The relationship between the compressive strength and ultrasonic pulse velocity concrete with fibers exposed to high temperatures

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Abstract – *The paper analyses the effects of high temperatures on the concrete residual strength using ultrasonic velocity (UPV). An experimental investigation was conducted to study the relationship between UPV residual data and compressive strength of concrete with different mixture proportions, cubic specimens with water-cement ratio of 0.35. They were heated in an electric furnace at temperatures ranging from 200°C to 600°C. In this experiment a comparison was made between the four groups which include two types of fibers steel 0,19%, 0,25% and 0,5%, polypropylene: 0,05%, 0,11% 0,16 % by volume. Cube specimens were tested in order to determine ultrasonic velocity. The compressive strength was tested too. According to the results, relations were established between ultrasonic velocity in the specimens and the compressive strength at different temperature and the range of the velocity of the waves were also determined for this kind of concrete. Result of the test showed that UPV test can be successfully used in order to verify the consistency of structures damaged by fire.*

Keywords: *Ultrasounds; non-destructive testing; concrete, fibers, temperature, steel, polypropylene.*
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I. Introduction

Concrete is a building material that finds its field of use virtually in all areas of civil engineering. That is, it includes buildings, tunnels, oil platforms, nuclear power plants and other several structures that may be exposed to high temperatures or fire. The effect of high temperatures study on concrete structures started in 1920 However, in the mid-1990s, a new interest in evaluating the performance of the concrete when it was subjected to extreme temperatures was carried out in particular after fires in different tunnels [1].

When concrete exposed to high temperatures, the chemical composition and physical structure change considerably, resulting in a significant reduction of the mechanical properties, such as strength, modulus of elasticity and volume stability[2].One of the successful techniques for detection of chemical and physical changes and damage in concrete is the use of nondestructive testing methods , The ultrasonic method is one of the nondestructive testing techniques and is frequently adopted for evaluating the quality in situ concrete structures[3,4, 5,6]. For concrete with a density of approximately 2400 kg/m3 are given as excellent, good, doubtful, poor and very poor for 4500 m/s and above, 3500–4500, 3000–3500, 2000–3000 and 2000 m/s and below UPV values, respectively According to the classification criterion for concrete based on ultrasonic pulse measurements by Whitehurst [7]. Several experimental studies had been carried out to investigate how the pulse velocity was affected by the damage of concrete caused by various high temperatures and have been made to develop the relation between the ultrasonic pulse velocity and the compressive strength at high temperature. The following equations are the most important ones established by various scientists given in table 1:

Table 1 the relationship between the compressive strength and the ultrasonic pulse velocity at high temperature established by various scientist.			
Formula	R2	The scientist	Year
(ft/ f o) = -0.07 + 3.29 (Vt/Vo) - 2.42 (Vt/Vo) 2 ft/ f o) = -0.08 + 2.15 {Vt/Vo) - 1.32 (V/Vo) 2	0.98 0.91	H.W.CHUNG [8]	1985
fc = 17,244 e0,2997v	0,8354	Suhaendi SL, Horiguchi T [9]	2006
Y= 37,43 x +3190 At 28 Days Y= 40,11 x +3093 At 90 Days	0,901 0,918	Prashant Y.Pawade [10]	2011
fc= 14,804 e0,0002UPV mesure methode direct fc= 7,5391 e0,0003UPV mesure methode semi direct fc= 6,5583 e0,0004UPV mesure methode indirect	0,63 0,70 0,68	K. PRASOPCHAICHANA [11]	2012
fc = 44,86 ln Vt +25,15 for Ordinary concrete fc = 22,09 ln Vt +15,81 for High performance concrete	0,949 0,961	Izabela Hager and Hélène Carré [12]	2012
fc = 19,034V-54,026	0,987	Olowofoyeku Adeoye M., [13]	2013

The article examines the residual compressive strength and ultrasonic pulse velocity of concrete that has been cured with water after exposure to elevated temperatures. The relationship between the residual strength ratio and the residual UPV ratio was developed. Cubic specimens were made of concrete with water-cement ratios of 0.35 after 56 days, the samples were heated in an electric furnace at temperatures ranging from 400 to 600 ° C. The speed of the ultrasonic pulse and the compressive strength of each test piece after curing of fire are measured immediately after 24 hours of cooling. The results obtained indicate that the application of UPV has demonstrated to be a trustworthy analysis, being able to prove the effectiveness of its use on fire-damaged concrete structures.

II. Experimental study

The materials used for the different concretes are:

-The cement used to make the concrete was the CPJ CEM II/A 42,5. The cement density was 3kg/dm3 and the compressive strength measured at 28 days was > 40 MPa

-Aggregates:

Crushed gravel class 8/15 mm, density was 2.61 kg/dm3

A crushed gravel class 3/8 mm, density was2.63 kg/dm3

Sand class 0/5 mm, density was 2.57 kg/dm3

- water-reducing superplasticizer named Sika Viscocrete Tempo 12.

-Steel fibers:The fibers used are SIKA FIBRE RL-45/50-BN which are made from steel wire. They have a mechanical ink consisting of hooks to the end. They were cylindrical of 50 mm length with a diameter of 1.05 mm. the tensile strength was 1000Mpa and Temperature de fusion are 1380°C

-Polypropylene fibers: Polypropylene high tenacity fibers are used for reinforcement of concretes with length 12 mm and density was 0.91 kg/dm3andTemperature de fusion are between 160 – 170 °C.

Tree groups of high strength concrete mixes were studied: The first group of concrete mixes without fibers (B), the second mixes with polypropylene fibers (BP), the third mixes with steel fibers (BM). All mixes have the same water/cement (W/C) ratio of 0.35 and the same paste volume. Three volume fractions of polypropylene fibers in the concrete were tested: 0.05, 0.11% and 0.17% (Equivalent to 0.5, 1 and 1.5kg/m^3). Three volume fractions of steel fibers were used: 0.19%, 0.25 % and 0.5 (equivalent to 15 to 19.5 and 39 kg/m^3).Of cubic specimens (10x10x10) cm were manufactured and preserved in water until 28 days after unmolding. After that they were dried in the open air (28 days) before the heat treatment. Three cycles of heating - cooling from room temperature (20°C) and up to bearing different temperatures: 200°C, 400°C and 600°C were applied to the specimens by means of an electric furnace. Each cycle consists of three phases. The first is a temperature rise at a ramp rate of 10°C/min. then constant temperature level in the oven for one hour. The mechanical properties of the specimens were determined before and after the heat treatment by conventional testing according to the standard NF EN 12390-3 [14] for the compressive strength. The mixture proportions of the different concretes are presented in Table 2.

Table 2Mix proportions

Mixture	without fibers	% steel fibers			% polypropylene fibers		
% of fibers	0	0.19	0.25	0.5	0.055	0.11	0.16
W/C	0.35	0.35	0.35	0.35	0.35	0.35	0.35
Water Kg	158	158	158	158	158	158	158
Cement Kg/m^3	450	450	450	450	450	450	450
Aggregates sizes (mm)							
8/15 mm Kg/m^3	182.91	181.91	180.91	180.91	180.66	180.26	179.16
3/8 mm Kg/m^3	1016.79	1001.79	1001.79	984.97	1016.29	1015.79	1015.29
0/5 mm Kg/m^3	585.44	585.44	581	580	585.44	585.44	585.44
Superplasticizer (% in dry extract)	1.5	1.7	1.9	2	2	2.1	2.2

III. RESULTS AND DISCUSSIONS

The results obtained in this study were presented in figures1– 6. They are evaluated and discussed below.

III.1.1. The Effect of the Steel Fibers on the compressive Strength and UPV Influenced by Temperature

For percentages of fibers 0.19 %,0.25% et 0.5% respectively, It is seen that at 200 °C the compressive strength decreased 14 % ,15 % and 3 % compared to the room temperature strength. The reduction in compressive strength for samples heated to 400 °C was 25%, to 33 % compared to the room temperature strength. After heating to 600 °C the compressive strength decreased 38%, to 44 % compared to the room temperature strength. Obviously, compressive strengths concrete deteriorates with the increasing in maximum heat temperature as shown in Figure 1.Similar behavior has already been observed in the literature [15, 16, 17, 18, 19]. The volume percentage has no efficacy after heating at 200° which is confirmed by [9]. (The fiber percentage is less than 0.5%).

It is known that concrete quality can be classified by UPV value: if the value is more than 4500 m/s, 3500–4500 m/s, 3000–3500 m/s, 2000–3000 m/s and less than 2000 m/s, the concrete is classified as ‘‘excellent’’, ‘‘good’’, ‘‘doubtful’’, ‘‘poor’’ and ‘‘very poor’’, respectively[6]. By comparing the residual UPV at different heating temperatures; It is seen UPV measurements at 200 °C is 4696.67 m/s, 4680 m/s and 4633.33m/s for percentages of fibers 0,38%,0,19% et 0.19% respectively the concrete is classified as excellent quality of concrete and at 400 ° C The (UPV) measurement are 3873.33 m/s for 0.5%, percentage of steel fibers the results obtained are considered good in-terms of quality ,the same remark for 0.25% were UPV are 3753.33 m/s were are considered good et doubtful for 0.19% where the UPV are 3260 m/s and from then temperature 600°the pulse velocity decrease there is a very significant reduction 2943.33 m / s, 2870 m / s and 2416.67 m/s are considered poor in-terms of quality..All specimens degraded from ‘‘excellent’’ to ‘‘good’’, to ‘‘doubtful’’, to ‘‘poor’’ respectively. The UPV values decreased for all mixture types after exposure to elevated temperatures as presented in figure2in accordance with other authors [5, 8, 9, 19,20,21 22,].

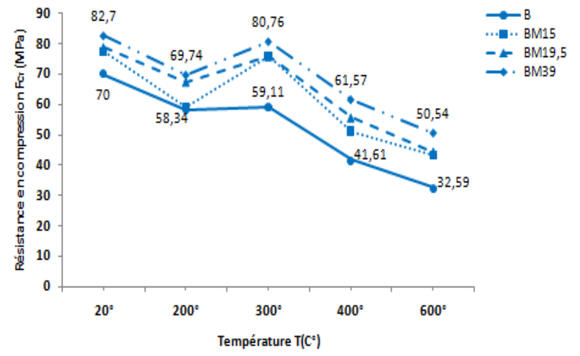

Fig. 1. Relationship between compressive strength and temperature for different percentage of steel fibers.

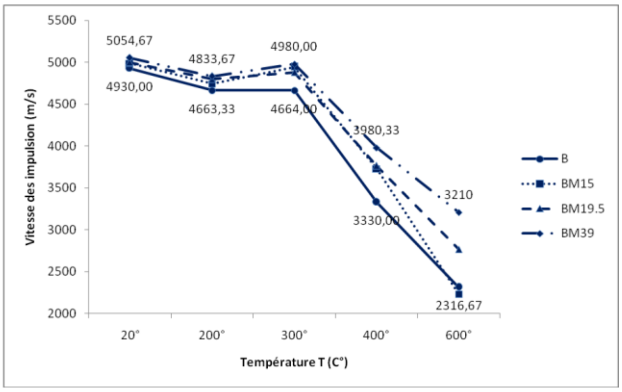

Fig. 2 The relationship between UPV (m/s) and temperature for different percentage of steel fibers

III.1.2. The Effect of the Polypropylene Fibers on the Compressive Strength and UPV Influenced by Temperature

For percentages of fibers polypropylene 0.16%, 0.11% and 0.05 % respectively; It is seen that at 200 °C the compressive strength decreased 17.15 %, 17.90% and 15.70 % compared to the room temperature strength. The reduction in compressive strength for samples heated to 400 °C was 30.45% and 32.79% and 33.55 % compared to the room temperature strength. After heating to 600 °C the compressive strength decreased 43.16%, 46.47 % and 47.70% compared to the room temperature strength. Obviously, compressive strength concrete deteriorate with the increasing in maximum heat temperature as shown in figure 3 , A similar behavior has already been observed by other scientists like Xiao [23]and others[24, 25, 26].

It is seen that UPV measurements at 200 c° is4681,55 m/s, 4653.33 m/s and 4620 m/s for percentages of fibers 0.17% , 0.11% and 0.05 % respectively the concrete is classified as excellent quality of concrete; and at 400°C The UPV measurement are 3743.33 m/s for 0.17 %, percentage of polypropylene fibers where the results obtained are considered excellent in-terms of quality , for the 0.11% and 0.05% UPV are 3393.33 m/s and 2993.33 m/s are considered good and from thence temperature 600° the pulse velocity decrease there is a very significant reduction 2666.67 m / s, 2593.33 m / s and 2286.67 m/s are considered poor in-terms of quality. The UPV values decreased for all mixture types after exposure to elevated temperatures as presented in figure 4accordance with works of [5, 8, 9, 19,20,21 22,].

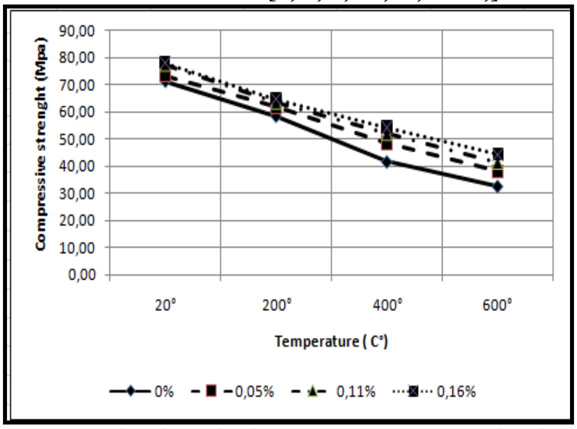

Fig. 3. The relationship between compressive strength and temperature for different percentage of polypropylene fibers.

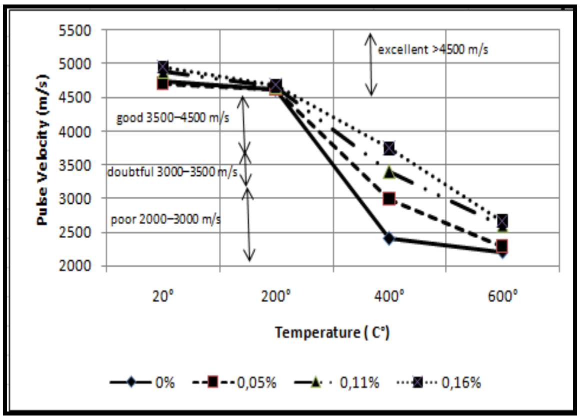

Fig.4. The relationship between UPV (m/s) et la temperature for different percentage of polypropylene fibers.

III.1.2. Relationship between ultrasonic pulse velocity UPV and Compressive Strength

Many scientists have studied how UPV can be correlated with concrete strength. According to previous research by [34] and [33], the compressive strength and ultrasonic pulse velocity UPV values are related by the following equation A (non-linear model is suggested)

$$f_c = ae^{bv} \qquad (1)$$

Where Fc is the compressive strength, Vc is the pulse velocity (km/s), a and b are empirical constants [33]

The following law relating compressive strength (f c in MPa) to UPV (Vc in m/s) for concrete with steel fibers:

$$Fc = 17{,}476e^{0{,}0003\,V} \quad \text{et } R^2 = 0{,}6739$$

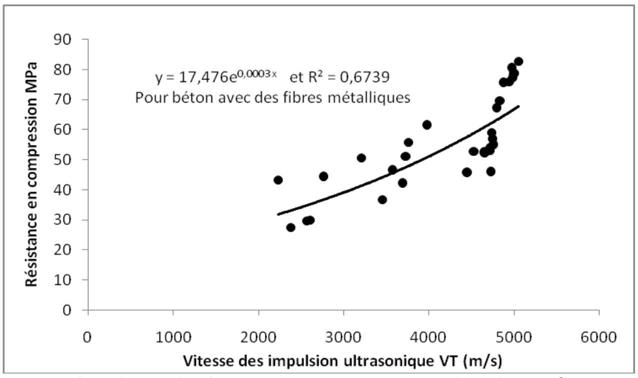

Fig.5. The relationship between compressive strength and UPV for concrete with steel fibers

The following law relating compressive strength (f c in MPa) to UPV (Vc in m/s) for concrete without fibers:

$$Fc = 8{,}5773e^{0{,}0004v} \quad \text{et } R^2 = 0{,}8419$$

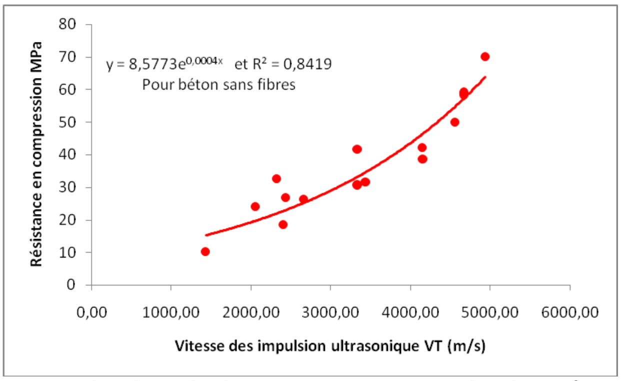

Fig.6. The relationship between compressive strength and UPV for concrete without fibers

The following law relating compressive strength (f c in MPa) to UPV (Vc in m/s) for concrete without fibers:

$$Fc = 16{,}312e^{0{,}0003v} \quad \text{et } R^2 = 0{,}8713$$

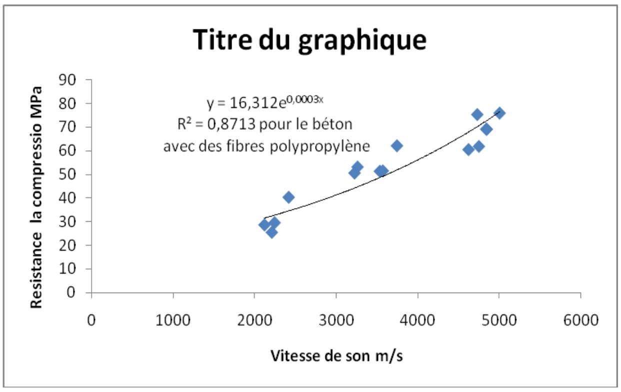

Fig.5. The relationship between compressive strength and UPV for concrete with polypropylene fibers

CONCLUSION

Based on the experimental results were noticed:

- The compressive strength and the UPV ultrasonic speed deteriorate with increasing temperature whatever the nature of the fibers.

- Analysis of local materials shows that they meet the standards for the manufacture of quality concrete.

- The steel fibers improve the compressive strength of concretes for all heating-cooling cycles. It is concluded that the incorporation of this type of fiber is advantageous in concrete that has been exposed to elevated temperatures.

- The polypropylene fibers are generally no significant influence on the improvement of the resistance to the residual compression for the concrete after high temperature heating.

- The different grades of polypropylene and metal fibers do not change the kinetics of the compressive strength loss.

- The increase of percentage of the polypropylene fibers in the concrete polypropylene fibers and metal is an adverse effect on the compressive strength.

- The feature of concrete with the mixture of polypropylene fibers and metal is closer to the concrete with metal fibers.

-An exponential relationship between UPV and compressive strength for the different concrete mix has provided an adequate approximation for comparing them with R^2 values in the range of 67 - 87%

- The results indicate that the exponential relationship provides an adequate approximation for comparing the values UPV and compressive strength.

- The constant b values in the range 0.0003 and 0.0004

- The ultrasound test is found to be an effective tool to assess the degree of damage in concrete structures exposed to high temperatures.

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