) inducing tangential cracking. These findings are similar to those reported in several studies in this field [43, 41, 30, 11].

The addition of fibers in concrete, when subjected to high temperatures, produces a positive influence on compressive strength. After heating to 180°C, an increase in the relative residual compressive strength is noted with the addition of AF fibers, it was seen in 90%, 80%, and 70%, respectively, of the residual relative compressive strength of AC, PC, and OC concretes. Relative residual compressive strength decreases with the increasing length of AF fibers. The 30 mm fiber length causes the greatest loss of compressive strength for AC concretes. This could be a consequence of increases in porosity of AC-30 concrete being more than AC-20 concrete which, therefore, decreases the mechanical properties of the concrete. After heating to 380°C, the residual compressive strength of AC-20 and AC-30 concrete are 20.1 MPa and 9 MPa, respectively, which represents 79% and 47% respectively of the initial compressive strength. At 600°C, compressive strength losses are closed and do not depend on the length of the AF fibers. The difference between the two is about 1%.

From the results of the evolution of residual flexural tensile strength obtained, a gradual decrease in the flexural tensile strength of concrete with rise in temperature was observed. AC concrete loses more residual flexural tensile strength than PC concretes; nevertheless, their strengths are still higher than those of concrete without fiber and slowly decrease up to 380°C due to the fiber melting at these high temperatures. When the fibers are melted, they create pores in the concrete which are considered a disadvantage for the performance of the material [20, 27].

Regarding the impact of the polypropylene fibers, a greater improvement in residual relative flexural tensile strength was recorded for PC-20 concrete than PC-30 concrete up to 380°C. After this temperature, the PC-20 concrete lost resistance more than the PC3 concrete. At 380°C, the relative residual flexural tensile strength of the PC-30 concrete is 52% while the resistance of the PC-20 concretes is 47%.

Compared to other concretes, the addition of 20 mm AF fibers improved the residual flexural tensile strength. At 180°C, we recorded 4.8 MPa and 3.6 MPa of the residual flexural tensile strength of AC-20 and AC-30, respectively.

For AC-20 concretes, an improvement of the residual flexural tensile strength was observed up to the 600°C heating-cooling cycle. The relative strength of this concrete is 69%, 45%, and 25% after heating at 180, 380, and 600°C, respectively.

Conversely, the residual tensile strength of the AC3 concretes decreases compared to the concretes without fibers. This decrease in resistance also appears at room temperature.

The pores created by the melting and inflammation of AF fibers at 600°C (Figure 17), form microcracks and connect existing capillary pores to provide channels for the escape of water vapor. Therefore, it appears that concrete with 20mm AF fibers has much better resistance to thermal spalling compared to concrete without fiber.

Fig. 17. The melting and ignition of AF fiber at 600°C temperatures

The effects of adding fibers on the failure behavior of concrete after exposure to temperature increases are shown in Figure 18**.** Compared to AC and PC concretes, it can be seen that the concrete without fiber presented significant spalling in compression at elevated temperatures.

Therefore, the addition of the AF fibers resulted in an increase in the ductility of the concrete, consistent with compressive and flexural tensile strength results. It can be also seen that more cracks appeared in the PC samples than in the AC samples.

Fig. 18. The failure behavior of concrete at compression after exposure to 380°C and 600°C temperatures

## 4. CONCLUSION

The purpose of this study was to investigate the effects of the elevated temperature on properties of concretes reinforced with Alfa fibers. The influence of fiber length on reinforced concretes was also investigated. Based on the results of the study, the following conclusions are drawn:

- At room temperature, the compressive strength of concrete decreases with the addition of alfa fibers. The increase of fiber length results in a considerable drop in the compressive strength due to the increase of the volume of the voids, therefore, the concrete compactness is reduced. In the case of the flexural strength, there is an improvement in the long term with the incorporation of fibers. The tensile strength increases with the addition of the fibers of 30mm in length, which gave the best performance.
- Compressive and flexural strength of concrete with AF fibers or PP fiber additions is greater than that of concrete without fibers when subjected to thermal aggression. This presence of fibers in the concrete affects the speed of the strength curve.
- Concrete reinforced with AF fibers had a slightly lower residual compressive strength than concrete reinforced with PP fibers, but is still superior to that of concrete without fiber.
- At higher temperature, the addition of AF fibers with a length of 20mm improved the residual flexural tensile strength compared to the PC concrete.
- The porosity of polypropylene concrete increases with temperature faster than with alfa concrete.
- Incorporating AF fibers with a length of 20 mm reduced the rate of degradation of the compression. This length of AF fiber leads to the greatest improvement up to a temperature of 600°C.
- The addition of AF fiber to concrete reduced the spalling and explosive failure under compressive load and increased the ductility of the concrete.

The results of the tests revealed that the optimum length of Alfa fibers to be incorporated into the concrete is 20 mm. Given these results, we can conclude that the Alfa fibers can be used to reinforce the concrete and improve their behavior under elevation of the temperature, similar to or better than the use of polypropylene fibers and with the added advantage of respecting the environment.

## REFERENCES

1. Ali, M, Li, X, and Chouw, N 2013. Experimental investigations on bond strength between coconut fibre and concrete. Materials & Design, 44, 596-605.
2. Ardanuy, M, Claramunt, J, García-Hortal, JA and Barra, M 2011. Fiber-matrix interactions in cement mortar composites reinforced with cellulosic fibers. Cellulose, 18(2), 281-289.
3. Bahloul, O, Bourzam, A and Bahloul, A 2009. Utilisation des fibres végétales dans le renforcement de mortiers de ciment (cas de l'alfa). In 1st International Conference on Sustainable Built Environment Infrastructures in Developing Countries, ENSET Oran.
4. Bazant, ZP, Kaplan, MF and Haslach, HW 1997. Concrete at high temperatures: material properties and mathematical models. *Appliedmechanicsreviews*, *50*, B75-B75.
5. Brahim, SB and Cheikh, RB 2007. Influence of fibre orientation and volume fraction on the tensile properties of unidirectional Alfa-polyester composite. Composites Science and Technology, 67(1), 140-147.
6. Dallel, M 2012. Evaluation du potentiel textile des fibres d'Alfa (Stipa Tenacissima L.) : Caractérisation physico-chimique de la fibre au fil (Doctoral dissertation).
7. De Almeida Melo Filho, J, De Andrade Silva, F and Toledo Filho, RD 2013. Degradation kinetics and aging mechanisms on sisal fiber cement composite systems. Cement and Concrete Composites, 40, 30-39.
8. Do Thi, VV 2011. Matériaux composites à fibres naturelles/polymère biodégradables ou non (Doctoral dissertation).
9. Dreux, G and Festa, J 1998. Nouveau guide du béton et de ses constituants.8th edition, Eyrolles, Paris, France.
10. Dügenci, O, Haktanir, T and Altun, F 2015. Experimental research for the effect of high temperature on the mechanical properties of steel fiber-reinforced concrete. Constr. Build. Mater. 75, 82-88.
11. Hager, I 2004. Comportement à haute température des bétons à haute performance: évolution des principales propriétés mécaniques (Doctoral dissertation, École nationale des ponts et chaussées (France)).
12. Handoo, SK, Agarwal, S and Agarwal, SK 2002. Physicochemical, mineralogical, and morphological characteristics of concrete exposed to elevated temperatures. Cement and Concrete Research, 32(7), 1009-1018.
13. Jarabo, R, Fuente, E, Monte, MC, Savastano Jr, H, Mutjé, P and Negro, C 2012. Use of cellulose fibers from hemp core in fiber-cement production. Effect on flocculation, retention, drainage and product properties. Industrial Crops and Products, 39, 89-96.

14. Joseph, PV, Joseph, K, Thomas, S, Pillai, CKS, Prasad, VS, Groeninckx, G and Sarkissova, M 2003. The thermal and crystallisation studies of short sisal fibre reinforced polypropylene composites. Composites Part A: Applied Science and Manufacturing, 34(3), 253-266.
15. Khelifa, MR 2017. Formulation et caractérisation d'éco-bétons renforcés aux fibres d'alfa pour des bâtiments verts et durables (Doctoral dissertation, Cergy-Pontoise).
16. Khelifa, MR, Leklou, N, Bellal, T, Hebert, RL and Ledesert, BA 2018. Is alfa a vegetal fiber suitable for making green reinforced structure concrete?. European Journal of Environmental and Civil Engineering, 22(6), 686-706.
17. Kim, J and Lee, GP 2015. Evaluation of mechanical properties of steel-fibre-reinforced concrete exposed to high temperatures by double-punch test. Construction and Building materials, 79, 182-191.
18. Kriker, A, Debicki, G, Bali, A, Khenfer, MM and Chabannet, M 2005. Mechanical properties of date palm fibres and concrete reinforced with date palm fibres in hot-dry climate. Cement and Concrete Composites, 27(5), 554-564.
19. Li, M, Qian, C and Sun, W 2004. Mechanical properties of high-strength concrete after fire. Cement and concrete research, 34(6), 1001-1005.
20. Liu, MY, Lin, ZW, Ding, QJ and Hu, SG 2007. Study on the Properties of High Performance Concrete with Different Content Polypropylene Fiber After High Temperature [J]. Journal of Huazhong University of Science and Technology (Urban Science Edition), 2.
21. Ma, Q, Guo, R, Zhao, Z, Lin, Z and He, K 2015. Mechanical properties of concrete at high temperature—A review. *Construction and Building Materials*, *93*, 371-383.
22. Maghchiche, A, Haouam, A and Immirzi, B 2013. Extraction and characterization of Algerian Alfa grass short fibers (StipaTenacissima). Chemistry & Chemical Technology, (7, № 3), 339-344.
23. Martins, MA and Joekes, I 2003. Tire rubber–sisal composites: Effect of mercerization and acetylation on reinforcement. Journal of appliedpolymer science, 89(9), 2507-2515.
24. NF P18-459. Mars 2010. Béton - Essai pour béton durci - Essai de porosité et de masse volumique.
25. NFP 18-451. 2007. Consistance et Ouvrabilité des bétons a l'aide du Cône d'Abrams.
26. Noumowe, A. 1995). Effet de hautes températures (20-600°C) sur le béton: cas particulier du béton a hautes performances (Doctoral dissertation, Lyon, INSA).
27. Noumowe, A 2005. Mechanical properties and microstructure of high strength concrete containing polypropylene fibers exposed to

temperatures up to 200°C. Cement and concrete research, 35(11), 2192-2198.

28. Ouajai, S and Shanks, RA 2005. Composition, structure and thermal degradation of hemp cellulose after chemical treatments. Polymerdegradation and stability, 89(2), 327-335.
29. Page, J 2017. Formulation et caractérisation d'un composite cimentaire biofibré pour des procédés de construction préfabriquée (Doctoral dissertation).
30. Pliya, P 2010. Contribution des fibres de polypropylène et métalliques à l'amélioration du comportement du béton soumis à une température élevée. Cergy: Thèse de doctorat de l'Université de Cergy-Pontoise.
31. Razafinjato, RN 2015. Comportement des bétons à haute température : influence de la nature du granulat (Doctoral dissertation).
32. Rokbi, M and Osmani, H 2011. L'effet des traitements de surface des fibres sur les propriétés mécaniques de composites Polyester-fibres Alfa. In Congrès français de mécanique. AFM, Maison de la Mécanique, 39/41 rue Louis Blanc, 92400 Courbevoie, France.
33. Sedan, D, Pagnoux, C, Smith, A and Chotard, T 2007. Propriétés mécaniques de matériaux enchevêtrés à base de fibre de chanvre et matrice cimentaire. In Congrès français de mécanique. AFM, Maison de la Mécanique, 39/41 rue Louis Blanc-92400 Courbevoie.
34. Sedan, D, Pagnoux, C, Smith, A and Chotard, T 2008. Mechanical properties of hemp fibre reinforced cement: Influence of the fibre/matrix interaction. Journal of the European Ceramic Society, 28(1), 183-192.
35. Sellami, A, Merzoud, M and Amziane, S 2013. Improvement of mechanical properties of green concrete by treatment of the vegetals fibers. Construction and Building Materials, 47, 1117-1124.
36. Serrano, R, Cobo, A, Prieto, MI and de las Nieves González, M 2016. Analysis of fire resistance of concrete with polypropylene or steel fibers. Construction and building materials, 122, 302-309.
37. Söylev, TA and Özturan, T 2014. Durability, physical and mechanical properties of fiber-reinforced concretes at low-volume fraction. Construction and Building materials, 73, 67-75.
38. TolêdoFilho, RD, Scrivener, K, England, GL and Ghavami, K 2000. Durability of alkali-sensitive sisal and coconut fibres in cement mortar composites. Cement and concrete composites, 22(2), 127-143.
39. Xie, X, Zhou, Z, Jiang, M, Xu, X, Wang, Z and Hui, D 2015. Cellulosic fibers from rice straw and bamboo used as reinforcement of cement-based composites for remarkably improving mechanical properties. Composites Part B: Engineering, 78, 153-161.
40. Xing, Z 2011. Influence de la nature minéralogique des granulats sur leur comportement et celui du béton à haute température (Doctoral dissertation).

41. Xing, Z, Beaucour. AL, Hebert, R, Noumowe, A and Ledesert, B 2015. Aggregate's influence on thermophysical concrete properties at elevated temperature, Constr. Build. Mater. 95 18–28.
42. Yang, H, Yan, R, Chen, H, Lee, DH and Zheng, C 2007. Characteristics of hemicellulose, cellulose and lignin pyrolysis. Fuel, 86(12-13), 1781-1788.
43. Yermak, N, Pliya, P, Beaucour, AL, Simon, A and Noumowé, A 2017. Influence of steel and/or polypropylene fibres on the behaviour of concrete at high temperature: Spalling, transfer and mechanical properties. Construction and Building Materials, 132, 240-250.
44. Ziane, S, Khelifa, MR, Mezhoud, S and Medaoud, S 2020. Durability of concrete reinforced with alfa fibres exposed to external sulphate attack and thermal stresses. Asian Journal of Civil Engineering, 21(3), 555-567.
45. Mezhoud, S, Clastres, P, Houari, H and Belachia, M 2017. Forensic investigation of causes of premature longitudinal cracking in a newly constructed highway with a composite pavement system. Journal of Performance of Constructed Facilities, 31(2), 04016095.
46. Mezhoud, S, Clastres, P, Houari, H and Belachia, M 2018. Field Investigations on Injection Method for Sealing Longitudinal Reflective Cracks. Journal of Performance of Constructed Facilities, 32(4), 04018041.
47. Le Hoang, T 2013. Etude de caractérisation du comportement de composites cimentaires incorporant des fibres courtes de lin (Doctoral dissertation, Caen).

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