EVALUATION OF THE RELATIONSHIP BETWEEN COMPRESSIVE STRENGTH AND UPV OF HSC EXPOSED TO HIGH TEMPERATURES

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Abstract:

An experimental program was adopted in this study to investigate the degree of dependency on the using of ultrasonic pulse velocity (UPV) to evaluate the residual strength of concrete exposed to high temperatures as in the case of fires. This experimental program focus on the relationship between compressive strength and UPV of high strength concrete (HSC) after high temperature exposure. The tests were carried out using 100mm cubes. Three concrete mixes were used with target compressive strengths of 40 MPa, 60 MPa and 80 MPa. Totally fifty four concrete cubes were tested in this study. The specimens were divided into three groups according to their original compressive strength. Four temperature levels of 150^{o}C, 350^{o}C, 500^{o}C and 700^{o}C were adopted. Three specimens from each group were heated to each temperature level, cooled and then tested. While, six specimens from each group were tested as reference specimens without heating. The test results show that both concrete compressive strength and UPV decreased after high temperature exposure. Another observation is that at temperatures (150^{o}C and 350^{o}C), the normal strength concrete (NSC) suffered higher percentage loss in strength than HSC, while the opposite stands at 700^{o}C. Also it is observed that the UPV showed higher percentage loss than in compressive strength for both NSC and HSC at temperatures of 350^{o}C and higher. Finally, it was found that the UPV-temperature behavior differs than the compressive strength-temperature behavior.

KEYWORDS: Concrete, high strength concrete, elevated temperatures, nondestructive, ultrasonic pulse velocity.

تقييم العلاقة بين مقاومة الانضغاط والموجات فوق الصوتيه للخرسانة عالية الأداء المعرضة لدرجات حرارة عالية

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الخلاصة:

في هذا البحث تم دراسة العلاقة بين كل من مقاومة الانضغاط و سرعة الأمواج فوق الصوتية من جهة، ودرجات الحرارة العالية من جهة أخرى للخرسانة عالية المقاومة دراسة عملية للتحري عن درجة الاعتمادية على استخدام سرعة الأمواج فوق الصوتية لتقييم مقدار المقاومة المتبقة للخرسانة بعد التعرض الى درجات الحرارة العالية كما في حالة الحرائق. نفذت الفحوصات باستخدام نماذج خرسانية مكعبة بقياس ١٠٠ ملم، كما تم اعتماد ثلاثة خلطات خرسانية بمقاومة تصميمية تساوي (٤٠، ٦٠ و ٨٠ نيوتن/ملم^{٢}). عدد المكعبات الكلي المستخدم في البحث يساوي ٥٤ مكعباً، تم تقسيمها الى ثلاثة مجاميع اعتماداً على المقاومة التصميمية. كما تم اعتماد أربعة مستويات لدرجة الحرارة وهي (١٥٠، ٣٥٠، ٥٠٠ و ٧٠٠ درجة مئوية). عرضت ثلاثة نماذج من كل مجموعة لكل درجة حرارة ومن ثم بردت الى درجة حرارة الغرفة وبعد ذلك تم فحصها. بينما تم فحص ستة مكعبات من كل مجموعة في درجة حرارة الغرفة كنماذج مرجعية دون تعريضها الى الحرارة العالية. أظهرت النتائج أن مقاومة الانضغاط وكذلك سرعة الأمواج فوق الصوتية تنقصان بعد التعرض الى الحرارة العالية. كما لوحظ أن الخرسانة ذات المقاومة الاعتيادية تخسر نسبة أعلى من تلك ذات المقاومة العالية بين (١٥٠ و ٣٥٠ درجة مئوية) بينما يحدث العكس بعد التعرض الى ٧٠٠ درجة مئوية. كما لوحظ أن سرعة الأمواج فوق الصوتية تعاني من نقص أكبر مما تعانيه مقاومة الانضغاط عند التعرض الى درجات حرارة مساوية الى أو تزيد عن ٣٥٠ درجة مئوية وذلك لكل من الخرسانة الاعتيادية المقاومة والخرسانة عالية المقاومة. وأخيراً، لوحظ أن العلاقة بين سرعة الأمواج فوق الصوتية مع الحرارة تختلف عن علاقة مقاومة الانضغاط مع الحرارة.

Introduction:

The assessing of concrete strength in existing structures by ultrasonic pulse velocity (UPV) nondestructive test is of considerable interest in the field of civil engineering. UPV and other nondestructive test methods measure some others properties of concrete than its mechanical strength. However, the evaluation of in-situ concrete strength is carried out by means of an established correlations of these properties with strength. Therefore, the reliability of assessing the concrete strength primarily depends upon the precision of the established calibration. The relationship between UPV and concrete strength is generally not unique. This arises from the diversity in the existing relations between the measured characteristic and the factors making up concrete strength, among others: cement contents, type of aggregates, bond between cement paste and aggregates and water cement ratio.

On the other hand, exposing of concrete structures to high temperatures as in the case of accidental fires deteriorates the concrete mechanical properties. The degree of deterioration depends on many factors such as concrete composition and the type of the induced stresses in each test. Many previous studies showed that after high temperature exposure, the behavior of compressive strength differs from other mechanical properties such as splitting tensile strength and modulus of rupture. Also, it was found that its behavior differs from the behavior of some nondestructive tests such as rebound number and UPV. The aim of this paper is to study the behavior of both concrete compressive strength and ultrasonic pulse velocity of high strength concrete (HSC) and to evaluate the relationship between them after exposure to elevated temperatures.

Experimental Program:

Fifty four concrete cubes were used to investigate the effect of high temperatures on both concrete compressive strength and ultrasonic pulse velocity (UPV) and to evaluate the relationship between these two properties after high temperature exposure. The cubes were 100mm in size and were divided into three groups A, B and C depending on their target compressive strength. Three concrete mixes with three different target compressive strengths of (40, 60 and 80 MPa) were used in this study. **Table 1** summarize the mix proportions of the three groups. The maximum size of coarse aggregate was 9.5mm as recommended by ACI 363R-92 (1). After de-molding, the specimens were cured for about 21 days in water containers, the water temperature in the containers ranged from 20 oC to 30 oC. The curing was initiated when the concrete surface begins to dry as recommended by ACI 308R-01 (2). After curing, the specimens were removed from the water containers and were dried in the laboratory environment for a bout 7 days until the time of heating at age of twenty eight days. Each group consisted of eighteen specimens. Six specimens from each group were tested at room temperature as reference specimens. While the rest twelve specimens from each group were heated to different levels of temperature using electrical furnace at a constant rate of (2 oC/min) to avoid explosive spalling of specimens. Three specimens from each group were heated to each temperature level. The adopted temperature levels were (150, 350, 500 and 700oC). After heating to each particular temperature, the specimens were air cooled in the laboratory environment for about 20 hours. Then after, the specimens were tested nondestructively using UPV test and destructively using 3000 kN capacity hydraulic testing machine, respectively.

Results And Discussion:

The results of compressive strength and UPV both before and after exposure to high temperatures for the fifty four cubes are represented in this section.

Compressive Strength:

Figure 1 shows the residual compressive strength of groups A, B and C. The original strength of the three groups were (41.3, 57.8 and 76.6 MPa) respectively. After exposure to the whole range of the studied temperatures, the residual compressive strength was lower than the original compressive strength.

At temperature 150 ^{o}C, the residual strength of group A was about 35.5 MPa. While the residual strengths for groups (B and C) were about (50.9 and 73.9 MPa) respectively. **Figure 2** shows that the percentage loss in strength still lower than 15% for all groups at 150 ^{o}C. It is noticed that the lower strength specimens suffered higher percentage loss in strength than the higher strength specimens. At temperature 350^{o}C, the compressive strength of the lower strength concrete cubes (Group A and B) were higher than at temperature 150^{o}C. The percentage residual strengths of

groups A and B at temperature 350°C were 87.4 % and 90 % compared to 85.9 % and 88 % respectively at temperature 150°C. While for higher strength cubes of group C, the compressive strength suffered further decrease at temperature 350°C. This behavior was noticed in many previous studied for normal strength concrete [3, 4, 5] and high strength concrete [6, 7].It is shown in **Figure 2** that at temperature 500°C, the percentage residual compressive strength for the three groups was in the range of (60% to 63%). However at temperature 700°C, the higher strength concrete lost higher percentages than lower strength concretes. Where the percentage residual strengths at temperature 700°C for groups A, B and C were about (34%, 32% and 29%) respectively.

Ultrasonic Pulse Velocity (UPV):

Ultrasonic pulse velocity was recorded for all cubes before testing under the compression machine. At least, three readings of UPV were recorded for each cube. Each point in the curves represents the average reading of at least three cubes. The ultrasonic pulse velocites of the original specimens of group A, B and C were (4.45, 4.72 and 4.88 km/sec) respectively.

Figure 3 shows the relationship between UPV and temperature for the three groups. From the observation of Figure **3**, it is obvious that UPV suffered continuous decrease as temperature increase both for normal and high strength concrete. Similar sequence of reduction was observed in many previous studies [4, 5, 6]. Another notice is that up to temperature 500°C, the UPV values of the higher strength specimens still higher the those of lower strength specimens. While at temperature 700°C, group B specimens retained lower UPV values than those of lower strength specimens (group A). **Figure 4** shows the residual UPV values at all the studied temperatures as a percentage ratio of the original UPV values. As shown in **Figure 4**, the percentage loss at temperature 150°C was almost the same for the three groups and was about 6%. While at 350°C, the percentage residual velocities were (62.7%, 73.7% and 75.6%) for group A, B and C respectively. Similar sequence of reduction was recorded at temperature 500 °C. Thus, between 350 °C and 500 °C, the lower strength specimens show higher loss percentages in UPV than the higher strength specimens.

Comparison between The Versus Temperature Behavior of UPV and Compressive Strength:

Figure 5, **Figure 6** and **Figure 7** show a comparison between the behavior of concrete compressive strength and UPV after exposure to temperatures up to 700°C. The comparison is in the means of percentage residual strength and UPV versus temperature for each group.

From the observation of **Figure 5** and **Figure 6** it can be noticed that the behavior of residual UPV differs from that of compressive strength, especially at the region between room temperature and 500°, where the compressive strength shows three different steps. The residual compressive strength decreased at temperature 150°C composing a descending line between room temperature to 150°C. Higher percentage residual strength is then retained at temperature 350°C

forming an ascending line between 150°C and 350°C. Then after, a second region of strength drop is noticed between 350 °C and 500 °C. On the other hand, the UPV curves show continuous decrease in strength as temperature increase and no such different regions can be recognized in the UPV-temperature curves. In **Figure 7**, it is noticed that the behavior of compressive strength-temperature curve of group C specimens is somewhat differs than for groups A and B. Where, the residual strength at temperature 350°C still lower than at temperature 150°C. However, the slope of the curve at this region is not sharp and can be considered as semi-flat as compared to the slope of the curve between 350°C and 700°C. Thus it can be concluded that UPV and compressive strength have different behaviors when concrete is exposed to elevated temperatures. Another difference between UPV and compressive strength-temperature curves is that the percentage loss is higher for UPV as temperature increase beyond 150°C which leads to another conclusion that for both normal strength (NSC) and high strength (HSC) concretes, the evaluation of compressive strength of concrete exposed to high temperatures using UPV-strength correlations made from unheated specimens is conservative beyond 150 °C.

Cnclusions:

Within the limits of the studied range of variables and depending on the experimental results of this study, the following conclusions were obtained:

1- Ultrasonic pulse velocity and compressive strength for both NSC and HSC decreases after high temperature exposure.

2- Ultrasonic pulse velocity and concrete compressive strength exhibit different behaviors after exposure to high temperatures.

3- UPV suffers higher percentage loss as compared to compressive strength between 350°C and 700°C. For concrete with original target strength of (40, 60 and 80 MPa), the percentage residual strength at 350°C was in the range of (87% to 90%), while the percentage residual UPV at the same temperature was in the range of (62 % and 75 %).

4- Depending on the previous conclusion, it can be concluded that the using of UPV-compressive strength correlations made from unheated specimens to evaluate the compressive strength of concrete exposed to high temperatures gives conservative estimations beyond 150 °C.

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Table (1): Mix proportions.

Group Notation	Cement kg/m^3	Fine Aggregate kg/m^3	Coarse Aggregate kg/m^3	Water kg/m^3	W/C	Super Plasticizer	Target Strength *MPa*
A	360	717	1147	162	0.45	0%	40
B	490	669	1065	162	0.33	1.5%	60
C	570	645	1040	162	0.28	3%	80

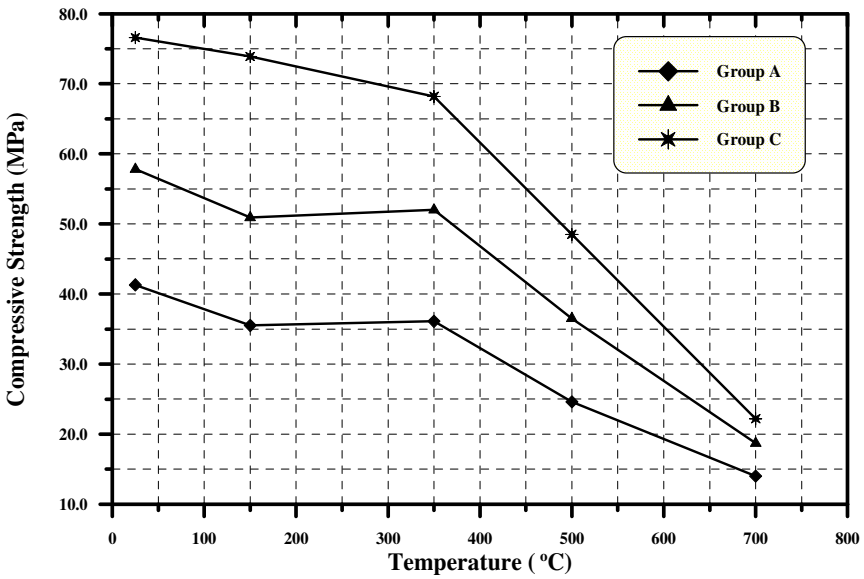

Figure 1: Compressive strength-temperature relationship.

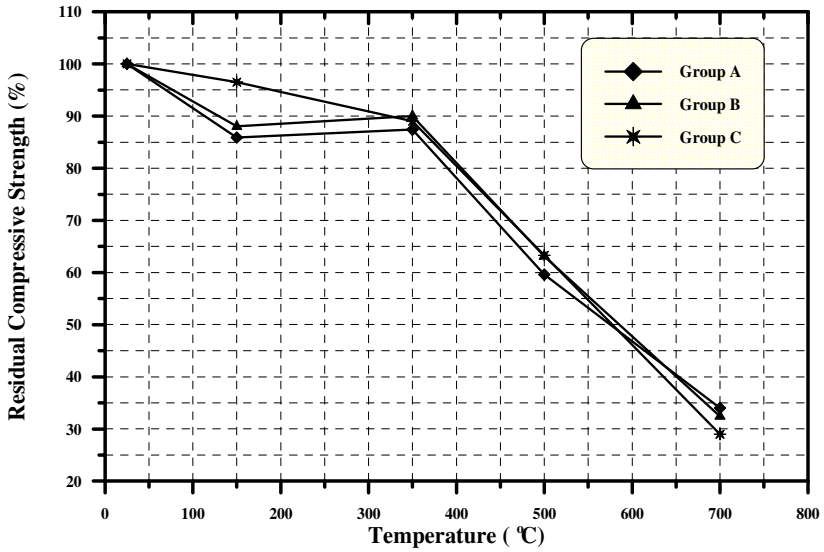

Figure 2: Percentage residual concrete compressive strength.

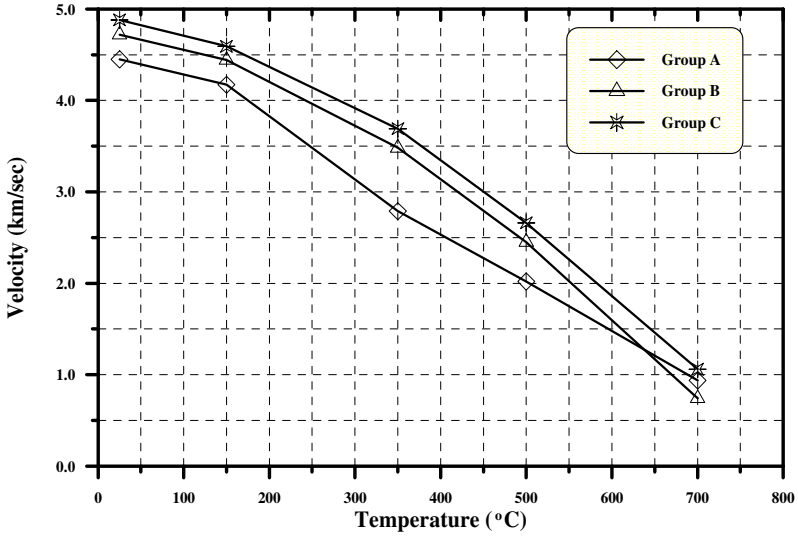

Figure 3: UPV-temperature relationship.

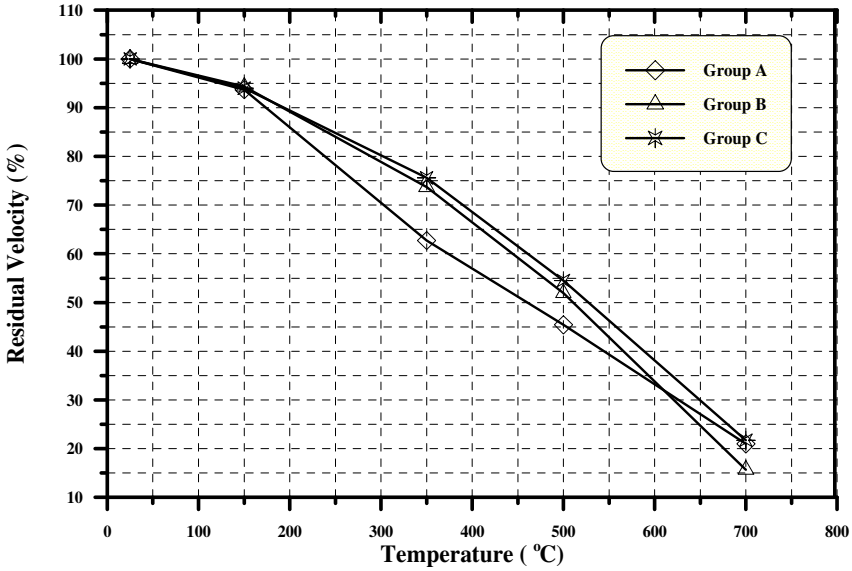

Figure 4: Percentage residual UPV.

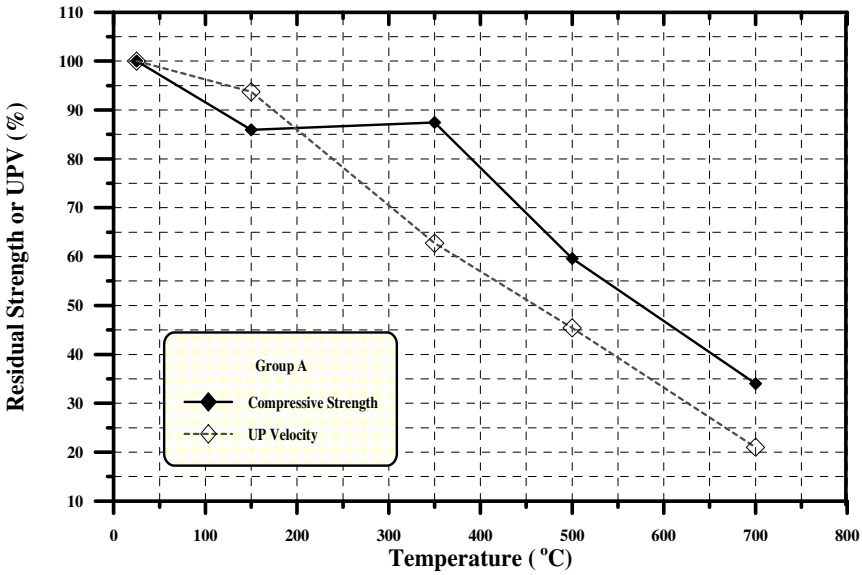

Figure 5: Compressive strength and UPV-temperature relationship of group A.

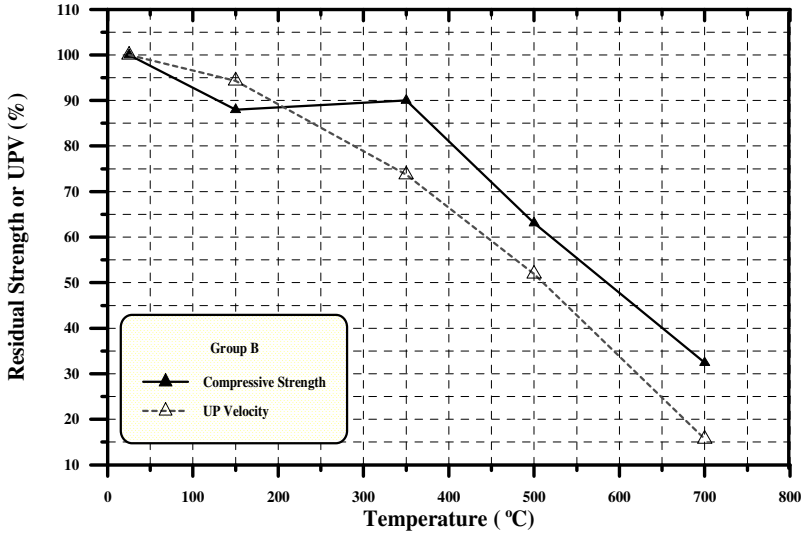

Figure 6: Compressive strength and UPV-temperature relationship of group B.

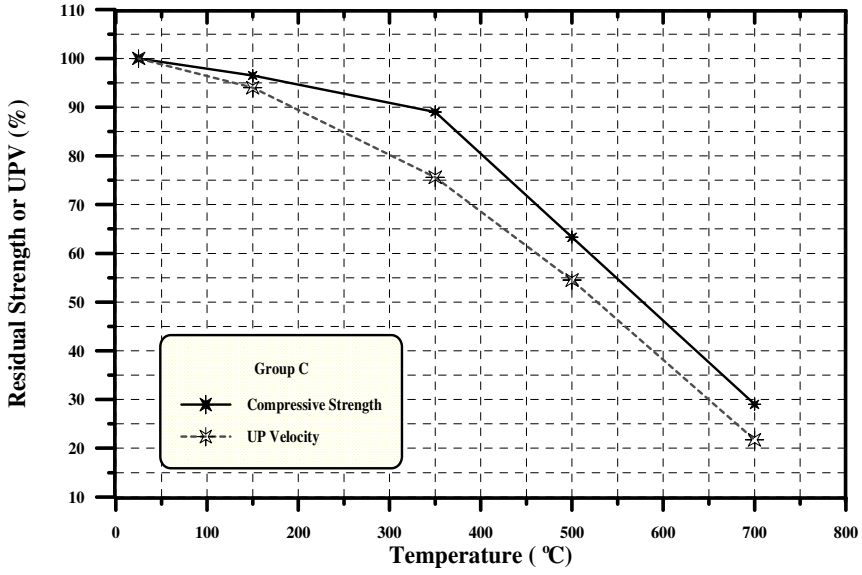

Figure. 7: Compressive strength and UPV-temperature relationship of group C.