DOI: 10.2478/sspjce-2022-0010

Experimental Research on the Thermal Instability of Fiber Polypropylene Concrete at 250 °C

Assia Aidoud[1*], Messaouda Bencheikh[1], Nacera Khaldi[1]

[1]University 8 May 1945 of Guelma, BP 401, Civil Engineering and Hydraulics Laboratory, Algeria
*e-mail: assia_aidoud76@yahoo.fr; aidoud.assia@univ-guelma.dz

Abstract
The high temperature in the concrete destroys the hydrates of the cement paste. This destruction means the weakness of the materials caused by the deterioration of their mechanical properties.
This work aims to study the behavior of high-performance fiber concrete sets at high temperatures; specifically, we used polypropylene fibers and studied their influence on deterioration behavior.
This study includes high performance concrete and three types of fiber concrete, each containing a specific ratio of polypropylene fibers (0.12 %, 0.18 %, and 0.24 %). Consequently, cubic test specimens (15 cm x 15 cm x 15 cm) were subjected to the temperature of 250 °C, with a speed of 2 °C/min followed by a step of one hour at the target temperature then cooling to the ambient temperature.
The results showed that fiber-reinforced concrete exhibited a better performance when exposed to the temperature studied. The mechanical properties were improved by up to 56% for compressive strength and 86% for tensile strength.

Key words: HPC, HPFC, fibers, high temperature, mechanical properties

1 Introduction

In recent years, several researches have been devoted to the development of the characteristics ultra-high-performance fiber-reinforced concrete (UHPC). This material has allowed the construction of several structures with complex architecture throughout the world [1]. Due to its durability on time [1]. In general, concrete is a composite material in which there are two phases: the matrix (hardened cement paste) and the aggregates (gravel and sand). Additionally, the paste/aggregate interface is present. This interface area is the strong point of High-Performance Concrete (HPC) which is characterized by better adhesion between the aggregates and the cement matrix. In addition, the resistance of the matrix is almost equal to the resistance of the aggregates and sometimes even higher [2]. Even if the mechanical resistance of HPC is significantly higher than that of ordinary concrete, there are other parameters to which the attention is drawn, and which have more advantages compared to ordinary concrete materials such as durability and fire strength [2].

However, when HPC is subjected to high temperatures, as in a fire situation, these dense concretes sometimes exhibit sensitive behavior, which results in damage to the microstructure and detachment of small or large fragments of concrete [3]. Several studies have reported the high risk of chipping of HPC during thermal stress [4, 5, 6, 7]. The best-known remediation process is the addition of polypropylene fibers (PPF) to improve the thermal stability of concrete and metallic fibers (MF) to increase residual mechanical performance [8, 9]. The properties of PPF fiber have great potential. Indeed, its major advantage is its ability to reduce plastic shrinkage and cracks by around 40% and more [10]. Their fusions occur at 160 – 171 °C, where they are completely or partially absorbed by the porous network of the cement matrix. A vacuum remains in the place of the fibers, providing additional space for the water vapor to circulate. Consequently, the risk of chipping decreases with the reduction of vapor pressures within the material [8].
The objective of this work is to improve the understanding of the behavior of high-performance concretes and concretes containing polypropylene fibers at high temperatures. For this, test specimens of different percentages of PPF were made, kept in water for 28 days, and then subjected to a heat treatment of up to 250 °C. This temperature was chosen because the major transformations of the different material characteristics are observed in several studies [9, 11] between 200 °C and 500 °C, whereas the first transformations are between 200 °C and 300 °C. Mass loss, ultrasonic velocity, compressive, and tensile strength tests and measurements were made before the heating and after the cooling, in order to assess the evolution of the mechanical and physical properties of fiber-reinforced concrete at high temperatures.

2 Experiment's Details

2.1 Materials

The materials used in this work for the preparation of the various concretes are of local origin (Figure 1) and their chemical compositions and their physical properties are shown in Table 1 and Table 2.



Figure 1: The materials used for making the various concretes studied. (a) Dune sand, (b) Natural sand, (c) Quarry sand, (d) Gravel 15/25, (e) Gravel 5/15, (f) Cement CPJ-CEM II/ A 42.5, (g) MEDAPLAST H silica fume, (h) MEDAPLAST-SP 40 super-plasticizer, (i) SIKAFIBRE Polypropylene 12/32

Table 1: Chemical compositions of cement, mineral addition, and sands

	CaO %	**SiO_2 %**	**Al_2O_3 %**	**Fe_2O_3 %**	**MgO %**	**K_2O %**	**Na_2O %**	**SO_3 %**	**Cl- %**	**Loss on Ignition**
Cement	58.6	24.92	6.58	3.65	1.21	0.85	0.08	2.17	-	1.7
Silica fume	0.2	93.7	0.6	0.3	0.2	0.5	0.2	<2.5	<0.5	2.9
Natural sand	0.23	97.97	0.58	0.26	0.05	0.29	0.06	0.03	-	0.46
Quarry sand	56.73	3.71	0.23	0.20	1.18	0.02	0.07	0.09	-	37.77
Dune sand	1.63	90.46	1.38	1.92	0.39	0.22	0.00	0.2	-	2.56

Table 2 : General material properties

	Unit	**$S_{natural}$**	**S_{career}**	**S_{dune}**	**$G_{5/15}$**	**$G_{15/25}$**	**Cement**	**Silica Fume**
Fineness modulus	%	3.04	3.51	0.84	-	-	-	-
Visual Sand Equivalent	%	78.07	80.61	99.56	-	-	-	-
Equivalent of sand per piston	%	71.92	76.53	85.97	-	-	-	-
Bulk density	g/cm^3	1.39	1.50	1.44	1.48	1.49	1.09	0.5
Absolute density	g/cm^3	2.83	2.71	2.51	2.46	2.71	3.11	-
Impurity	%	-	-	-	12.36	3.39	-	-
SSB	cm^2/g	-	-	-	-	-	3371	>15000

2.1.1 Sands

The three sand types used for making concrete have different classes and natures:

a) Very clean dune sand (S_{dune}) of class 0/1. It is very fine with too tight a pace; its apparent and absolute densities are respectively 1.44 and 2.50 g/cm^3.

b) Clean natural sand ($S_{natural}$) of class 0/4 fine with a slightly spread appearance; its apparent and absolute densities are respectively 1.39 and 2.83 g/cm^3.

c) Clean, well-spread, class 0/5 quarry sand (S_{career}); its apparent and absolute densities are respectively 1.50 and 2.71 g/cm^3.

2.1.2 Gravels

The two kinds of gravels used for making concrete have the following fractions: 5/15 and 15/25; their apparent and absolute densities are respectively 1.485; 2.46 g/cm^3, and 1.49; 2.71 g/cm^3. They are washed and air-dried before use.

2.1.3 Cement

The cement (C) used for all the concretes made in this study is a composite Portland cement of the type CPJ-CEM II/ A 42.5. This cement is mainly made of 75% Clinker, 5% gypsum, and 20% blast furnace slag.

2.1.4 Additive

The super-plasticizer (Sup) used is MEDAPLAST-SP 40 high water reducer per standard EN 934-2 [12] as well as the standards established by the (CNERIB) in January 2007 [12]. In the liquid form, it is brown-colored with a pH of 8.2 and a density of 1.20 ± 0.01, and its chlorine content is less than 1g/L.

2.1.5 Addition

MEDAPLAST HP [NF P 18-502] is the addition of silica fume (SF) for making high-performance concrete (HPC. In the powder form, it has gray color; its density is 0.5 and its humidity in the oven at 105°C is less than one (< 100 %). The size of its products is less than 0.1 microns.

2.1.6 Polypropylene Fiber

We used synthetic fibers (12/32 polypropylene) marketed by the SIKA company called SIKAFIBRE based on specially treated polypropylene, presented in pre-dosed palpable sachets for 1 m^3 of concrete of density 0.91 g/cm^3 and length of 12 mm with a diameter of 32 µm. Their tensile strength f_t is 270 to 430 MPa and their Modulus of Elasticity E is 3000 to 6000 MPa.

2.1.7 Water

The water (W) used for making the mortar mixes is drinking water.

2.2 Method

A high-performance control concrete and three fiber-reinforced concretes with different dosages of polypropylene fiber PPF, 600 g/m^3 (0.12%), 900 g/m^3 (0.18%), and 1200 g/m^3 (0.24%) for each concrete (Table 3) were the subject of this comparative study. This choice of percentages was due to the method of introducing this type of fiber at the end of mixing, by a bag of 600 g/m^3. The tests concerned the determination of the compressive strength, the tensile strength, the speed of ultrasound, therefore the dynamic Elastic Modulus and the loss of mass. All the tests were carried out on cubic specimens (15 cmx 15 cm x 15 cm). These residual properties were determined before and after subjecting the specimens to the study temperature of 250°C and their cooling to the environment. A temperature rise rate of 2°C/min was used to reach the target temperature followed by a 1-hour plateau for homogenization of the temperature in the test piece (Figure 2).
The compression and tensile tests (by splitting) were carried out by a maximum force of 2000 kN with speeds of 0.3 MPa/s and 0.05 MPa/s [13]. The ultrasound velocity measurements were carried out in direct transmission mode [14] by an ultrasonic tester [EN 12504-4] (brand controls) comprising a transmission head and a reception head of 54 kHz [15]. The compressive strength f_c was determined directly by the force used depending on the breaking force and the section (Equation 1), the splitting tensile strength was calculated by the formula of Equation 2 after the determination of the breaking force by the force used. For the dynamic elastic modulus E_d was calculated by an empirical formula (Equation 3) after the determination of the ultrasonic velocity by the ultrasound used.

$$f_c = F/S \quad (1)$$

f_c: Compressive strength (MPa),
F: The breaking load (N),
S: Section of the specimen (mm^2).

$$f_t = 2P/\pi DL \quad (2)$$

f_t: Tensile strength by splitting (MPa),
P: The breaking load (N),
L: Length of the contact line of the specimen (mm).
D: Diameter of the specimen (mm).

$$E_d = \frac{(1+\nu)(1-2\nu)}{(1-\nu)} \cdot \rho \cdot V^2 \quad (3)$$

ν: Poisson's ratio,
ρ: Density in kg/m^3,
V: Speed of propagation of sonic waves in m/s.

Table 3: Composition of the concretes studied

Composition	Unit	HPC	HPFC1	HPFC2	HPFC3
$S_{natural}$	kg/m^3	76.49	76.49	76.49	76.49
S_{career}	kg/m^3	549.35	549.35	549.35	549.35
S_{dune}	kg/m^3	169.60	169.60	169.60	169.60
$G_{5/15}$	kg/m^3	216.09	216.09	216.09	216.09
$G_{15/25}$	kg/m^3	787.39	787.39	787.39	787.39
Cement	kg/m^3	500	500	500	500
Water	kg/m^3	193.05	193.05	193.05	193.05
Silica Fume	kg/m^3	75	75	75	75
Super-plasticizer	kg/m^3	10	10	10	10
Polypropylene fibers	kg/m^3	0	0.6	0.9	1.2
Water/Binder		0.336	0.336	0.336	0.336
Slump	(cm)	12	14	17	22

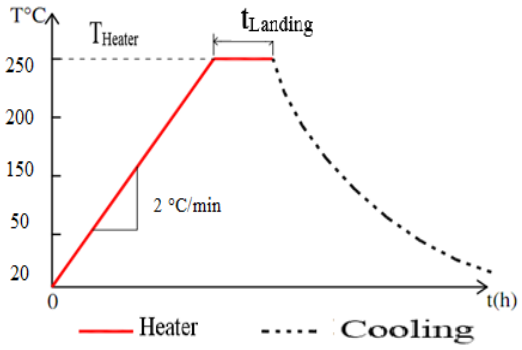


Figure 2: Heating cycle - cooling

3 Influence of Temperature on Fiber-reinforced Concrete

3.1 The Effect of Adding Fiber

The different results had grouped in Table 4 and illustrated by Figures 3, 4, 5, and 6 below.

Table 4: Effect of adding polypropylene fibers on the properties studied

20°C	**Unit**	**HPC**	**HPFC1**	**HPFC2**	**HPFC3**
Mass (m)	kg	7.993 ± 0.267	8.143 ± 0.063	8.101 ± 0.066	8.076 ± 0.656
Modulus of dynamic elasticity (E_{dyn})	MPa	47860.135 ± 1691.453	44810.508 ± 851.905	41821.248 ± 1985.935	44496.768 ± 2058.731
Compressive strength (f_c)	MPa	70.119 ± 5.0784	68.424 ± 1.0234	44.91 ± 6.143	62.694 ± 3.687
Splitting Tensile Strength (f_t)	MPa	2.114 ± 0.153	1.726 ± 0.026	2.681 ± 0.367	2.644 ± 0.115

3.1.1 The Mass

For HPFC1 we notice a very remarkable increase in mass (Figure 3) compared to the two other fiber-reinforced concretes, despite the fact that the concrete contains less fiber. This can be explained by the location of the fibers without any replacement of the constituents of the matrix.

The HPFC2 of 0.18% of polypropylene fibers also marked an increase in the mass compared to the mass of the control HPC, and a decrease of the latter compared to the HPFC1 of 0.12% of polypropylene fibers. Similarly, the HPFC3 of 0.24% PPF compared to the control HPC, HPFC1, and HPFC2.

It can be concluded that beyond an addition of 0.12% of polypropylene fibers the mass decreases as a function of the percentage of fibers, to reach the mass of the control HPC at a percentage to be determined. In addition, it can be also said that the fibers above this percentage replace a certain volume of the matrix.

3.1.2 The Dynamic Elastic Modulus

The incorporation of 0.18% of polypropylene fiber reduces the dynamic elastic modulus E_d by 12.62% to that of the control HPC.
On the other hand, the incorporation of 0.12% and 0.24% of polypropylene fiber reduces the dynamic elasticity modulus by 6.37% and 7.03% respectively to that of the control HPC (Figure 4).

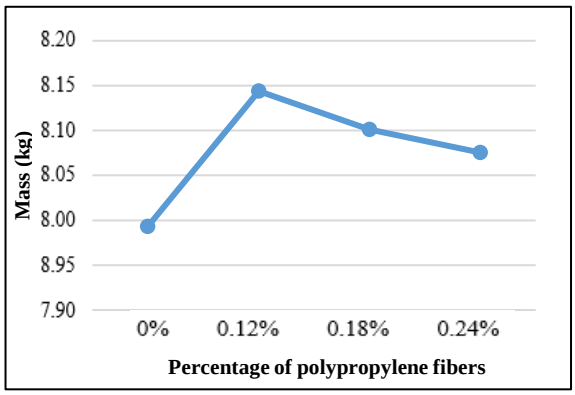


Figure 3: Evolution of the mass ($m_{20°C}$) as a function of the percentage of polypropylene fibers

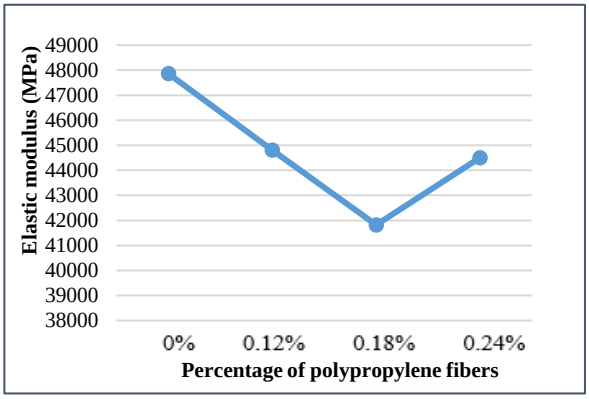


Figure 4: Evolution of the dynamic elastic modulus ($E_{d20°C}$) as a function of the percentage of polypropylene fibers

3.1.3 Compressive Strength

The compressive strength f_c dropped slightly (2.42%) for the incorporation of 0.12% of polypropylene fiber, in contrast to the incorporation of 0.18% PPF, where the drop in resistance is very remarkable, 35.95%, compared to the compressive strength of the control concrete HPC. The fall in compression resistance of HPFC3 is 10.59% compared to that of control concrete HPC (Figure 5).

Regarding the rupture of the matrix, we noticed a rupture even with aggregates according to the literature [16] for the four concretes, with the presence of fibers like hair threads that hold the pieces of fiber concrete together after rupture (Figure 7).

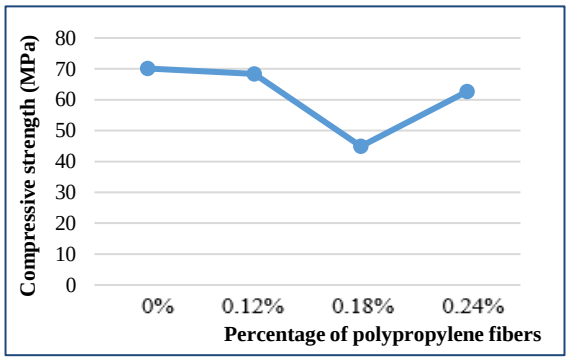


Figure 5: Evolution of the compressive strength ($f_{c20°C}$) as a function of the percentage of polypropylene fibers

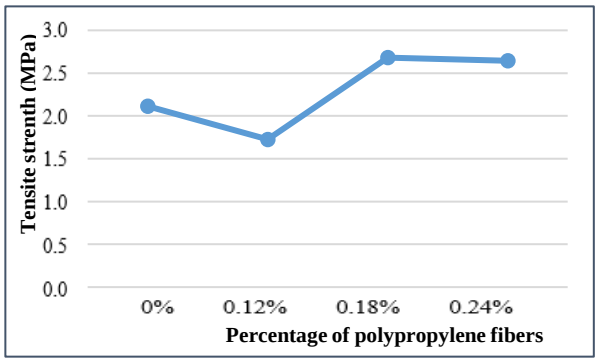


Figure 6: Evolution of the tensile strength ($f_{t20°C}$) as a function of the percentage of polypropylene fibers

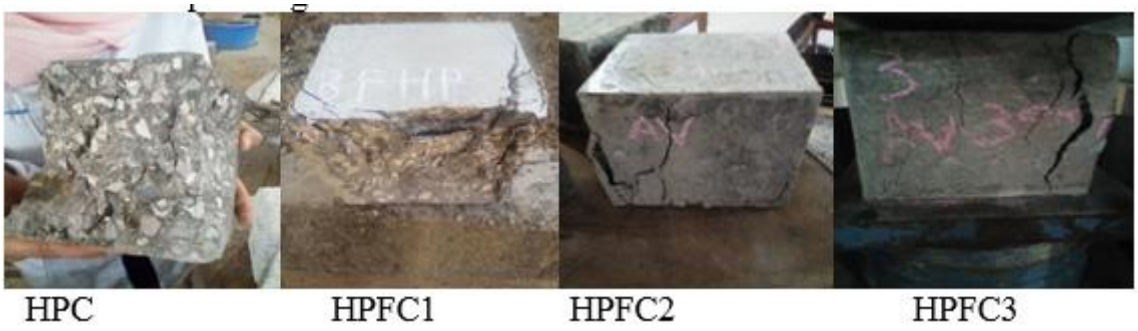


Figure 7: Failure of the compression specimens of the various concrete at 20°C

3.1.4 Tensile Strength

The incorporation of 0.12% polypropylene fiber HPFC1 decreased the tensile strength by 18.35% compared to that of the control concrete (HPC). On the other hand, the incorporation of 0.18% of PPF into the HPFC2 increased the resistance by 26.82%, compared to the tensile strength of the control concrete. It is caused by the high tensile strength of polypropylene fibers. A slight decrease in the tensile strength is observed, compared to HPFC2 of an order of 1.38%, compared to HPFC2, when incorporating 0.24% of PPF to create the HPFC3 (Figure 6).
Concerning the rupture of the matrix, the same remark as quoted above is observed for the resistance to compression (Figure 8).

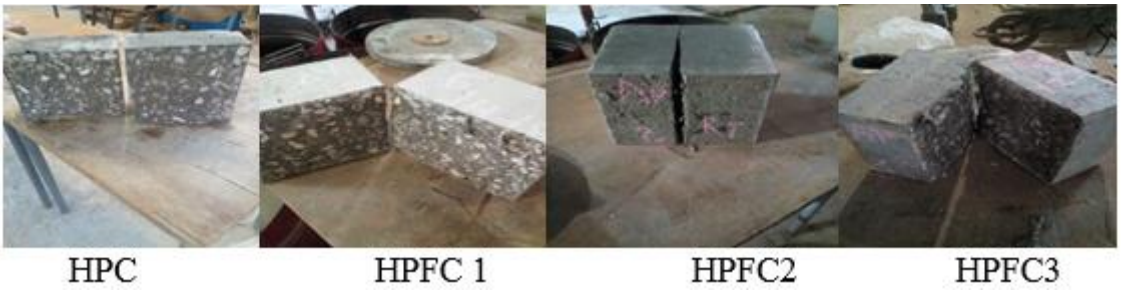


Figure 8: Failure of tensile test pieces by splitting different concrete at 20°C

3.2 The Effect of Temperature

For a better interpretation, the results are presented in the form of reports of the different properties at the temperature studied (250 °C) and compared to the results of the reference concrete at (20 °C). The reports obtained are grouped inTable 5 and illustrated in the figures below (Figures 9, 10, 11, and 12). The results are then compared to the normative results of Eurocode EC2 [17] and the Unified Document DTU [18] at the study temperature.

Table 5: Report of the different residual properties as a function of the percentage of polypropylene fibers

Properties at 250°C/ Properties at 20°C	**HPC**	**HPFC 1**	**HPFC 2**	**HPFC 3**	**DTU**	**EC2 (silica send)**	**EC2 (limestone sand)**
m (kg)	0.988 ± 0.003	0.9917 ± 0.034	0.9913 ± 0.007	0.9912 ± 0.005			

E_{dyn} (MPa)	0.941 ± 0.105	1.007 ± 0.034	1.088 ± 0.076	1.050 ± 0.040	0.45	0.39	
f_c (MPa)	0.719 ± 0.148	0.786 ± 0.147	1.560 ± 0.224	0.872 ± 0.186	1	0.9	0.94
f_t (MPa)	0.937 ± 0.317	1.860 ± 0.054	1.458 ± 0.000	1.557 ± 0.274	058	0.7	

3.2.1 The Mass

The mass loss of 0.62% in HPC is the smallest compared to other fiber-reinforced concretes. HPFC2 and HPFC3 have almost the same mass loss of 0.76% and 0.74%, respectively. On the other hand, HPFC1 has a loss of 1.10% (Figure 9). This can be explained by the free water content of the test pieces before heating. Also, a favorable effect of PPF for transporting moisture can be a contributing factor.
The mass loss of the four concretes is almost zero at 250 °C, so it did not exceed 2%. This value is a little less than that found by [19], which is due to the better compactness of these concretes and their very low porosity resulting from a low (Water/Binder) ratio.

3.2.2 The Modulus of Elasticity

The decrease in the dynamic elastic modulus E_d at 250 °C reached 5.9% for HPC. This decrease in the dynamic modulus of elasticity down to this temperature is twice that of the ultrasonic velocity respecting the proportionality with the ultrasonic velocity, in accordance with the results of [6] but with different values.
Still, the three types of fiber-reinforced concrete have an increased dynamic elastic modulus at 250 °C (Figure 10) of 0.7%, 8.8%, and 5% for HPFC1, HPFC2, and HPFC3, respectively. The results differ from the results of Sideris et al. [20] who observed a linear decrease in the modulus of elasticity up to 300 °C.
All ratios determined for the four types of concrete have higher values than those of DTU [18] and EC2 [17] at a temperature of 250 °C, in fact, even more than double. However, it should be noted that elastic modulus is deduced from ultrasonic velocities (dynamic modulus), so the results also depend on the procedures and formulas used as indicated by Pimienta et al. [21].

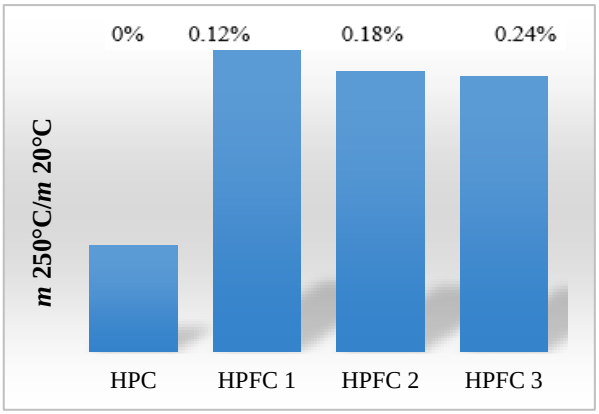


Figure 9: Evolution on the mass ratio as a function of the percentage of polypropylene fibers

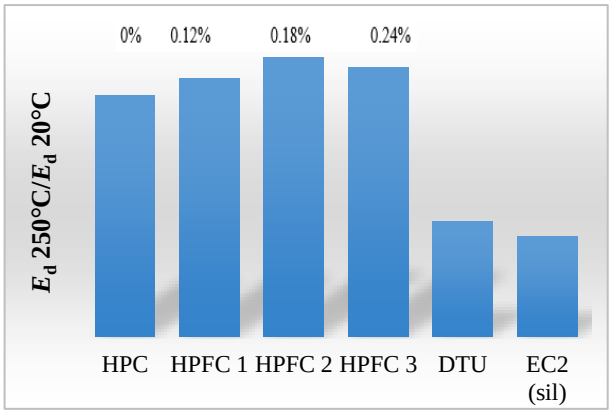


Figure 10: Evolution of the dynamic elastic modulus ratio as a function of the percentage of polypropylene fibers

3.2.3 Compressive Strength

Three types of concrete have relatively low compressive strength f_c at 250 °C for this temperature level. They reach 28.1% for the control HPC ample, 21.4% for HPFC1, and 12.8% for HPFC3 (Figure 11). This drop in the compressive strength is relatively close to those suggested by the Eurocode, where they do not exceed 25%. On the other hand, HPFC2 presents a remarkable improvement of 56% at the tested temperature and with the incorporation of 0.18% of PPF. So, the effect of adding 0.18% of PPF is more favorable after a cycle of 250 °C than that at 20 °C. The results are in contrast to the results of [22, 23] on polypropylene fiber concrete with an addition of 1 kg/m^3 i.e., 0.2%, where there is no significant improvement in compressive strength with temperature changes. The change as a function of percentage (PPF) of the compressive strength after 250°C underwent a slight increase on the plateau (0% to 0.12%), then a jump at the point of (0.18%) of (PPF) , to fall to (0.24%) of (PPF). The values of the ratios determined for the three types of concrete are around and lower than the values of DTU [18] and EC2 [17] (siliceous or limestone). After reaching 250 °C, the polypropylene fibers behave as an adhesive, which was noticed after different ruptures of the test pieces (Figure 13). Yagoub indicates that PPF melts at around 160 °C [10].

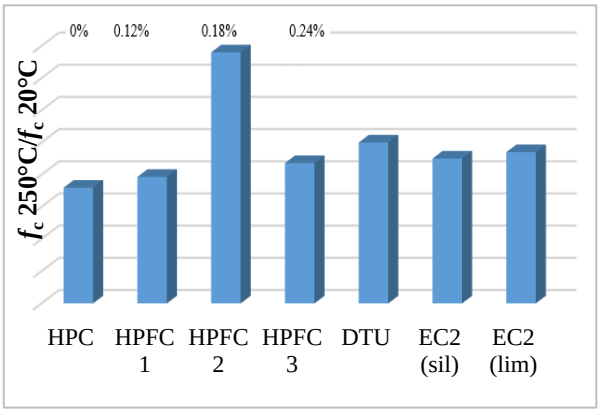


Figure 11: Evolution of the compressive strength ratio as a function of the percentage of polypropylene fibers

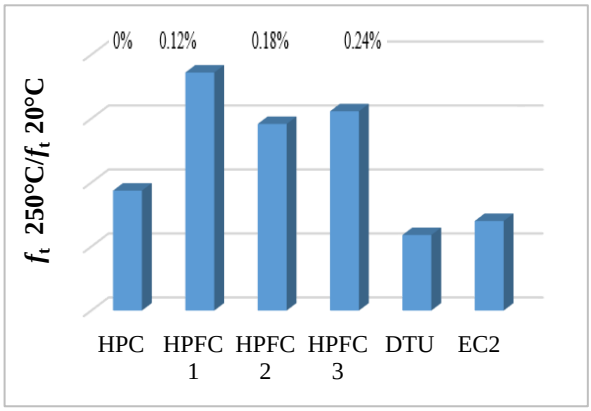


Figure 12: Evolution of the tensile strength ratio as a function of the percentage of polypropylene fibers



Figure 13: Rupture of test specimens by compression exposed to 250°C

3.2.4 Tensile Strength

The decrease in tensile strength f_t for HPC is 6.3% at 250 °C. It is relatively similar to that in compression (Figure 12). On the other hand, the three types of fiber-reinforced concrete have undergone remarkable increases, on average by 50%. The increases are respectively 86%, 45.8%, and 55.7% for HPFC1, HPFC2, and HPFC3, which converges to the results of Pilya [24] for ordinary concretes with polypropylene fibers but not for high performance concretes with polypropylene fibers (HPCF) between 150 °C and 450 °C. Pilya attributed this improvement in resistance to the melting of polypropylene which fills the pores of the concrete and re-solidifies during the cooling phase. The contact forces and the connections between the different grains thus improve. The concretes tested have values much higher than those of DTU [18] and EC2 [17].

4 Effect of Temperature and Fibers on the Relationships Between the Properties of Concrete

The relationships between the resistances (compression and tensile) and between the compressive strengths and the elasticity moduli can be influenced by the rise in temperature and even the incorporation of fibers. It was proved through the results that these properties can have different values. In this part of the work, we explore the effect of temperature and fibers on these relationships, between compressive and tensile strengths on the one hand and between the compression strength and elastic modulus on the other. These relations between properties also go in relation to those given by the regulations DTU [18] and EC2 [17].

4.1 The Relationships between Compressive Strengths and Tensile Strengths

The previous curves show the f_t-f_c relationships for HPFC with 0%, 0.12%, 0.18%, and 0.24% of PPF at 20 °C and 250 °C. Note that the difference between the regulatory curves and the experimental curve of HPFC at 250 °C is not as large as at 20 °C (Figures 14 and 15). On the other hand, we notice the quality reverse of the f_t-f_c regression $R^2 = 0.5273$ at 20 °C and $R^2 = 0.3828$.

At the two temperatures: 20 °C and 250 °C, the f_t-f_c relationships for HPFC always give underestimated values, but at 250 °C, the f_t-f_c relationships have the same appearance as those of the regulations BAEL [18] and EC [17]. In addition, at 20 °C the f_t-f_c relationships begin to wane, decreasing beyond 40 MPa. We can see that the f_t-f_c relationships were influenced by the percentage of PPF fiber incorporation.

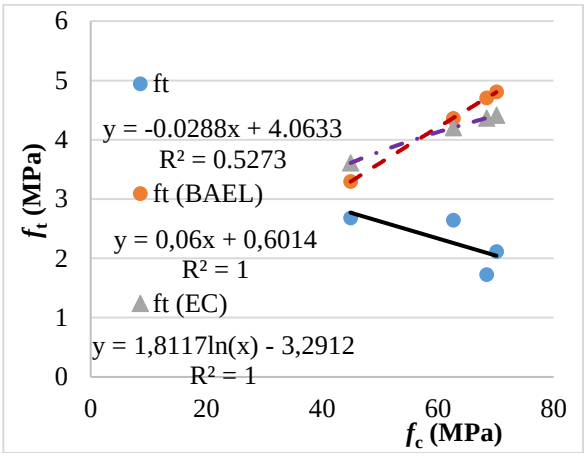


Figure 14: Relations between compressive strengths and tensile strengths at 20 °C

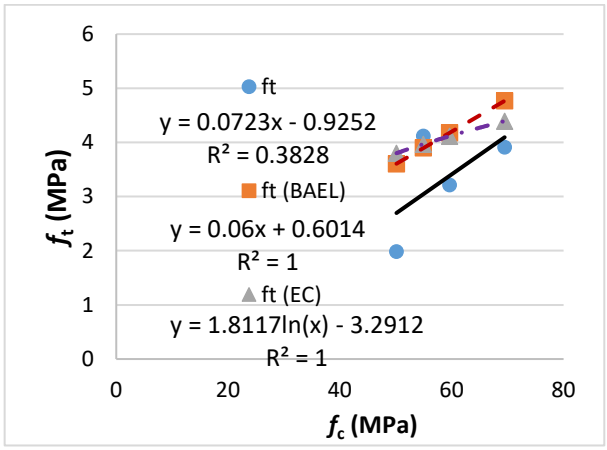


Figure 15: Relationships between compressive strengths and tensile strengths at 250 °C

4.2 The Relationships between Compressive Strengths and Elastic Modulus

We can notice that the majority of the points connecting E_d to f_c (Figures 16 and 17) at either 20 °C or 250 °C are located above the curves given by the regulations (BAEL [18] and EC [17]).

On the other hand, at 20°C, there is an improvement in the relationship for the HPFC (R2 = 0.780), with a rapprochement of the estimate of E_d with those of the regulations for compressive strengths around 65 MPa. But despite the fact that the E_d-f_c relationship at 250 °C tends to become confused with that of EC, its quality of regression is very small (R^2 = 0.003).

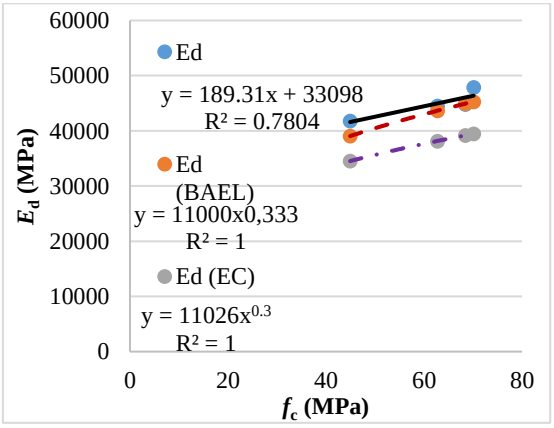


Figure 16: Relationships between compressive strengths and dynamic elastic modulus at 20 °C

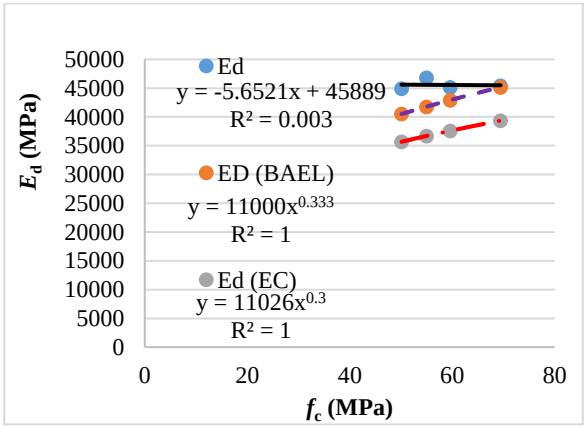


Figure 17: Relationships between compressive strengths and dynamic elastic modulus at 250 °C

5 Conclusion

This study highlighted the difference in behavior with respect to high temperatures of 250 °C between high-performance concrete and three types of concrete with polypropylene fibers. The former is much more influenced by the increase in temperature compared to the latter.
The decrease in compressive strength has exceeded 28% for HPC, while it is between 12% to 22% for HPFC with 0.12 and 0.24% of PPF. An increase of 56% in f_c was observed for HPFC with 0.18% PPF.
In traction, the improvement reaches on average 50% for HPFC. This implies that the tensile strength for HPFC is improved with the rise of temperature than is the compressive strength.
The increase in dynamic elasticity modulus E_d is between 0.5% and 9% for HPFC and the decrease reached almost 6% for HPC. Thus, up to this temperature, the dynamic modulus of elasticity of HPFCs is more improved by the rise of temperature than it is in the case of HPCs. We conclude that the residual mechanical properties of HPFC concretes are higher than the properties of the HPC control sample.
In general, the mechanical performance of the concretes studied and the physical characteristic, which is the mass, are positively influencing by the incorporation of PPF fibers. However, the most remarkable thing is that these incorporated fibers improved all the residual properties studied after the exposure of these concretes to the thermal cycle studied. These results are due to the chemical transformations, which have undergone the PPF under temperature. The relationships between compressive strength and tensile strength at 20 °C and 250 °C taking into account the presence of PPFs were underestimated compared to those of normative documents, therefore we can note that PPFs influence these relationships even at the atmospheric temperature.
The relationships between compressive strength and dynamic elastic modulus present were estimated as higher than those of normative documents.

References

[1] Kheddache, L., Chahour, K. and Safi, B. "Effet de la répartition des fibres sur le comportement mécanique en flexion des mortiers autoplaçants" Articles scientifiques sélectionnés - Journal of Civil Engineering, vol.15, no.1, 2020, pp.129-148. https://doi.org/10.1515/sspjce-2020-0012

[2] Lakhal, R. (2011) Elaboration des bétons à hautes performances a base des sous-produit locaux formulation et caractérisation physico-mécanique.» Mémoire de magister, Université Badji Mokhtar,Annaba. .

[3] Kalifa, P., Menneteau, F-D., Quenard, D. (2000) Spalling and pore pressure in HPC at high temperatures. Cement and Concrete Research. 30 (12), 1915-1927.

[4] Noumowé, A. (1995) Effect of high temperatures (20-600°C) on concrete. Special case of high concrete. PhD thesis. France. National Institute of Applied Sciences of Lyon.

[5] Hager, I. (2004) High temperature behavior of high performance concretes - evolution of the main ones. PhD Thesis. France. National School of Bridges and Roads and the School.

[6] Mindeguia, J. (2009) Experimental contribution to understanding the risks of thermal instability in concretes. PhD thesis. France. University of Pau and the Adour countries.

[7] Aidoud, A., Benouis, A.H. (2018) Investigation of the Evolving Relationship Between the Properties of Ordinary Concrete and High Performance Concrete at High Temperatures. Journal of Materials and Environmental Sciences 9 (4), 1335-1342.

[8] Kalifa, P., Chéné, G., Gallé, C. (2001) High-temperature behaviour of HPC with polypropylene fibres - From. Cement and Concrete Research. 30 (10), 1487-1499.
[9] Yermak, N., Pliya, P., Beaucour, A-L., Simon, A., 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.
[10] Yagoub, M. (2009) Assessment of the quality of fiber concrete in situ case of self-placing concrete with mixed fibers. Masters thesis. Algeria. Mohamed Khider University - Biskra.
[11] Hager, I. (2013) Behaviour of cement concrete at high temperature. Bulletin of the Polish Academy of Sciences 61 (1), 145-154.
[12] Technical manual (MEDAPLAST- SP 40 (GRANITEX)), available at: https://fr.scribd.com/document/427211373/Medaplast-Sp-40#
[13] EN (2003) European Standard 12309-3.Tests for hardened concrete - part 3: Resistance to compression of test pieces. CEN. 02.
[14] NF (2005) EN standar. NF 12504-4. Sonic auscultation test. AFNOR.
[15] CONTROLS (2002) Instruction Manual: Ultrasonic Pulse Velocity tester. Mod. 58-E0048.
[16] https://www.holcim.be/fr/les-betons-speciaux-beton-a-hautes-performances
[17] Eurocode 2 (2001) (ENV 1992-1-2): Design of concrete structures, Part 1-2: General rules - calculation of fire behavior. February.
[18] BAEL 91 rules (DTU P 18-702) (revised February 99, 2000) Technical rules for the design and calculation of reinforced concrete structures and structures using the limit states method Fascicle 62, title 1 of the CCTG - Works section 1: reinforced concrete 1.
[19] Chouiter, Y (2016) Study of the behavior of a high performance concrete (HPC) with glass fibers subjected to high temperature. Master memory. Algeria. Materials. M'sila: Mohamed Boudiaf University.
[20] Sideris, KK; Manita, P; Chaniotakis, E (2009) Performance of thermally damaged fiber reinforced concretes. Construction and Building Materials 23 (3), 1232-1239.
[21] Pimienta, P; Mindeguia, JC; Simon, A; Behloul, M; Felicetti, R; Bamonte, R; Gambarova, PG (2012) Performance of concrete subjected to high temperature, from material to structure. Symposium Cergy-Pontoise University. France. 23 October.
[22] Khaliq. W; Kodur.V (2011) Thermal and Mechanical Properties of Fiber Reinforced HighPerformance Self-Consolidating Concrete at Elevated Temperatures. Cement and Concrete Research. 41 (11), 1112-1122.
[23] Behnood, A; Ghandehari, M (2009) Comparison of compressive and splitting tensile strength of high-strength concrete with and without polypropylene fibers heated to high temperature. Fire Safety Journal. 44 (8), 1015-1022.
[24] Pliya, P (2010) Contribution of polypropylene and metallic fibers to improving the behavior of concrete subjected to high temperature. PhD thesis. France. University of Cergy Pontoise.