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Investigation on the Properties of HPC Exposed to Elevated Temperatures

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***Abstract* - When concrete is subjected to elevated temperatures, a destruction of its constituent hydration products can be occurred. This destruction implies a weakening of the material degradation of its mechanical properties such as stiffness and strength. The elevated temperature generates significant fluid pressure, leading to damage it and also causing breakdown of the concrete, which is characterized by the deteriorations of the hydrated material.This study focuses the evolution of residual properties of three High performance concrete (HPC). The specimens (16x32) cm^2 were subjected to different temperatures: 200°C, 400°C and 600°C with a rate of 2°C/min followed by a stage of three hours at the target temperature and then cooling to room temperature. The evaluation of different properties was evident compared to room temperature (20°C), with a maximum drop of compressive strength is of 79%. The loss of tensile strength is 62%. Losses masses and decreases dynamic elastic modulus are 6% and 89% respectively. It was observed an explosive burst of one of HPC between 400°C and 600°C.**

***Keywords*: HPC, weight loss, high temperatures, strength, dynamic elastic modulus, explosive.**

I.INTRODUCTION

The high - performance concrete often provides economic benefits, architectural and structural significant compared to conventional concrete (Phan and others, 2001). The use of (HPC) has expanded the area of use of concrete. With the limited porosity, durability, rheological qualities and outstanding mechanical properties, its use is growing strongly.

However, when subjected to high temperatures such as in a fire or a nuclear accident, these dense and compact concrete may have spallings, Breakouts occur or explosive behavior, breakouts occur or explosive behavior (Gawęska Hager, 2003). However, the high-performance concrete gives rise to explosive spalling associated with high temperatures [3, 4].

Degradation and loss of mechanical strength of concrete are due; on the one hand, to the physico- chemical changes of the material and on the other hand, the development of high vapor pressures and high mechanical stresses of thermal origin [5, 6, 7, 8].

This relative loss of compressive strength is lower when the W/C ratio is higher. There is no difference in loss between a concrete made with Portland cement and one another with additions such as fly ash or blast furnace slag etc. [3, 4]. In recent years much research has been undertaken to understand the behavior of high performance concrete (HPC) at high temperatures. This experimental study contributes into this research.

II.EXPERIMENTAL DETAILS

Three high- performance concrete (Table 1) were the subject of this study. The tests involved the determination of the compressive strength, tensile strength, sound velocity, so the dynamic elastic modulus and the loss of so mass density.

All tests are performed on cylindrical specimens (16/32). These residual properties were determined after subjecting the test specimens at various temperatures 20°C, 200°C, 400°C and 600°C and cooling at the ambience. A temperature rise rate of 2°C/min was used to achieve different temperatures followed by a stage for 3 hours at each temperature.

Compression and tensile testing (splitting) were performed on a 2000 kN press with respective speeds of 0.5 MPa/s and 0.05 MPa/s [4, 9, 10]. Measurements of ultrasonic velocities were performed in direct transmission mode, in accordance with standard [11].

They were carried out by an ultrasonic tester (Controls trademark) including a transmitting head and a receiving head 54 kHz [12]. The loss of mass is determined by weighing. The results are summarized below with tables and graphically.

TABLE 1. COMPOSITIONS OF HPC AND PROPERTIES AT 28 DAYS.

Concrete **Composition**(kg/m^3)	**HPC 1**	**HPC 2**	**HPC 3**
Sand$_{sea}$	575,12	/	243
Sand$_{career}$	/	492	492
Sand$_{dune}$	/	243	/
Gravel$_{5/12,5}$	/	461	/
Gravel$_{5/15}$	630,76	/	461
Gravel$_{12,5/20}$	/	448	/
Gravel$_{15/25}$	649,32	/	448
Cement	500	500	500
Water	172,5	173	173
SF	75	/	75
Sup	10(L/m^3)	3,4(Kg/m^3)	3,4(Kg/m^3)
W/B	0.495	0,346	0.496
Slump (cm)	18	14	08
f_c (MPa)	54.60 ± 3.45	65.80 ± 0.87	69.73 ± 0.36
f_t (MPa)	2.99 ± 0.33	3.59 ± 0.09	3.86 ± 0.11
V (m/s)	5127 ± 412	4639 ± 21	4781 ± 29
E_{dyn} (MPa)	54770 ±9197	43078 ± 311	46531 ± 801

III. THE RELATIONSHIP BETWEEN THE PROPERTIES OF HPC AND TEMPERATURE

3.1 Compressive Strength

TABLE 2. RELATIONSHIP BETWEEN COMPRESSIVE STRENGTH RATIO (FC_T PER $FC_{20°C}$) AND TEMPERATURE.

Temperature (°C)	**HPC1**	**HPC 2**	**HPC 3**
200	0.76 ± 0.139	0.55 ± 0.03	0.48 ± 0.011
400	0.74 ± 0.06	0.42 ± 0.203	0.47 ± 0.011
600	0.19 ± 0.021	0.23*	0.20 ± 0.002

* Explosive bursting of the test-tubes.

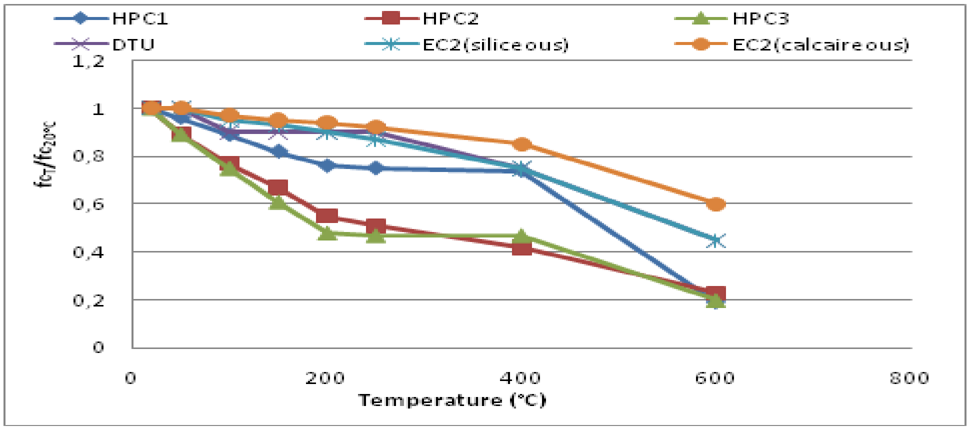

Fig.1 Evolution Of Compressive Strength Ratio (Fc_t Per $Fc_{20°C}$) With Temperature

Table 2 and Figure 1 it is noted:

1. One notices well that the fall of the compressive strength of the three HPC with 200 °C is very impotent it exceeds half for HPC3 much more than the fall obtained by Harada et al [13] and Z.A. Kameche et al [14], and of a quarter for HPC1 by contribution with initial resistance, on the other with 400 °C the fall is very weak for (HPC1, HPC3) does not exceed the 2% and 13% for HPC2

by contribution with that of the 200 °C then we can say that it is almost stable and it did not increase as they underlined Harada et al [13] and Kameche ZA et al [14], but we clearly noticed that 600 °C loss revenue is almost 80 % for the three HPC initial resistance as confirmed A. Gargouri , A. Masmoudi [3]. This explains the presence of the cracks after heating (front loading). (Change color after 400°C, and remarkable appearance cracks after 600°C. See Figures. 2-3).

2. Note also that the reports of compressive strength (HPC1 and HPC3) evolve similarly except for HPC2 which does not have the level of stability between 200°C and 400°C.
3. The values of the ratios determined for the three HPC lie below those of DTU [15] and EC2 [16] siliceous or calcareous.

Fig.2 Change In Color After 400 °C

Fig.3 Appearance of significant cracks after 600 °C

3.2 Tensile strength

TABLE 3 RELATIONSHIP BETWEEN TENSILE STRENGTH RATIO (FT$_T$ PER FT$_{20°C}$) AND TEMPERATURE

Temperature (°C)	**HPC1**	**HPC 2**	**HPC 3**
200	0.95 ± 0.063	0.75 ± 0.031	0.93 ± 0.094
400	0.90 ± 0.023	0.67 ± 0.045	0.86 ± 0.015
600	0.45 ± 0.005	/ *	0.31 ± 0.011

* Explosive bursting of the test-tubes.

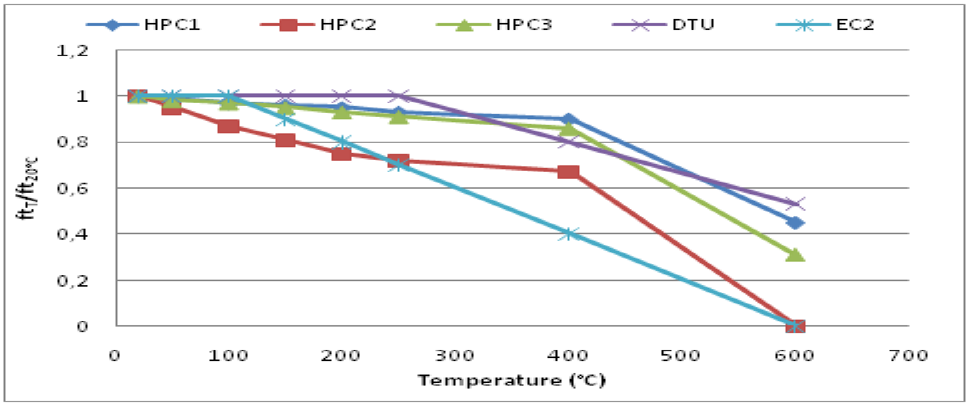

Fig. 4 Evolution Of Tensile Strength Ratio (Ft$_t$ Per Ft$_{20°C}$) With Temperature

Table 3 and Figure 4 it is noted:

1. The decrease in compressive strength varies quarter to 200°C to more than half at 400°C for up to two thirds of 600°C of the initial resistance. As for the tensile strengths , it is observed a much smaller drop in compression except for HPC2 that is to say that the tensile strength of (HPC1, HPC3) to 400°C it not exceed 15% of initial strength but at 600°C it exceeds half for HPC1 and two tires for HPC3 by contributing to the initial resistance. For HPC2 it broke at the temperature of 544°C, which is in line with previous studies where the break occurs above 300°C and greater than the interval reported by A. Menou [17], after falling from the fourth to 200°C at 33% at 400°C. So we can say that the tensile strength is influenced differently by the rise of temperature of a HPC to another in comparison to the compressive strength.
2. All values of the ratios calculated for the three HPC lie below those of DTU [15] and above those of the EC2 [16].
3. Only the value determined at 400°C of HPC1 and HPC3 is located above the DTU [15] and the values determined to 200°C of HPC2 lie below the EC2 [16].

3.3 Mass Loss

TABLE 4. RELATIONSHIP BETWEEN MASS LOSS RATIO (M_T PER $M_{20°C}$) AND TEMPERATURE.

Temperature (°C)	**HPC1**	**HPC 2**	**HPC 3**
200	0.98 ± 0.004	0.99 ± 0.003	0.99 ± 0.0006
400	0.95 ± 0.003	0.95 ± 0.0006	0.96 ± 0.005
600	0.93 ± 0.005	0.95*	0. 95 ± 0.001

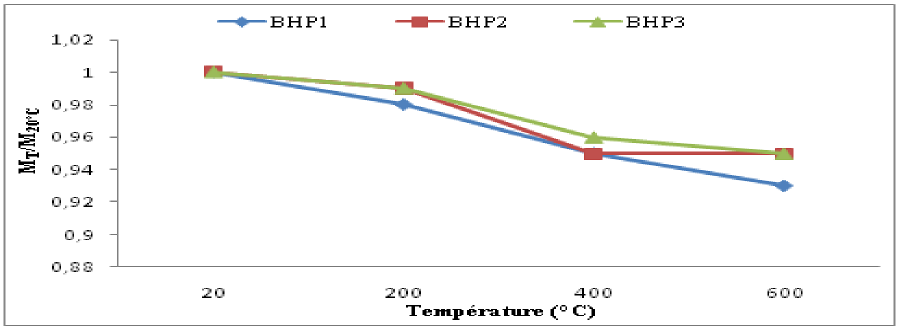

Fig.5 Evolution Of The Mass Loss Ratio (M_T Per $M_{20°C}$) With Temperature.

Table 4 and Figure 5 it is noted:

1. The mass loss is almost zero at 200°C, it has not exceeded 3 % for the three HPC, this is due to the better compactness of these concretes and their very low porosity this low porosity could generate the explosion of HPC2 before reaching 600°C (Figure 6). At 400°C the loss remains low because it has not exceeded 6 % for the three HPC, reaching 7% at 600°C (HPC1) and this is a questionable loss as can be said that it is due to the top of the decarbonation concrete or other gases that escape from the concrete during the heating [14].
2. In cooling stage, free lime (CaO) formed during decarbonization, combines with atmospheric moisture in the form of Ca $(OH)_2$ with a volume increase of 44% [17]. This causes cracks (see figure 3).
3. It is also noted that the explosion (see figure 6) is produced in the lighter HPC by weight contribution to the other two and which does not contain silica fume, and the test piece that has not exploded module dynamic highest contribution by the other two ie of less porosity confirming that the explosion was due to internal pressures and thermomechanical stresses.

Fig. 6 Explosive Burst Of HPC2 To 544 °C

IV.DYNAMIC MODULUS OF ELASTICITY

TABLE 5. RELATIONSHIP BETWEEN DYNAMIC MODULUS RATIOS (E_{DT} PER $E_{D20°C}$) AND TEMPERATURE

Temperature (°C)	**HPC 1**	**HPC 2**	**HPC 3**
200	0.82 ± 0.035	0.79 ± 0.045	0.79 ± 0.024
400	0.43 ± 0.047	0.66 ± 0.118	0.48 ± 0.042
600	0.01 ± 0.004	0.28*	0.03 ± 0.03

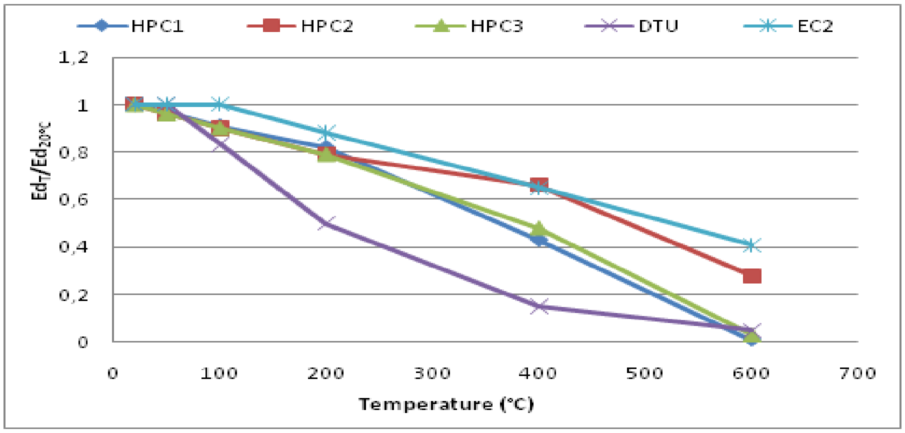

Fig.7Evolution Of The Dynamic Elastic Modulus Ratio (E_{dt} Pere$_{d20°C}$) With Temperature.

Table 5 and Figure 7 it is noted:

1. We notice a loss between 19 % and 21 % at 200°C and between 34 % and 57 % at 400°C from the initial dynamic modulus for the three HPC. These losses represent to that temperature twice that ultrasound speeds while maintaining proportionality with them. But at 600°C we see very significant losses 99 % (HPC1), 97 % (HPC3) and a loss that exceeds two thirds (HPC2).
2. All values of the ratios determined for the three HPC lie below those of EC2 [16] and above those of the DTU [15].
3. Only the value determined at 400°C of HPC2 lies on the curve of the EC2 [16].

V. EVOLUTION OF RELATIONS BETWEEN PROPERTIES DEPENDING ON TEMPERATURE

5.1Temperature Effect

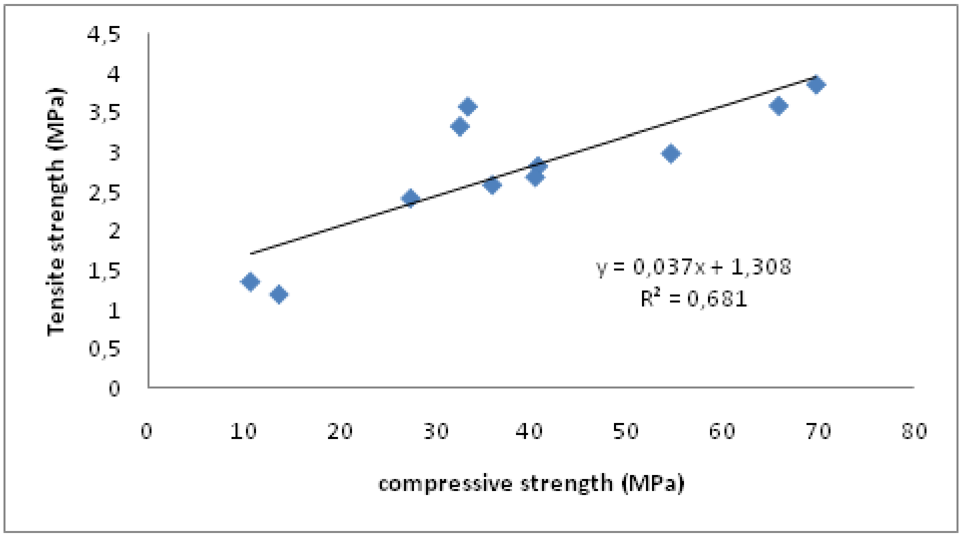

Fig. 8 Relationship between compressive strength and tensile strength

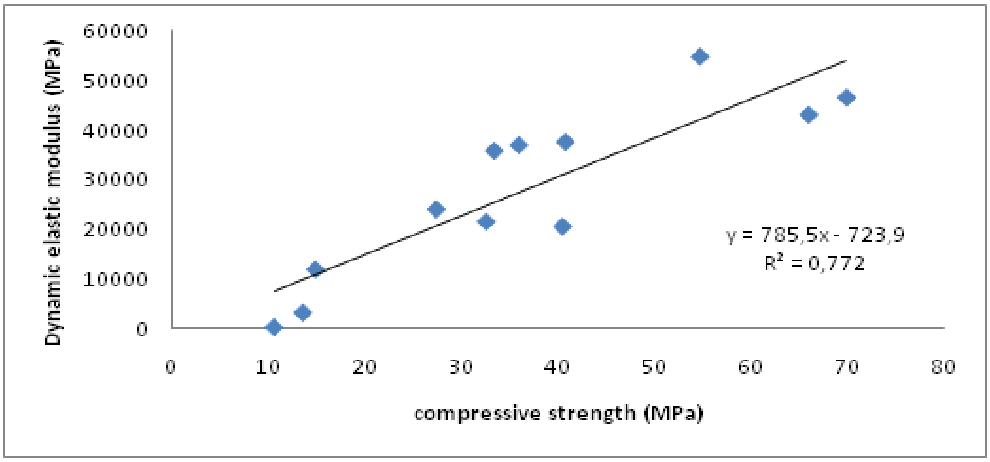

Fig. 9 Relationship between compressive strength and dynamic elastic modulus.

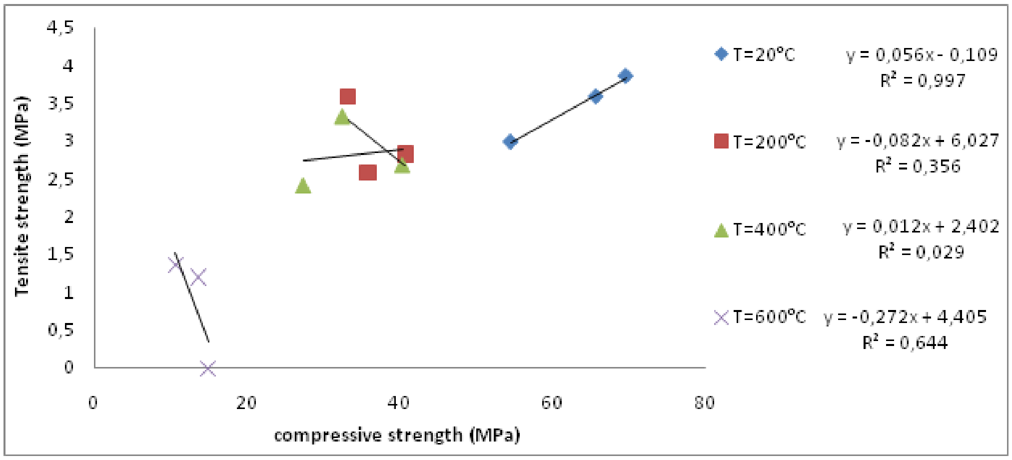

Fig.10 Relationship between compressive strength and tensile strength at each temperature

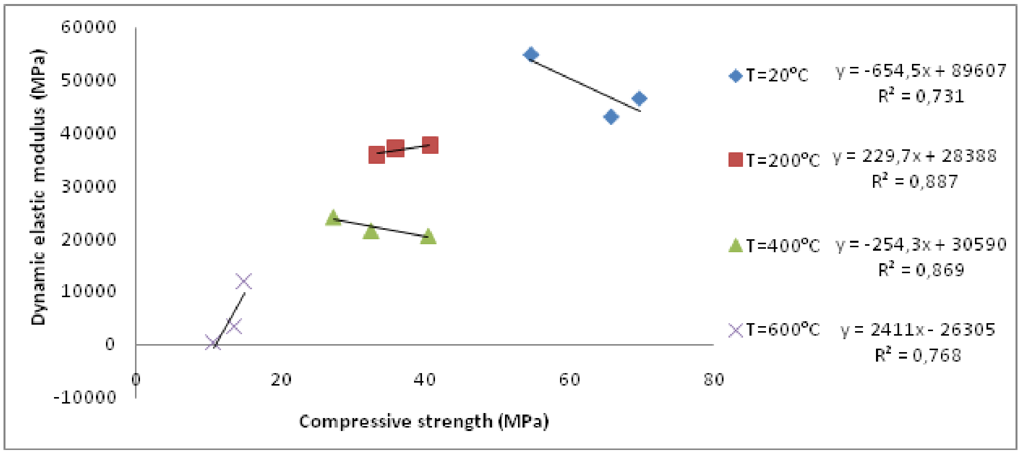

Fig.11 Relationship between compressive strength and dynamic elastic modulus at each temperature

If study the relationship between the compressive strength and the tensile one hand, and between the compressive strength and the other dynamic elastic modulus for each temperature we see for the first a large dispersions (Fig. 10) with very low quality coefficients especially at 400°C except at 20°C (0.997). This relationship becomes more acceptable if one considers all temperatures (Fig. 8) against for by the second dispersion is noticed in the case of all temperatures with a quality factor of 0.77 (Fig. 9) and becoming more acceptable to each temperature with quality coefficients ranging from 0.73 to 0.88 (Fig. 11). So we can say that the fc- ft for each temperature relationships have different evolutions tends said the relationship fc- ft by taking it consideration all temperatures has a straight.

The relationship between fc and Ed exhibit different changes at each temperature with gentle slopes except at 600°C.

5.2 *Effect of composition*

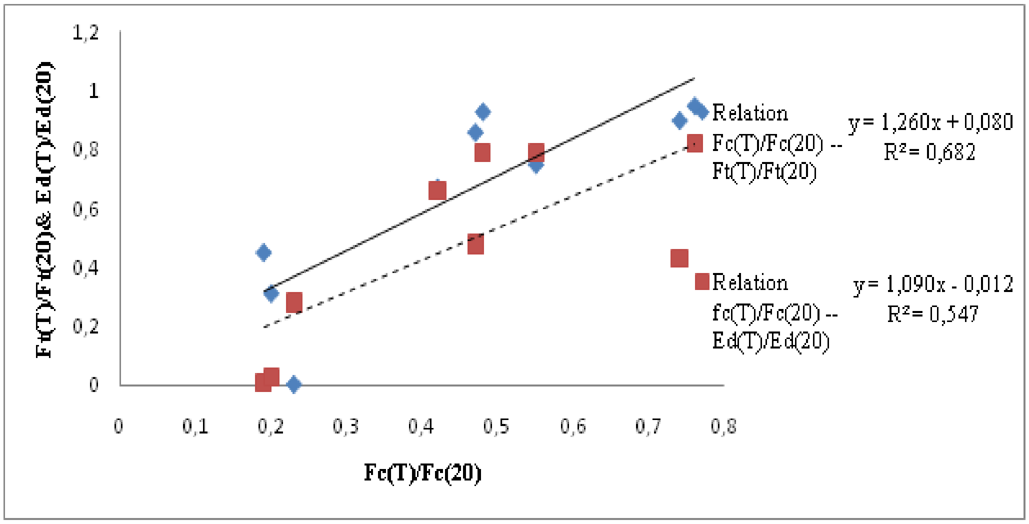

Fig. 12 Relationships between the ratios in compression and tensile strengths, module of elasticity at each temperature

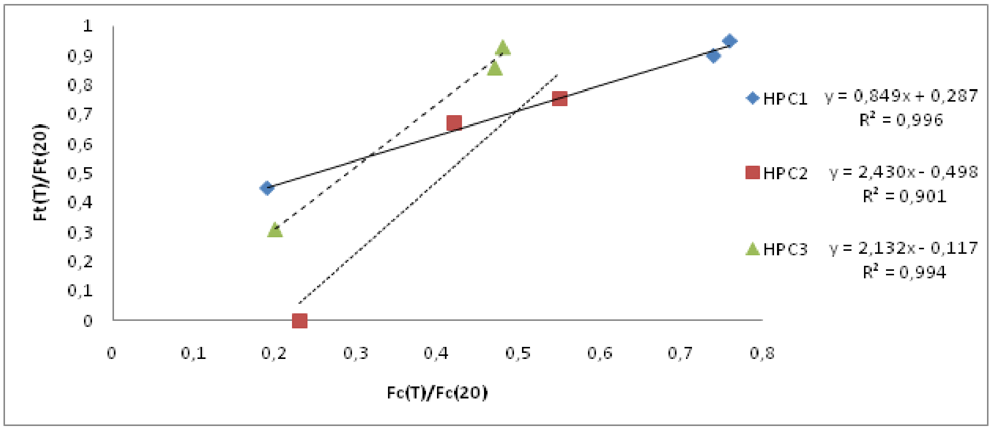

Fig. 13 Relationship between compressive strength ratios and tensile strength ratios for each concrete

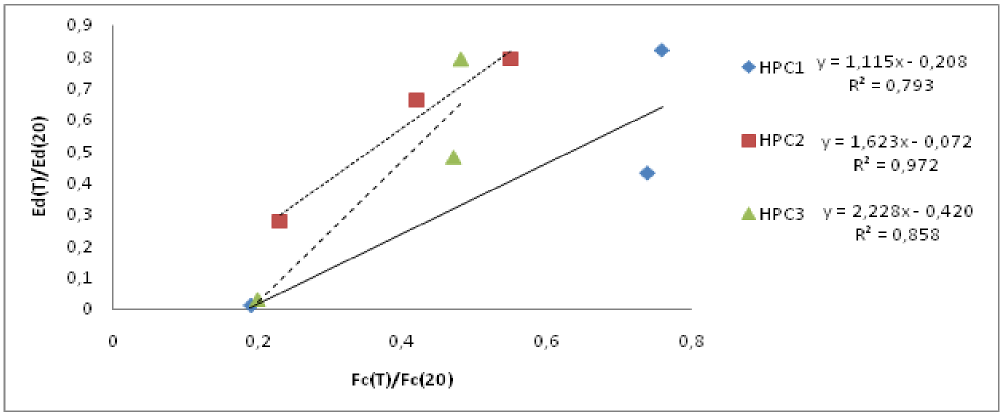

Fig.14 Relationship between compressive strength ratios and elastic dynamic modulus ratios for each concrete

Based on the evolution of the relationship $f_t(T)/f_t(20°C)$ and $E_d(T)/E_d(20°C)$, depending on $f_c(T)/f_c(20°C)$, noted that these relationships have also less accurate correlations (R_t^2 = 0.68 et R_E^2=0.54) where as in all the compositions and temperatures (Fig. 12)

The fact of interest to each concrete composition leads to better correlations between the ratios even considering all temperatures (fig. 13 and 14).

The curves connecting the relationship $f_t(T)/f_t(20)$ reports to $f_c(T)/f_c(20)$ show similar trends while that of HPC1 has a smaller slope.

Loss reports of resistance in tension (HPC2, HPC3) is less important than in compression (explosion HPC2).

It is noticed that the evolution of the slope of the curves connecting the reports $f_t(T)/f_t(20)$ and $E_d(T)/E_d(20)$ reports to $f_c(T)/f_c(20)$ is proportional to the modulus dynamic elasticity.

VI. PHENOMENON FLAKING AND PHENOMENON BURST

Fig.15 Phenomenon flaking

Fig.16 Phenomenon burst

During testing in the HPC2 undergoes two explosion phenomena are two different intervals. The first explosion is the phenomenon of flaking (Figure 15) that occurred between 200°C and 400°C to 354°C exactly what is in accordance with the results of previous studies where the explosion occurs above 300°C. The second explosion is bursting phenomenon (Figure 16) that occurred between 400°C and 600°C to 544°C exactly, it was noticed while the difference was the states of preservations of specimens before testing or oven: The specimens for the first explosion were stored at water until the 28th days then outdoors for 24 h then put in the oven, by cons for the second explosion test specimens were stored in water until the 28th day and then outdoors for 3 years then bake.

By (Figure 15) we notice a progressive and continuous detachment of small pieces of concrete that are expelled forcefully siding exposed to fire. These pieces are very numerous and are similar to thin chips that come off in succession in large numbers and on very large surfaces in proportion to their size. By against in (Figure 16) this is pretty big pieces of concrete and few, confirming that the first explosion is the phenomenon of flaking and the second explosion is the phenomenon of burst following their definitions.

So you could say that the flaking can occur for HPC subjected to a temperature of 300°C going at 400°C in the first months of his life, while the bursting phenomenon occurs at temperatures between 400°C and 600°C of a HPC several years of age.

VII.CONCLUSION

This experimental study has highlighted the high temperature behavior of high performance concretes. The latter are more influenced by the increase in temperature where the maximum depth of the compressive strength exceeded two-thirds (80%) of the initial resistance at 600°C. In tension, it does not exceed 15% (HPC1, HPC3) at 400°C of the initial strength but at 600°C it exceeds half for HPC1 and two dashes for HPC3 by contributing to the initial resistance, and there is them a burst at 544°C of HPC2.

This means that the tensile strength is influenced differently by the rise of the temperature of a HPC to another in comparison with the compressive strength. The loss of mass is generally low at 200°C (3%) and it becomes a double to 400°C (6%) to reach 7% at 600°C by the addition to the initial mass , causing color changes and appearances remarkable cracks. The dynamic elastic modulus drops by about a quarter to 200°C in excess of the half at 400°C. They face very significant falls and tend to cancel at 600°C (loss of 99%).

The most important one as high-performance concrete that exploded is the HPC has the least significant drops different properties compared to other HPC falls and even the color change and the appearance of cracks is less. This explains why it is the bursting phenomenon caused this explosion. In addition the same HPC to score two explosions, the first is chipping and the second represents the break in two cases and different intervals.

The relationship between the compressive strength and the tensile one hand and between the compressive strength and the elastic modulus of the other part have large dispersions. They are more acceptable considering all temperatures first. The fc- ft for each temperature relationships have different evolutions tends says it has a right in another.

The relationship between fc and Ed have different developments at each temperature with gentle slopes but at 600°C.

The curves connecting the relationship ft(T)/ft(20) reports to fc(T)/fc(20) show similar trends while that of HPC1 has a smaller slope. Loss reports of resistance in tension (HPC2, HPC3) is less important than in compression (explosion HPC2).

It is noticed that the evolution of the slope of the curves connecting the reports ft(T)/ft(20) and Ed(T)/Ed(20) reports to fc(T)/fc(20) is proportional to the modulus dynamic elasticity.

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