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COMBINED EFFECT OF SILICA FUME AND ADDITIVE ON THE BEHAVIOR OF HIGH PERFORMANCE CONCRETES SUBJECTED TO HIGH TEMPERATURES

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Abstract: This study examines the effect of the additions of silica fume and super plasticizer on the mechanical performance of high performance concretes at high temperatures. The tested concretes are formulated with 5% silica fume and two dosages of super plasticizers in the ratio of (2%, 2.5%) the weight of cement after having been exposed to four maximum temperatures, 200 °C, 400 °C, 600 °C and 900 °C without any imposed load during the heating. The results obtained show that the mechanical resistance at 28 day increases with the degree of temperature compared to that measured at 20 °C. On the contrary, a clear decrease is observed between 600 °C and 900 °C. However, material composition seems to have great influence on the mechanical strength.

Keywords: *Mechanical strength, Silica fume, Super plasticizer, High temperatures, Porosity, High performance concrete.*

INTRODUCTION

At high temperatures or under thermal conditions such as in tunnel fires (Channel 1996, Mont Blanc1999, Tauern 1999) and nuclear reactors, prediction of concrete performance is of great importance for the evaluation of the structural safety. Concrete is a quasi-brittle, heterogeneous and multiphase material. On a macroscopic scale, it is a mixture of aggregates bonded together by a matrix of hardened cement paste surrounding them, with a rather weak inter-facial transition zone. On a microscopic scale, the cement paste itself is found to be heterogeneous, consisting of an hydrated cores of

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cement grains, crystalline and amorphous hydration products, and pores. The microstructure of the cement paste in the vicinity of the aggregates differs from that of the bulk paste (Hadjab et al., 2010).

Many aspects of concrete behaviour under stress can be explained by the characteristics and behaviour of the cement paste-aggregate interfacial zone. This transition zone is generally weaker than either of the two main components of concrete, and it therefore has a disproportionate influence on the mechanical behaviour of concrete compared to its size (Bazant et Jirasek ,1994).

It is important to note that concrete properties and their variation as a function of the various influencing factors, such as loading, temperature and moisture, depend on the properties of the concrete constituents. It can be stated that concrete microstructure derives its macro-properties through the combination of the properties of the aggregates and the cement paste . The large number of different aggregate types can be used within concrete at ambient temperature. However, under fire conditions, when concrete is heated, many changes occur in physical structure, chemical composition and fluid content. Therefore, the mechanical properties of concrete, in particular strength and stiffness, are significantly altered when exposed to high temperature. (Burlion et Skoczylas , 2003).

Generally, it can be said that concrete has good properties with respect to fire resistance . It has a resistance to flame penetration as well as a lower thermal conductivity compared to other construction materials (steel, timber). However, the high temperature gradients and the moisture conditions introduced during fire can cause concrete spalling (Gambarova et al., 2007; Dwaikat et Kodur , 2009). Consequently, the ensuing reduction of the cross sectional area results in a reduced load carrying capacity, and potential structural failure (Bazant et Kaplan, 1996).

Malhotra et al. (1989) determined the influence of silica fume on the behaviour of concrete at high temperature. The tests were performed on eight different concrete mixes; four values of W/C were tested: 0.23, 0.35, 0.5 and 0.71. For each W / C, two concretes were studied with and without silica fume. Silica fume was not used to replace cement, but was added at a rate of 8% of the mass of cement . The sand was natural sand (Ottawa Valley). The aggregate (crushed) had a maximum diameter of 19 mm . The authors do not specify the mineralogical nature of these aggregates . The super plasticizer sulfonated naphthalene formaldehyde condensate was used in all mixes . The focuse of the analysis was on the concrete with W / C ratios = 0.35 and 0.23 and whose resistance is greater than 50 MPa . The resistance of these two types of concrete determined after 28 days of moist cure ranged from 53 to 87 MPa . The specimens subjected to high temperatures were cylinders (102 × 203) mm in the case of the compression tests . The specimens were previously kept moist cured for 7 days and then at T = 21 °C and 50% RH for 21 days . The specimens were subjected to temperatures of 150, 300 and 450 °C respectively . They were maintained at this temperature for 72 hours before the cooling phase that was achieved by simply turning off the oven .

Other study undertaken on the subject reported that high performance concrete exhibits greater resistance than ordinary concrete strength; this is due to the increase in cement content and the decrease of the silica fume dosage (Ahmad et al., 2010).

In the research of Papayianni and Valiasis (Diederichs et al., 1992; Papayianni et al.,1991) he has been shown that replacement of 40% of the Portland cement by fly ash causes a greater reduction in compressive strength for the temperatures 200, 400, 600 and 800 °C. So, prediction of mechanical behaviour, thermo mechanical deformations and moisture migration in heated concrete is important for safe operation of concrete containment . For this purpose it is necessary to determine the instantaneous and residual behaviour of concrete subjected to high temperatures (up to 900 °C).

In 2004 Yüzer et al., carried out a study on the effects of fire and extinguishing on the properties of concrete. Mortars with and without silica fume were exposed to different temperatures, such as (100, 200, 300, 600, 900 and 1200) °C and cooled slowly in the air and fast in water in two groups. Flexural and compressive strength tests were performed on the samples which were cooled up to room temperature and changes in compressive strength in color were determined by Munsell Color System. High temperature has caused damages in decrease in mechanical strengths at 600 °C. Researchers observed that the changes in color's hue component and the compressive strength have similarities. Test results show that residual color changes in mortar can give an idea about the effect of high temperatures on mechanical properties of mortar during a fire.

A.H.Ahmad’s research (2010) includes an experimental investigation to study the effect of high temperatures on the mechanical properties of concrete containing admixtures. A comparative study was conducted on concrete mixes, reference mix without an additive and that with an admixture. Concrete was exposed to three levels of high temperatures (200,400,600) °C, for duration of one hour, without any imposed load during the heating. Super plasticizer, plasticizer, retarder and water reducing admixture, an accelerator and an air entraining admixture, five types of admixtures were used. Mechanical properties of concrete were studied at different high temperatures, including: compressive strength, splitting tensile strength, modulus of elasticity and ultimate strain. Test results showed a reduction in the studied properties by different rates for different additives and for each temperature, the decrease was very limited at temperature up to (200 °C) but was clear at (400, 600) °C. In the present study, two factors were studied at high temperatures:

- Influence of super plasticizer on the mechanical strength ;
- The additions of silica fume on the behaviour of HPC and the internal structure. XRD patterns, ATG, and ATD of concrete subjected at high temperature.

MATERIALS AND METHODS

The Portland cement type CEM II/A 42.5 from Hammam Dalâa local factory was used in this experimental study. The used cement type has an absolute density, consistency and fineness values of 3.1 g/cm^3, 28 % and 4000 cm^2/g, respectively. The chemical composition of the cement is shown in Table 1.

The silica fume is obtained from GRANITEX (Algeria region). It results from melting in the silicon and ferro-silicon industry. The reduction of high-purity quartz to silicon at temperatures up to 2000 °C produces SiO_2 vapors, which oxidize and condense in the low-temperature zone to tiny particles consisting of non-crystalline silica (Siddique, 2011).

The physical properties and particle size wich done by laser granulometer (Mastersizer 2000) of silica fume are shown in Table 1 and Fig. 1.

The natural fine aggregates used were dune sand with particles ranging from 0.08 mm to 5 mm in size, with a fineness modulus, M_f of 2.44. This natural sand was taken from the region of Boussâada, (250 km east of Algiers). The sieve analysis is performed according to the European standard NF EN 933-1. After the treatment process that allows eliminating a significant portion of clay minerals impurities. The mineralogical composition determined by X-ray diffraction shows that the siliceous sand is more than 95% of quartz and calcite traces.

Tab. 1. The chemical, physical properties of cement and silica fume

<table>
<tr><th colspan="2"></th><th colspan="3">Cement (%)</th><th colspan="2">Silica fume (%)</th></tr>
<tr><td colspan="2">SiO_2</td><td colspan="3">20.7</td><td colspan="2">>85</td></tr>
<tr><td colspan="2">Al_2O_3</td><td colspan="3">04.75</td><td colspan="2">-</td></tr>
<tr><td colspan="2">Fe_2O_3</td><td colspan="3">03.75</td><td colspan="2">-</td></tr>
<tr><td colspan="2">CaO</td><td colspan="3">62.92</td><td colspan="2">-</td></tr>
<tr><td colspan="2">MgO</td><td colspan="3">01.90</td><td colspan="2">-</td></tr>
<tr><td colspan="2">SO_3</td><td colspan="3">1.98</td><td colspan="2">< 2.5</td></tr>
<tr><td colspan="2">CL</td><td colspan="3">-</td><td colspan="2">< 0.2</td></tr>
<tr><td colspan="7">Mineralogical composition of cement</td></tr>
<tr><td>Item</td><td>C_3S</td><td>C_2S</td><td colspan="2">C_3A</td><td colspan="2">C_4AF</td></tr>
<tr><td>Content</td><td>59</td><td>14</td><td colspan="2">6</td><td colspan="2">10</td></tr>
<tr><td colspan="7">Physical properties of silica fume</td></tr>
<tr><td>Particle size</td><td colspan="2">Density</td><td colspan="2">Specific surface</td><td colspan="2">Moisture by store at 105°C</td></tr>
<tr><td><0.1microns</td><td colspan="2"><0.5</td><td colspan="2">>15 m^2/gr</td><td colspan="2"><1%</td></tr>
<tr><td colspan="7">Characteristics of the chemical admixture</td></tr>
<tr><td>Super plasticizer</td><td>Form</td><td>Color</td><td>PH</td><td>Density</td><td>Chlorine content</td><td>Dry extract</td></tr>
<tr><td>Medaplast SP 40</td><td>Liquid</td><td>Brown</td><td>8.2</td><td>1.2±0.01</td><td>< 1g /l</td><td>40%</td></tr>
</table>

The coarse fraction of aggregate is gravel (G1) of size 3/8 mm and gravel (G2) of size 8/15 mm. The adjuvant used is a super plasticizer high water reducing (Medaplast SP40). It is a solution of pH = 8.2 and a density of 1.22, with 40% of solids. Its normal use scale is fixed by the manufacturer's recommendation which is between 0.6 and 2.5% of the cement weight. The tap water used all through the study from mixing was taken from the laboratory of civil engineering.

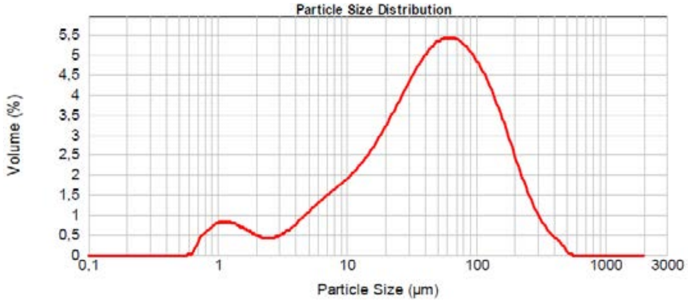

Fig. 1. Particle size distributions of silica fume

MIXTURES DESIGN

Fresh concrete mixes were prepared in a modified laboratory mixer; the mixing procedure is explained in Table 2. The concrete specimens were preserved in their moulds in a wet place at a temperature of 20°C and 95% relative humidity (RH) during 24 hours. After demoulding, they were immersed in water at 20° C until the age of testing. The physical and mechanical characteristics of the concretes with and without the addition of silica fume have been compared. The silica fume is added at dosages of 5% of cement weight and the super plasticizer at 2% and 2.5% respectively. The final compositions of High Performances Concrete (HPC) with addition, after optimization is reported on table 3 (Rahmouni and Tebbal, 2014; Tebbal et al. 2016; Tebbal and Rahmouni, 2016).

Tab. 2. Mixing procedure

Time, sec.	Mixing procedure
60	Mixing of aggregates, silica fume, cement
30	Addition 100% of water and a third of the volume super plasticizer
180	Mixing
30	Addition of the remaining super plasticizer
60	Mixing

Tab. 3. Compositions of concrete with and without silica fume

Mix (kg/m^3)	Cement	Sand	Gravel (3/8 , 8/15)	Water	Additions	
					Silica fume (%)	Super plasticizer (%)
$CR_{2.5}$	400	662	1090	220	-	2.5
$HPC_{2.5}$	444	645	1042	119	5	2.5
HPC_2	444	662	1042	122	5	2

The following acronyms will be used henceforth:

$CR_{2.5}$: Concrete without silica fume and 2.5% (by weight of cement) of the chemical admixture;
$HPC_{2.5}$: Concrete dosed at 5 % of silica fume and 2.5% of the chemical admixture;
HPC_2: Concrete dosed at 5 % of silica fume and 2% of the chemical admixture.

After 28 days, specimens with dimensions (100 × 100 ×100) mm^3 are dried in an oven (at 100 °C), until stabilization of their mass. All specimens are subjected to high temperatures: 200 °C, 400 °C, 600 °C and 900 °C according to the time-temperature schedule of ASTM E 119-00. After cooling, they were subjected to compression tests.

The slump values were obtained for all three mixtures according to the NF EN 12390 - 4 EN 12390-5. The axial compressive strength tested at 28 days according to NF EN 12390- 4 for the concrete at 20 °C that was not subjected to high temperatures.

The protocol of porosity accessible to water conform the recommendations of AFREM group (AFPC-AFREM Groupe de travail Durabilité des bétons 1998) recommendations. The open porosity allows us to appreciate the evolution of hydration and structuration of hydrated products; this is a key for identification of the most sustainable concrete **(**Bessa, 2004). The test pieces for testing of water porosity are dried in an oven at a temperature of 100°C to constant weight and then returned to room temperature in a desiccator.

The porosity test is carried out on test pieces of dimensions 10×10×10 cm^3, by applying the following steps:

1) Drying in an oven at 105 ° C of the sample for at least 24 hours until obtaining a constant mass. Then they were weighed once dry (A);
2) Immersion of the sample in water for 24 hours;
3) Heating to boiling for 5 hours, then weighing the sample in air (weight "C");
4) Finally, hydrostatic weighing (D : weight of saturated samples subjected to Archimedes).

The porosity was calculated by the formula:

$$P\,(\%) = \frac{C-A}{C-D}.100 \qquad (1)$$

Phase compositions of these concretes were investigated on the fine powders using x-ray diffraction method. the powder samples of concretes heat treated aggregates at 20, 600 and 900 °c were collected after abrasion. X-ray diffraction analysis was performed on an x-ray diffractometer (X'Pert) coupled to a computer system. The essential purpose of this analysis is to identify the different crystalline phases present in a sample.

Gravimetric and differential thermal analyzes (ATG and ATD) make it possible to quantify portlandite, these techniques are used to characterize degradations.

RESULTS AND DISCUSSION

HIGH TEMPERATURE EFFECTS ON SURFACE PROPERTIES OF CONCRETE

As seen in Fig.2, some color changes happen on surface of concrete samples due to high temperature effects. As a result of these color changes, it can be certainly appraised the range of temperature values. It can be seen that cracking, rupture, and color changes happened much more in the concrete samples exposed to 900 ^{o}C than the ones with 400 ^{o}C and 600 ^{o}C.

Fig. 2. Concrete samples exposed to high temperature

LOSS OF CONCRETE'S MASS RELATED TO TEMPERATURE

Figure 3 shows the evolution of mass loss during the heating cycle of the studied specimens. Before 100 °C, the mass exchange is very low. The mass loss in this temperature range corresponds mainly to the water escape from concrete pore.

Between 100 and 600 °C, a strong mass loss for all concrete specimens tested. Each concrete lost from 3 to 12% of its original mass. Most of water in each concrete specimen evaporated during heating between 100 and 400 °C. The increase is almost linear up to a temperature of 600 °C. This is due to the evaporation of water and the progressive dehydration of CSH gel. Several authors; Noumowé et al., confirm that beyond 600 °C there is no more water in the concrete specimen (Noumowé, 2001; Tsymbrovska, 2015).

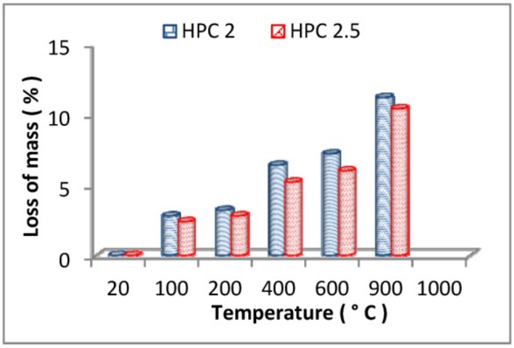

Fig. 3. Evolution of mass loss related to temperature

RESULT OF THE CRUSHING OF CONCRETE AFTER COOLING

The compressive strength of all concretes mixtures at ambient temperature and after heating to 200 °C, 400 °C, 600 °C and 900 °C is illustrated by Fig. 4.

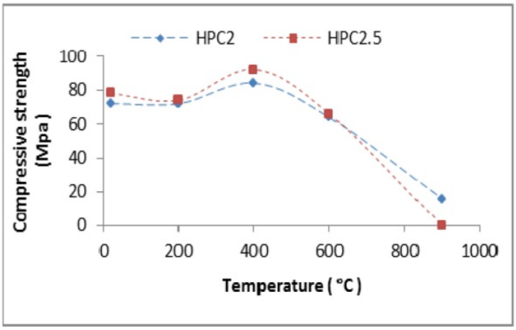

Fig. 4. Compressive strength after cooling relative the initial strength

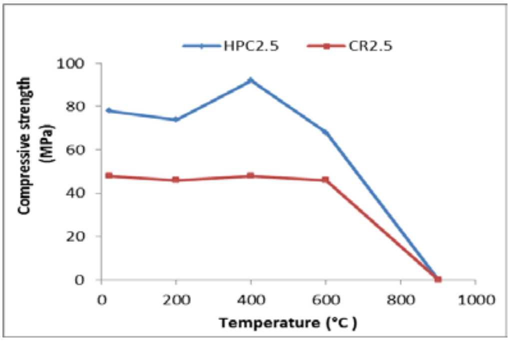

Fig. 5. Compressive strength of (HPC $_{2.5}$) and (CR$_{2.5}$) with temperatures

This figure clearly shows that the compressive strength of all concrete mixtures decreases at elevated temperature. According to the results obtained from present investigation, the strength of concrete HPC_2 after being heated to 200 ^{O}C, 600 ^{O}C and 900 ^{O}C decrease of 3%, 11%, and 78% of its unheated strength respectively.

The concrete $HPC_{2.5}$ exhibited greatest loss in strength, about 4%, 15.38% and 100% of its unheated strength when heated to 200 ^{O}C, 600 ^{O}C and 900 ^{O}C respectively. We observe a stress peak at 400 °C indicating a maximum value of the compressive strength of the concretes. The decomposition temperature of $Ca (OH)_2$ varies between 400 ° C and 600 ° C. If static temperature conditions are maintained, $Ca (OH)_2$ will decompose at 400 °C. This temperature seems to be the critical temperature for a portland cement concrete **(**Dias **et al ., 1990).**

Kalifa's work et al, have shown the role of water on the performance of HPC temperature. Pressure values observed in HPC 100 MPa to 4 MPa were only 3cm deep from the heated side to the vicinity of 250 °C (Kalifa et al., 2001). This further explains the prestressing force caused by the water trough described by Burlion et al., (2003).

After the evaporation of physically and chemically bound water, a pressure is built-up which leads to an extensive inner cracking. This inner cracking is the main reason for reduction in strength of all concrete mixtures. Apart from it, the cement paste contracts and aggregate expands due to loss of water at higher temperature which leads to loss of the bond between paste and aggregates.

INFLUENCE OF SUPER PLASTICIZER ON THE MECHANICAL STRENGTH

A 900 ^{O}C, we notice a low resistance for concrete with 2% adjuvant and a bursting of the concrete to those dosed of 2.5% super plasticizer (Fig. 4). This can be explaining by:

- The concrete with superplasticizer has high resistance. The role of the super plasticizer in the distribution of cement particles and improving the compactness of concrete is highlighted. The concrete mixes containing superplasticizer are affected by high temperatures especially at 600 ^{O}C and above compared to those with less super plasticizer dosage ;
- The decrease of resistance estimated at 78% for HPC with 2% super plasticizer exposed to a temperature of 900 ^{O}C. On the other hand, it is zero for ordinary concrete. During these processes, some cracks occur and concrete is crumbled and becomes porous material (Kan, 2016). Aggregate's effect on concrete at high temperatures is related to their mineral structures. This process results in volume increase and damage (Rahmouni et al. 2014).

INFLUENCE OF SILICA FUME ON THE MECHANICAL STRENGTH

In this part of the study, we want to highlight the influence of silica fume on the mechanical behaviour of HPC. After the passage in the oven, the concrete specimens were cooled for 24 hours in the laboratory, at a temperature of 20 ± 5 ° C before submitting to compressive strength test. The specimens of HPC exposed at high temperature are schematized in (Fig. 5).

As expected, the replacement of cement by 5% of silica fume increased the compressive strength approximately 30% at 28 days. This is due to the reaction of the silica fume with calcium hydroxide formed during the hydration of cement that caused the formation of calcium silicate hydrate (CSH) as well as filler role of very fine particles of silica fume. In general, it can be concluded that concretes containing silica fume had significantly higher strength than those of CR concretes at room temperature. After exposure to 200 °C, significant reductions occurred in the compressive strength of concretes without SF. Results showed the strength recovery of 18% for the concretes $HPC_{2.5}$ after heating to 400 °C when compared to 200 °C. The compressive strength gains at 400 °C are attributed to the increase in the forces between gel particles (Van der Walls forces) due to the removal of water content (Castillo et Durrani, 1990).

In the range of 400–600 °C, severe strength losses occurred in two concretes $HPC_{2.5}$ and $CR_{2.5}$. During exposure to high temperatures, cement paste contracts, whereas aggregates expand. Thus, the transition zone and bonding between aggregates and paste are weakened. After heating to 600 °C, the compressive strengths of CR were lower than those of the concretes $HPC_{2.5}$. This is attributed to the presence and amount of silica fume in concretes that produced very denser transition zone between aggregates and paste due to its ultra-fine particles as filler and its pozzolanic reactions.

At 600 °C, the quick losses in compressive strength for $HPC_{2.5}$ concretes are attributed to the dense microstructure in this type of concretes, which caused the build-up of higher internal pressure due to the water vapor transition of the interlayer water. As a result, this process as well as chemical decomposition of hydration products causes severe deteriorations and strength losses in concrete after subjecting to high temperatures. It seems that the dosage of silica fume has no significant effect on the relative residual compressive strength at 200 °C. However, between 200 °C and 400 °C, the amount of 5% of silica fume has significant effects on the residual compressive strength. The greatest relative residual strength losses of concrete $HPC_{2.5}$ and without silica fume were observed at 600 °C, which were 24% and 2%.

Beyond 600 °C, the concrete may lose the majority of these properties i.e there are properties that can cancel out one can say that the concrete has become weak.

When temperature increases beyond 400 °C, the concrete strength decreases more rapidly due to the degradation of calcium-silica-hydrate (C–S–H). Second phase of the C–S–H decomposes in the temperature range from 600 to 800 °C forming β-C_2S (Hager , 2013). At a temperature of 900 °C, the C–S–H breaks down completely.

Therefore, the critical temperature for concrete ranges from approximately 400 to 900 °C. In this range concrete loses most of its strength.

POROSITY

The results of the porosity for the HPC after various heat treatments ranging from 20 ° C to 900 ° C are shown in Fig. 6.

- For all high-performance concretes, a monotonic and fairly regular increase in porosity with temperature is observed.
- For CR $_{2.5}$, the porosity values are higher than that of the HPC for all the temperatures.

Between 20 and 200 °C, the porosity increases very little. The HPC shows a decrease of 0.26%. Kalifa explains that the decrease in the porosity of HPC is associated with the densification due to the complementary hydration of HSC.

Between 200 °C and 400 °C, the porosity increases by 4.5% for the HPC. This growth is associated with the discharge of water, whether present in the water network or chemically bonded. Kalifa explains that the decrease in porosity of CR between 200 °C and 300 °C compared to HPC is associated with densification due to complementary hydration and carbonation of portlandite under internal autoclaving conditions; that is to say under a pressure higher than atmospheric pressure. On the other hand, this densification is not observable in the HPC which contains very little portlandite, thanks to the presence of silica fume.

At 600 °C, the porosity value has substantially increased by 6.1% compared with that of 20 °C. For the CR $_{2.5}$ and is almost 6.33% for the HPC. The evaluation of the porosity at 900 ° C is practically impossible as the test tubes have undergone severe damage and have disintegrated.

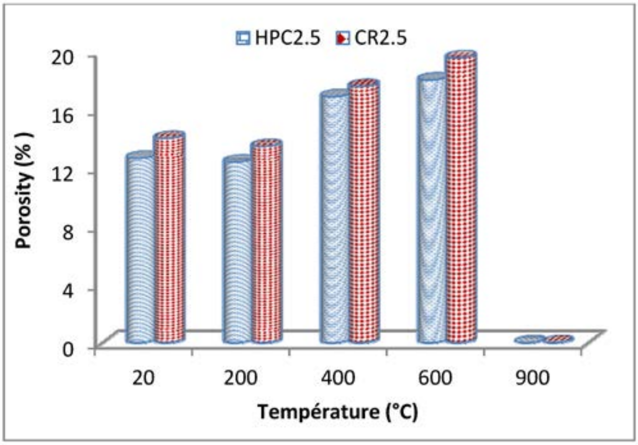

Fig. 6. Porosity as a function of temperature

Concerning the porosity of cement paste at high temperature, J. Piasta (1984) has shown that the porosity increases in a parabolic manner according to the temperature. This increase, also noted in other works by Bazant et al., is accompanied by an increase in the average pore size and total pore volume. This is due in part to the internal fracture of the CSH gel structure during the dehydration process (Bazant et al. 1996).

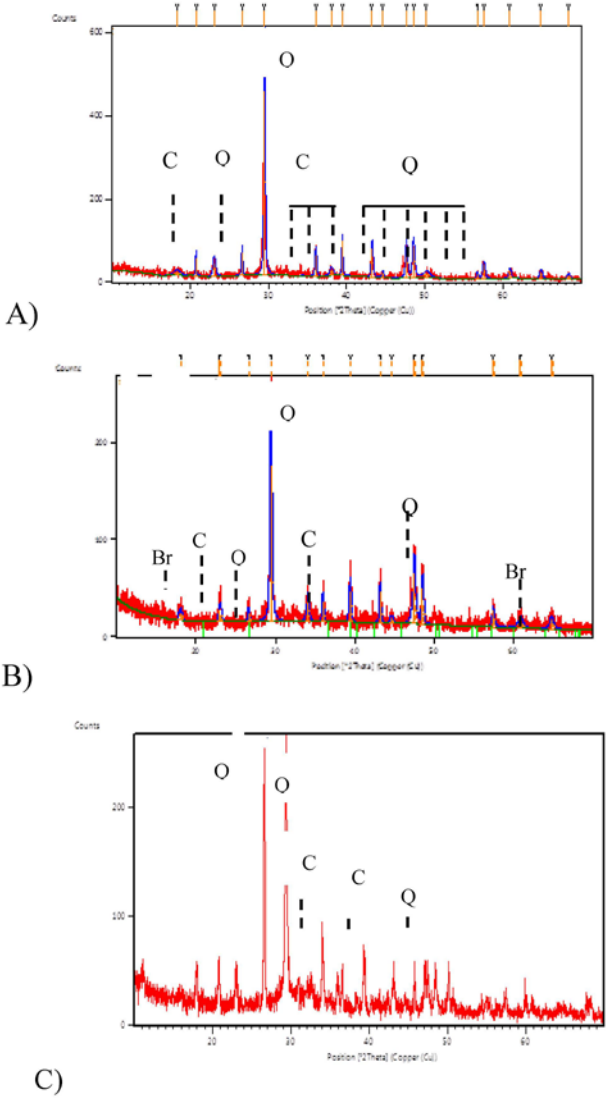

Fig .7. XRD patterns powder of HPC at: (A) 20°C, (B) 600 °C, (C) 900 °C
(Notes: C calcite, Q quartz, Br brucite)

INTERNAL STRUCTURE. ATG, AND ATD OF CONCRETE

Dehydration of the cement paste, thermal expansion and cracking, crystal processing and mineral decomposition of aggregates are important reasons for the deterioration of concrete at high temperature.

Internal structure. XRD patterns, ATG, and ATD of concrete subjected at high temperature are shown in figs 7, 8.

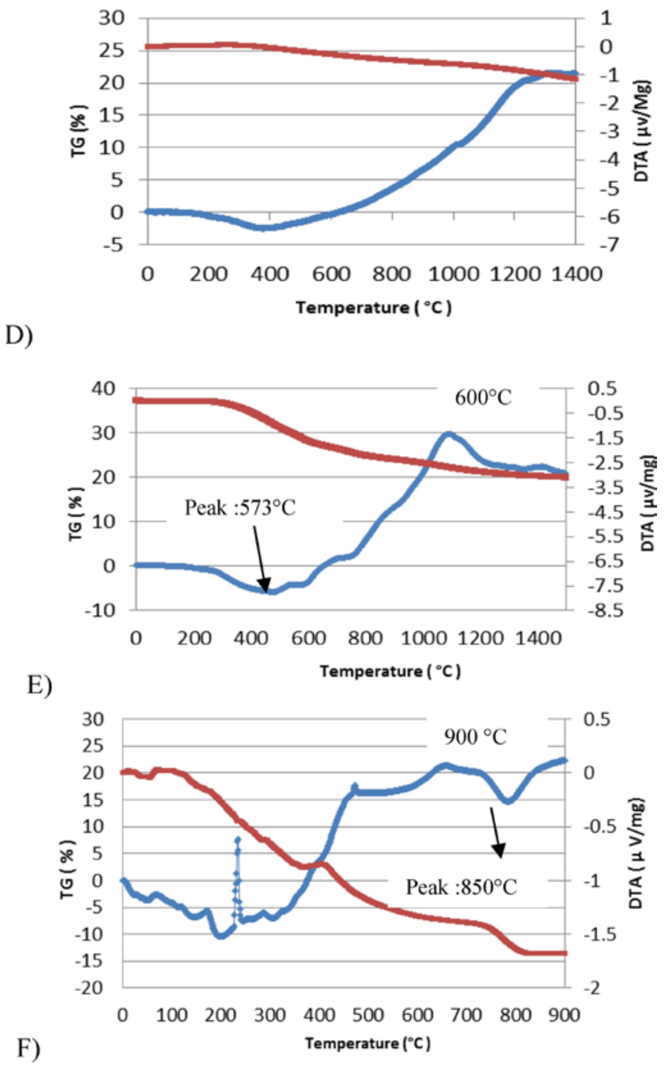

Fig. 8. ATG and ATD powder of HPC at: (D) 20 ° C, (E) 600 °C, (F) 900 °C

The analysis by X-ray diffraction is carried out in the physics Laboratory University of M’sila by an X-ray diffractometer (X’Pert) coupled to a computer system. The essential purpose of this analysis is to identify the different crystalline phases present in a sample.

The analysis of the spectrum of figure 7 is used to report the following findings:

- The presence of quartz SiO_2, confirming the presence of sand;
- The presence of calcite $CaCO_3$, obtained by carbonation of lime;
- The presence of traces of portlandite $Ca(OH)_2$.

The results of the ATG and ATD powder of HPC at 20°C, 600°C and 900 °C are shown in Fig. 8. A test sample of 200 mg of the concrete was analyzed according to linear heating from ambient temperature to 1400 ° C. with a speed of 10 ° C /min.

Six endothermic peaks were observed: 110 -130 ° C, 180 ° C, 400 ° C, and 450-550 °C, 573 ° C and 800 ° C. These thermal flux peaks are essentially related to the phase exchange temperatures of the different hydrates of the cement paste.

The double peak at 110 and 130 °C, the free water starts evaporating rapidly. In the temperature range from 80 to 150 °C, dehydration of ettringite takes place followed by the decomposition of gypsum between 150 and 170°C (Hager , 2013). In contrast, a small endothermic peak is observed at a temperature of 180 °C; this peak indicates the dehydration of the calcium monocarboaluminate hydrate (Nonnet et al., 1999).

Between 200 °C and 300 °C, a so-called “water plug” develops in concrete pores, slight variations in flux to the continuous dehydration of C-S-H (Srinivasa Reddy , 2013).

At 400 °C, a small peak was observed which we could not identify clearly phase. A similar transformation was observed by Sha et al., on cement pastes (Sha , 1999). These authors attribute this change of crystalline state or dehydration to a solid solution of Fe_2O_3. But other sources (Persy, 1986) attribute this peak to the decomposition of brucite ($Mg(OH)_2$).

Between 450°C and 550°C, the peak corresponding to the decomposition of the free limestone $Ca(OH)_2$ CaO (Platret , 2002). At 573 ° C, the allotropic transformation of the quartz-α quartz-β accompanied by a phenomenon of expansion (cracking of the siliceous aggregates) (Tufail , 2017). Between 600 °C and 700 °C, C-S-H decomposes and transforms into a new form of hydrates less rich in water and donation without it being formed of anhydrous compounds. These are mainly bi-calcium silicates B-C2S) and β-wollastonite (β-CS) (Platret , 2002).

The last peak coincides with the temperature of 800 ° C. It is well defined in that in the temperature range from 700 °C to 900 °C, The limestone decomposes, so this peak indicates the decomposition of Calcium carbonates ($CaCO_3$), also known as "calcite", by releasing Lime accompanied by a release of CO_2 (Khoury , 1992) according to the highly endothermic reaction which is as follows:

$$CaCO_3 \rightarrow CaO + CO_2$$

A quasi-linear decrease is observed up to 800 °C, the concrete exhibits a severe decrease in the density above 800 °C. This decrease in density is related to two phenomena. i.e. complete dehydration and anhydrous formation take place only at temperatures in the region of 900 °C.

CONCLUSIONS

From this study, one can conclude, that, when using HPC specimen, the speed of temperature rising, influences the drop in strength between 400 and 600 °C.

- The critical temperature, which causes maximum attenuation properties of different compressive strength, mass loss is between 400°C and 600 °C.
- Beyond 600 ° C the concrete may lose the majority of these properties i.e there are properties that can cancel out .One can say that the concrete has become weak.
- The concretes with super plasticizer are affected by high temperatures especially at 600^{O}C and above compared with less than super plasticizer dosage;
- For more resistant concrete, the addition of silica fume leads to lower resistance (24%) in the temperature range tested, between 400 and 600 °C.
- The HPC specimens containing silica fume have high compressive stress compared to HPC specimen without silica fume (CR).
- Color changes were observed on concrete under the effect of high temperature.

COMPETING INTERESTS

The authors declare that they have no competing interests.

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