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 0,13%, 0,19 % and 0,38%, polypropylene: 0,05%, 0,11% 0,22% and mixing of fibers (polypropylene and steel) 0,18 % and 0,30% by meter cube. 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. The result of the test showed that UPV test can be successfully used in order to verify the consistency of structures damaged by fire.

Mots Clés: *Ultrasounds, Non-destructive Testing, Concrete, Fibers, Temperature, Steel, Polypropylene.*

NOMENCLATURE

Symbols :	**Subscripts**
UPV ultrasonic Pulse Velocity , Km s^{-1}	BPM concrete mixes with polypropylene and steel fibers
T temperature, K	BP concrete with polypropylene
fc compressive strength Mpa	BM concrete mixes with steel fibers
R coefficient of correlation	

1. 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. 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 [1]. 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 [2]. 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, respectivel. According to the classification criterion for concrete based on ultrasonic pulse measurements by Whitehurst [3]. 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 [4,5]. 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 400to 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.

2. EXPERIMENTAL STUDY

The materials used for the different concretes are:

- The cement used to make the concrete was the cement CPJ CEM II/A 42,5. The cement density was 3 kg/dm3 and the compressive strength measured at 28 days was > 40 MPa.
- Aggregates: Crushed gravel class 8/15 mm, density was 2.57 kg/dm3 , a crushed gravel class 3/8 mm, density was 2.73 kg/dm3 and 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/dm^{3}and Temperature de fusion are between 160 – 170 °C.

Four 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 concrete mixes with steel fibers (BM) and the forth group of concrete mixes with polypropylene and steel fibers (BPM). 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 0.16% (equivalent to 0,5 ,1 and 2 kg/m3). Three volume fractions of steel fibers were used: 0.13%, 0.19% and 0.38 (equivalent to 10 to 15 and 20 kg/m3) and two volume fractions for polypropylene fibers and metal fiber mixture tested: 0.18 and 0.30% [(0.05% + 0.13) % and (0.11% + 0.19%) equivalent to (0.5 + 10) kg/m3, and (1 + 15) kg/m3. 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 last phase is a partially controlled cooling to room temperature at an average speed of 10 ° C / min. The mechanical properties of the specimens were determined before and after the heat treatment by conventional testing according to NF EN 12390-3 [6] for the compressive strength. Obviously in table 1 the mix proportions.

Mixture	without fibers	% steel fibers			% polypropylene fibers			% steel fibers + polypropylene	
% of fibers	0	0,13	0,19	0,38	0,05	0,11	0,16	0,13+0,05	0,19+0,11
W/C	0,35	0,35	0,35	0,35	0,35	0,35	0,35	0,35	0,35
Water Kg	140	140	140	140	140	140	140	140	140
Cement Kg/m^3	400	400	400	400	400	400	400	400	400
Aggregates sizes (mm)									
8/15 mm Kg/m^3	1029,8	1029,8	1029,8	1029,8	1029,8	1029,8	1029,8	1029,8	1029,8
3/8 mm Kg/m^3	145,59	145,59	145,59	145,59	145,59	145,59	145,59	145,59	145,59
0/5 mm Kg/m^3	598,81	598,81	598,81	598,81	598,81	598,81	598,81	598,81	598,81
Superplasticizer (% in dry extract)	1,5	1,7	1,9	2	2	2.1	2.2	2,1	2,1

TABLE 1 Mix proportions

3. RESULTS

3.1. Compressive Strength and Ultrasonic Pulse Velocity UPV

The results obtained in this study were presented in figures 1– 6. They are evaluated and discussed below.

3.1.1. The Effect of the Steel Fibers on the compressive Strength and UPV Influenced by Temperature:

For percentages of fibers (0,38%,0,19% et 0,13%) respectively; It is seen that at 200 °C the compressive strength decreased 13,85 % ,13,25 % and 20,92 % compared to the room temperature strength. The reduction in compressive strength for samples heated to 400 °C was 23,95 % and 28,29 % and 31,47 % compared to the room temperature strength. After heating to 600 °C the compressive strength decreased 37,57 %, 42,67% and 41,69 % 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 [5]. The volume percentage has no efficacy after heating at 200° which is confirmed by Suhaendi and al 2006 [7] (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. 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 different % of steel fibers . The concrete is classified as excellent quality of concrete and at 400 ° C the (UPV) measurement are 3873,33 m/s for 0,38%, percentage of steel fibers the results obtained are considered good in-terms of quality , the same remark for 0,19% were UPV are 3753,33 m/s were are considered good et doubtful for 0,13% where the UPV are 3260 m/s and from thence 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 figure 2 in accordance with other authors [2,4,5,7].

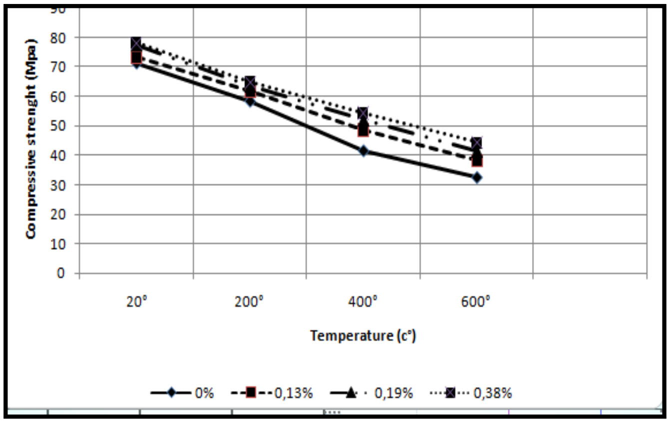


FIGURE 1. The relationship between compressive strength et la temperature for different % of steel fibers

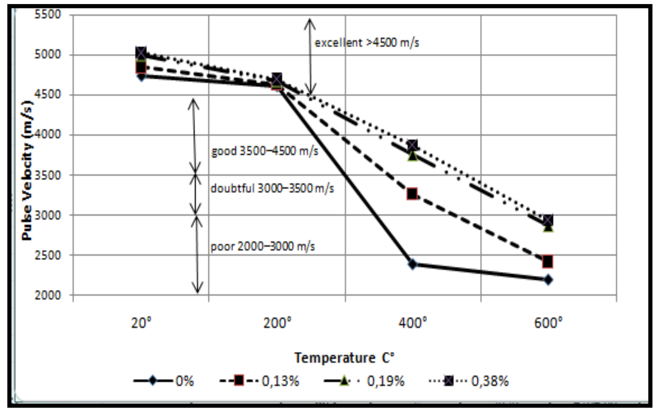
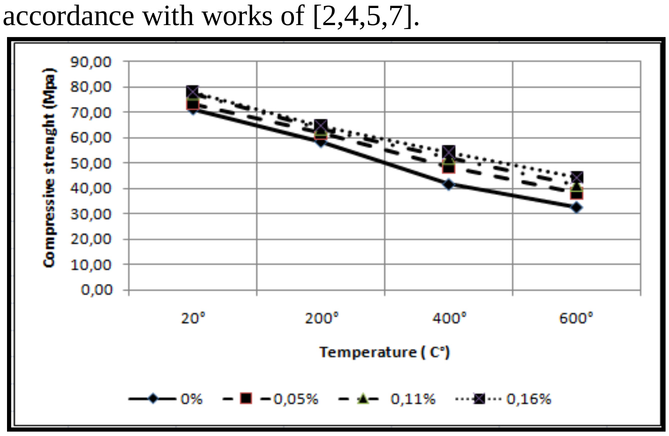


FIGURE. 2. The relationship between UPV (m/s) et la temperature for different % of steel fibers

3.1.2. 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 [9].

It is seen that UPV measurements at 200 c° is 4681,55 m/s, 4653,33 m/s and 4620 m/s for percentages of fibers 0,16% , 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 0,16 %, 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 4 accordance with works of [2,4,5,7].



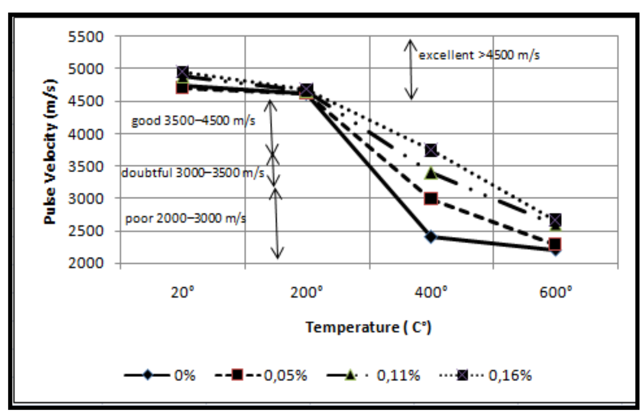


FIGURE 3. The relationship between compressive strength et la temperature for different % of polypropylene fibers

FIGURE. 4. The relationship between UPV (m/s) etla temperature for different % of polypropylene fibers

3.1.3. The Effect Mixing Steel Fibers + Polypropylene on the Compressive Strength and UPV Influenced by Temperature

Figure 5 shows the results obtained from the compressive strength tests of concrete with mixing (0,13 %, 0,19 %) steel fibers and (0,05 %, 0,11 %) polypropylene fibers specimens subjected to different high temperatures, it is shown that the residual compressive strength of the heated specimens decreases with an increasing temperature. It is seen for percentage (0,13+0,05) % and (0,19+0,11) % respectively that at 200°C the compressive strength decreased 22,63 %, and 19,28% compared to the room temperature strength. The reduction in compressive strength for samples heated to 400 °C was 30 %, and 39,35% compared to the room temperature strength. After heating to 600 °C the compressive strength decreased 42,63 % , and 46,19 % compared to the room temperature strength. There is a light compression strength gains compared to concrete without the fiber is notable gains beyond the temperature 200°c [10]. They explain that the inclusions of steel fibers which do not melt at high temperature, improves the resistance of the high performance concretes, creating bonds of bridges in the matrix. In contrast, the polypropylene fibers melt and leave channels conducive to the discharge of water to the outside [5] have also studied the influence of fibers polypropylene and steel) .The same authors also observed a decrease in mechanical properties of the concrete, and underline the fact that the decrease in mechanical properties of concrete containers polypropylene fibers is proportional to the volume of fibers introduced.

It can be seen that the influence for percentages of fibers (0,13+0,05) % and (0,19+0,11) % respectively; It is seen UPV measurements at 200 °C is 4693,33 m/s, 4510 m/s is classified as excellent quality of concrete above at 400°C, The UPV measurement are 3656 m/s for (0,13+0,05) %, percentage of mixing steel fibers and polypropylene fibers the results obtained are considered good in-terms of quality , for (0,19+0,11) % UPV are 2650,33 m/s m/s were are considered poor and beyond this temperature the quality of concrete decrease at temperature 600° there is a major reduction 2510,66 m/s ,2367,66 m/s are considered poor in-terms of quality. It is generally understood that this reduction in the change of velocity is due to the deterioration of the microstructure of the concrete exposed to high temperature. R.Demirbog [11] attributed this type of change to degradation of the C-S-H gel at temperature above 450C which increases the amount of air voids in the concrete decreasing the transmission speed of sound waves through the test specimens. The pulse velocity UPV reduces almost proportionally with the increase in maximum heating temperature.

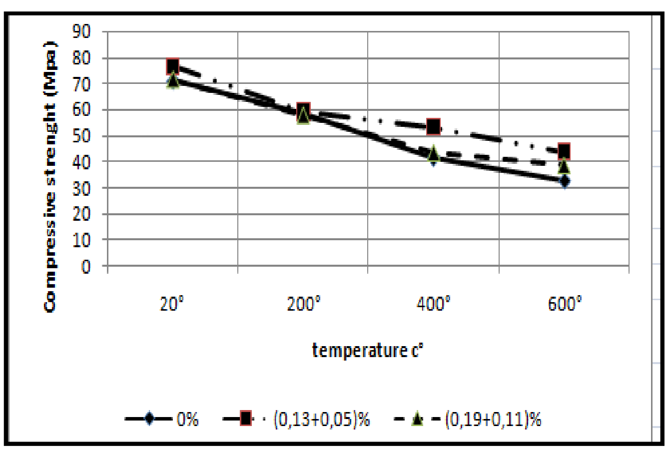


FIGURE 5. The relationship between compressive strength et

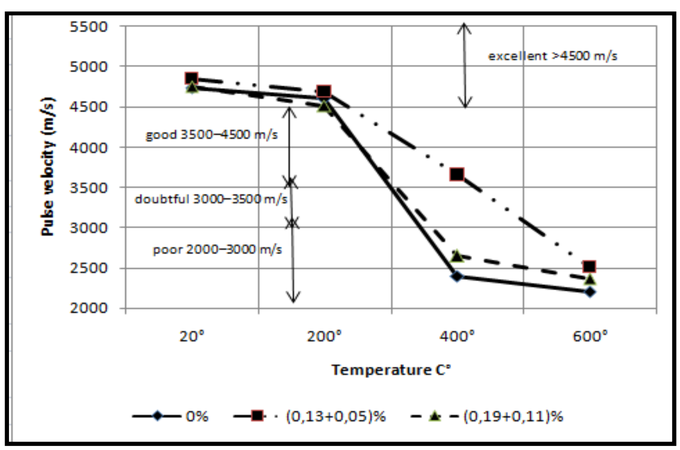


FIGURE. 6. The relationship between UPV (m/s) and the la

la temperature For different % of mixing steel fibers + polypropylene

temperature for different % of mixing steel fibers + polypropylene

3.2. 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 Tharmaratnam [12]. The compressive strength and ultrasonic pulse velocity UPV values are related by the following equation A (non-linear model is suggested)

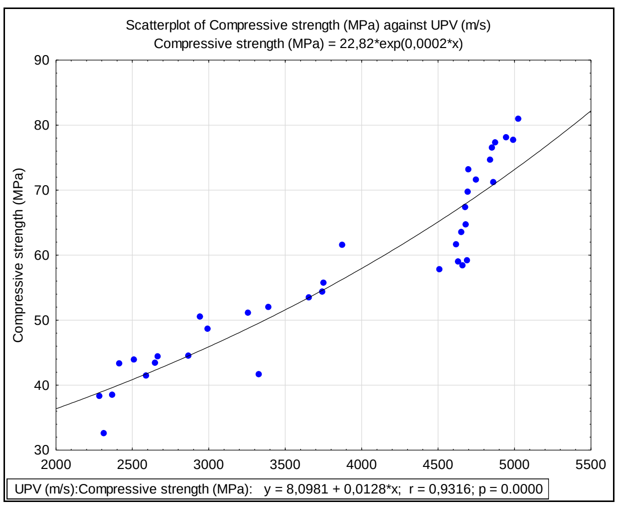
$$\boldsymbol{f_c = ae^{bV_c}} \qquad \textbf{(1)}$$

Where F_c is the compressive strength, V_c is the pulse velocity (km/s), a and b are empirical constants.

For all results, we found the following law relating compressive strength (f c in MPa) to UPV (Vc in m/s):

$f_c = 22{,}82\ e^{0{,}00023V_c}$ R^2=0.88 all the grouped results **(2)**

There was a acceptable exponential relationship between UPV and compressive strength. Because R^2=.86, we can say that 86% of the variation in the values of compressive strength is accounted for by exponential relationship with UPV (see Figure 7)



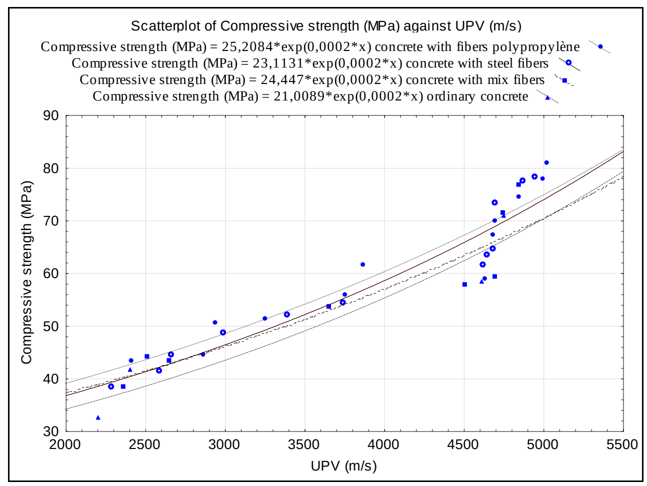


FIGURE.7. The relationship between compressive strength and UPV for all the grouped results UPV

FIGURE 8.the relationship between compressive strength and for Different type of fibers used in this study

Show in figure 8 the relationship between compressive strength and UPV for Different type of fibers used in this study, and we found the below models respectively:

$f_c = 25,2084e^{0{,}0002V_c}$ R^2= 0,91 For concrete with polypropylene fibers (3)
$f_c = 23{,}1131e^{0{,}0002V_c}$ R^2= 0,88 For concrete with steel fibers (4)
$f_c = 24{,}447e^{0{,}0002V_c}$ R^2= 0,85 For concrete mixing of steel fibers + polypropylene (5)
$f_c = 21{,}0089e^{0{,}0002V_c}$ R^2= 0,86 For ordinary concrete (6)

These results are also indicated the presence of a relatively good correlation also between the strength and UPV where the coefficients R^2 were 0,90 and 0,88 and 0,85 and 0,90, respectively.

4. CONCLUSIONS

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. And who can face in case of fire.

- An exponential relationship between UPV and compressive strength for the different concrete mix has provided an adequate approximation for comparing them with R2 values in the range of 85 - 91%

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

- It can be noted also from the equations found that their constant b is fixed and constant a varied between 21,0089 et 25,2084

- 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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