

Effect of Addition of Steel Fiber on the Compressive Strength of Composite Concrete Materials under High Temperatures (Experimental & Statistical Work)

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Abstract

This study presents the benefit gained from using steel fiber reinforcement on concrete mixture. The effect of fire on compressive strength is investigated. Two different tests, one of them is the non destructive test which is the ultrasonic pulse velocity (UPV) test and the other is the destructive compression test, are carried out using (10cm) cubs.

Forty-eight cubes (half of them are with steel fiber reinforcement of fiber/concrete ratio of (0.01) by volume and the remaining cubes are without fiber reinforcement) are heated to temperature levels of (100,200,300,400,500,600 and 700°C). Then after specimens are air cooled and (UPV) test is done, the specimens are destructively tested.

The results indicated that the addition of steel fiber increases the compressive strength at all tested heating levels with a maximum percentage increase of (56.9%) at temperature level (500°C) in spite of that they have the same behavior but the residual compressive strength decreases with the addition of steel fiber for the tested heating levels lower than (400°C) and increases for the heating levels above this degree. Statistical analysis are done to find mathematical relationships to predict some variables of fibrous reinforced

الخلاصة

الدراسة الحالية تتسلط الضوء على الفائدة الحاصلة من استعمال تسليح الألياف الفولاذية في تكنولوجيا الخرسانة حيث بحث تأثير الحرارة على مقاومة انضغاطها. اجري نوعان من الفحص احدهما لاتلافي وهو فحص سرعة الأمواج فوق الصوتية (UPV) والأخر لاتلافي باستعمال نماذج مكعبة بطول ضلع (10 cm). تم تسخين (48) نموذج (نصفها مقواة بألياف الفولاذ بنسبة حجمية للألياف الفولاذية إلى الخرسانة مقدارها (0.01) والنماذج الأخرى المتبقية غير مقواة) إلى مستويات من درجات الحرارة هي (100,200,300,400,500,600, and 700) درجة سيليزية. فحصت النماذج لا اتلافيا بعد تبريدها بتعريضها للهواء ثم فحصت اتلافيا. بينت النتائج ان إضافة الألياف الفولاذية يزيد من مقاومة الانضغاط في كل مستويات درجات الحرارة التي قيست فيها بأعلى نسبة زيادة مقدارها (56.9%) من تلك غير المقواة عند درجة حرارة (500) درجة سيليزية بالرغم من ان لهما نفس السلوك ولكن نسبة ما تبقى من المقاومة بعد الحرق من المقاومة الأصلية يقل بإضافة الألياف الفولاذية عند كل مستويات درجات الحرارة الأقل من (400) درجة سيليزية لكنها تزداد بعد تلك الدرجة. اجري تحليل إحصائي للنتائج لإيجاد علاقات رياضية تربط عدة متغيرات للخرسانة المقواة بالألياف بتلك غير المقواة.

1. Introduction

The fibrous reinforced concrete is a composite materials essentially consisting of concrete reinforced by random placement of short discontinuous, and discrete fine fibers of

specific geometry ^[1-4]. When concrete members including that reinforced by fibers are exposed to high temperatures as in the case of accidental fires, the material properties and consequently the structural behavior could be damaged. The degree of damage depends on several factors, such as the temperature level to which concrete is exposed and exposure duration ^[5]. In some cases the building members deteriorate to such a limit, at which reconstruction becomes the only available choice. In other cases only repairing is needed. The decision of reconstruction or repairing depends on the evaluation of the adequacy of structural members after high temperature exposure, which needs an accurate assessment to the residual compressive strength. The prediction of the residual concrete strength can be done by many ways such as the destructive and non destructive tests. Another way of prediction can be done by finding general statistical relationships between the results of those tests.

In this work, an experimental program is directed to study the residual fibrous concrete compressive strength after exposure to high temperatures up to (700°C), using cubical samples. Non destructive test (UPV) is taken to the same samples. Also, statistical analysis to the experimental results to predict the fibrous concrete compressive strength mathematically is made. The aim of this work is to provide an understanding to the behavior of the steel fibrous reinforced concrete when exposed to high temperature.

2. Experimental Program

In the experimental work, forty-eight concrete cubes of (10x10x10 cm) are used to carry out the non destructive test (UPV) and the destructive concrete compressive strength. A single dry concrete mix of (1:1.7:2) (cement: fine aggregate: coarse aggregate) in proportion by weight is used. The cement content is (463 kg/m³). Steel fibers, of specifications given in **Table (1)** as supplied by manufacturer, added with a steel fiber/concrete ratio of (0.01) by volume.

Table (1) Steel fiber specifications

Fiber Type	Density (kg/m³)	Ultimate tensile strength (MPa)	Modulus of Elasticity (MPa)	Poisson's ratio	Length (mm)	Nominal diameter (mm)	Aspect ratio
Hooked Steel Fibers	7860	1130	200000	0.28	25	0.2	125

The water/cement ratio used for both groups is (0.45) by weight and the slump of the mix is medium. The specimens are divided into two groups, each group consist of twenty-four cubes. Group (A) specimens are cast with the addition of steel fiber with the percentage

mentioned above, while group (B) specimens are cast without fiber reinforcement. The cubes are heated to seven temperature levels of (100,200,300,400,500,600 and 700°C). Three cubes of each group are heated to each temperature level, and three cubes from each group are tested at room temperature as reference specimens.

Ordinary Portland cement (type I), which is manufactured in (Kubaisa) factory according to Iraqi Standards (1QS 5:1984) is used. Fine aggregate from Rahhalia (Anbar) region, and crushed river gravel from (Al-Niba'ai) region with maximum size of 10 mm are used.

After about 24 hours from casting time, the specimens are stripped from their moulds, and placed in water containers to be cured for 28 days. Then after, the specimens are stripped out from the water containers, and are left in the laboratory environment for 24 hours to be dried then tests are carried out.

The heating process is carried out using electrical furnace. The specimens are heated slowly at a constant rate of (2 °C/min) to avoid steep thermal gradient [6]. Once the required temperature level is attained the specimens are saturated thermally at that level for one hour. The specimens are then air cooled until testing.

At the time of testing, non destructive test is taken to the specimens using the (UPV). The (UPV) test is made on three places (two of them parallel to the direction of compacted layers and the other normal to it). After carrying out the non destructive test, the concrete compressive strength for each cube is tested (destructively).

3. Results and Discussion

3-1 Concrete Compressive Strength

The results of the experimental work are represented in Fig.(1) and Fig.(2). Figure (1) shows the residual compressive strength-temperature relationship for the two groups of specimens, while the percentage residual compressive strength-temperature relationship is shown in Fig.(2).

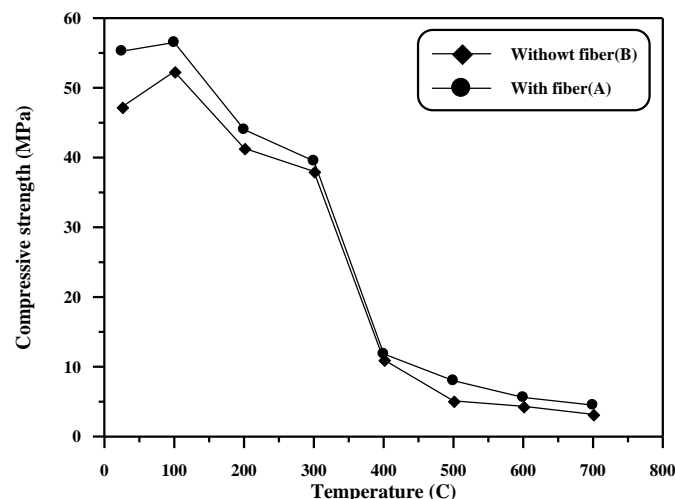


Figure (1) Compressive strength-temperature relationship for fibrous and non fibrous concrete

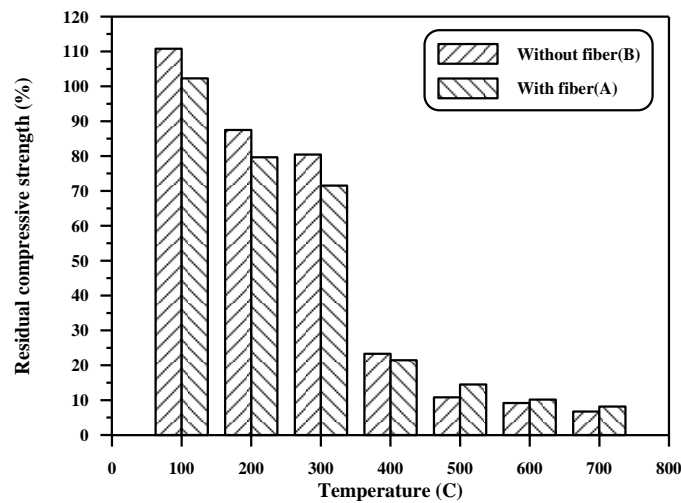


Figure (2) Residual compressive strength-temperature relationship for fibrous and non fibrous concrete

From the observation of the mentioned figures it can be noticed that concrete compressive strength suffers a noticeable deterioration when exposed to high temperatures. The compressive strength-temperature relationship of fibrous concrete simulates that of non fibrous concrete, but with slightly higher values. This is an expected result, since exposing to elevated temperatures makes a lot of physical and chemical changes in concrete, [7]. When temperature reaches about 300°C interlayer C-S-H water and some of chemically combined water from the C-S-H and sulfoaluminate hydrates would be lost. At about 500°C, further dehydration of cement paste due to decomposition of $(Ca(OH)_2)$ begins. In addition, the paste tries to shrink as the adsorbed, capillary and hydration water are driven out, whereas, the aggregate tends to expand while the paste is shrinking. Such behavior lead to micro-cracking in the transition zone and growth of the cracks that are formed previously either in the earlier stages of heating or cracks that exist before heating (drying shrinkage cracks), and consequently leads to deterioration of concrete strength. The steel fibers in fibrous concrete give slight resistance to the growing of these cracks.

3-1-1 Effect of Original Strength

Figure (1) shows a comparison between concrete compressive strength temperature relationships for the two groups of specimens which are related to the presence of steel fiber reinforcement and have original concrete compressive strength of about (55.25 & 47.25 MPa) for groups (A) and (B), respectively. It is observed that the compressive strengths of the fibrous specimens are slightly higher than those of non fibrous ones for the whole studied range of temperatures in this study. This may leads to the conclusion that the influence of original strength (concrete strength before heating) on the percentage reduction in

compressive strength after high temperature exposure is somewhat little to make a noticeable change in the compressive strength-temperature relationship curves.

This conclusion may be more clear and noticeable when figure two is observed. **Figure (2)** shows a comparison between the percentages residual compressive strength-temperature relationship for the two groups it is shown that the distribution of the percentage residual compressive strength for the two groups at temperature higher than higher than (400°C) differs than that of lower temperature.

For the temperature levels (100,200,300 and 400°C) the residual compressive strengths for group (A) (fibrous specimens) are (102.26, 79.64, 71.49 and 21.41%) from its original strength while for group (B) (non fibrous specimens) the values are (110.75, 87.47, 80.42 and 23.28%).

It can be noticed that the reduction in compressive strength for the non fibrous specimens is lower than that of fibrous ones for the previously mentioned temperatures. For the temperature levels (500, 600 and 700°C) the residual compressive strengths for group (A) are (14.8, 10.14 and 8.14%) from its original strength while for group (B) the values are (10.79, 9.16 and 6.71%).

It can be noticed that the reduction in the in the compressive strength in the non fibrous concrete is higher than that of fibrous concrete.

These observations confirm the conclusion that original strength (in the studied range) has no clear effect on the compressive strength behavior after high temperature exposure.

3-2 Ultrasonic Pulse Velocity (UPV)

The relation between (UPV) and temperature for the two studied groups of specimens are shown in **Figs.(3), (4), (5) and (6)** in the direction parallel and perpendicular to the direction of compacted layers.

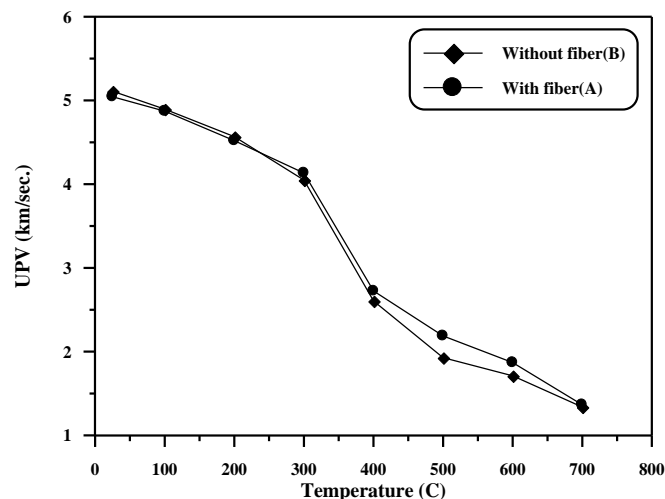


Figure (3) UPV parallel to the direction of compacted layers-temperature relationship for fibrous and non fibrous concrete

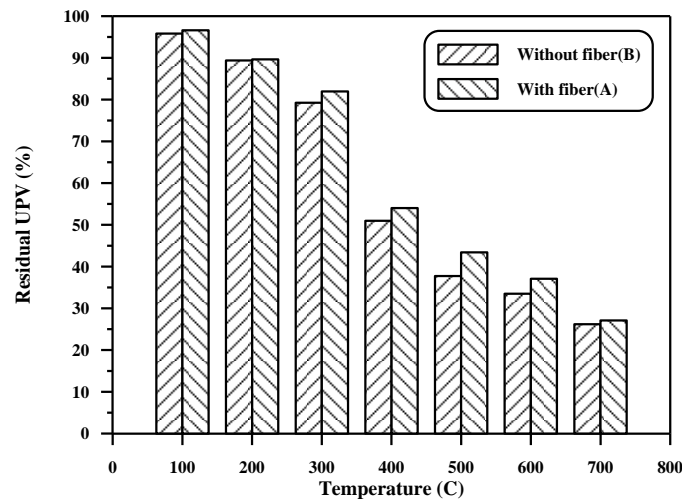


Figure (4) Residual UPV parallel to the direction of compacted layers-temperature relationship for fibrous and non fibrous concrete

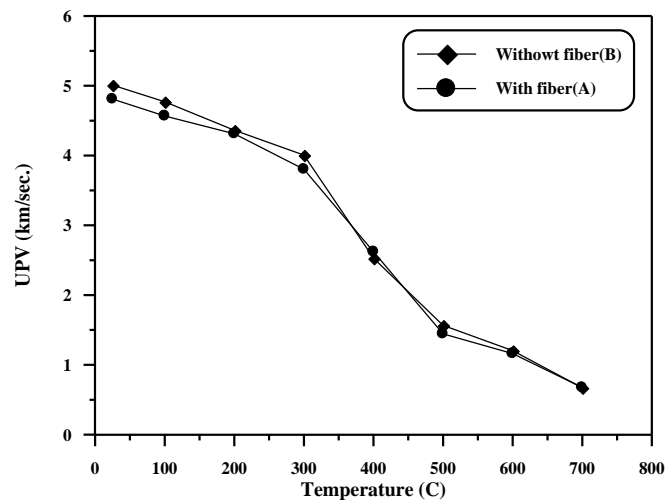


Figure (5) UPV perpendicular to the direction of compacted layers-temperature relationship for fibrous and non fibrous concrete

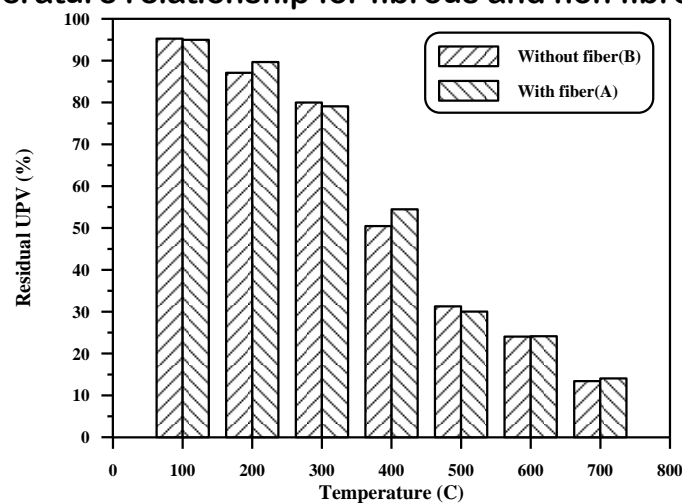


Figure (6) Residual UPV perpendicular to the direction of compacted layers-temperature relationship for fibrous and non fibrous concrete

3-2-1 UPV Parallel to the Direction of Compacted Layers

The results are shown in **Figs.(3)** and **(4)**. The recorded velocities for group (A) and (B) before heating are (5.04 and 5.11 km/sec.), while after heating to temperature levels (100, 200, 300, 400, 500, 600 and 700°C) the UPV for group (A) are (4.87, 4.52, 4.13, 2.72, 2.19, 1.87 and 1.37 km/sec.), respectively. For group (B) the UPV are (4.9, 4.57, 4.05, 2.6, 1.93, 1.71 and 1.34 km/sec.), respectively.

From these results it can be noticed that the UPV for group (A) is lower than those for group before temperature levels (100 and 200°C) but higher than those of group (B) for the remaining temperature levels. **Figure (4)** shows the percentage residual (UPV) at each tested temperature levels. From this figure, it can be noticed that the percentage residual velocities for the fibrous specimens are higher than those of fibrous specimens.

3-2-2 UPV Perpendicular to the Direction of Compacted Layers

The results are shown in **Figs.(5)** and **(6)** the recorded velocities for group (A) and (B) before heating are (4.81 and 5.01 km/sec.) while after heating to temperature levels (100, 200, 300, 400, 500, 600 and 700°C) the UPV for group (A) are (4.57, 4.31, 3.8, 2.62, 1.44, 1.16 and 0.68 km/sec.), respectively, but for group (B) the UPV are (4.77, 4.36, 4.01, 2.53, 1.57, 1.2 and 0.67 km/sec.) from the observation of these results it can be noticed that for all temperature levels. The velocities for group (A) are less than those of group (B) but at temperature levels (400 and 700 °C) the results are reversed. **Figure (6)** shows the percentage residual velocities for each tested temperature levels for group (A) and (B). From these figures, it can be seen that the distribution of the percentage residual velocities for the two groups at a particular temperature differs than at the others.

From the observation of the above **Figs.(3)**, **(4)**, **(5)** and **(6)** it can be seen that the velocity shows continuous decrease as the temperature increase. The exposure of concrete to high temperature leads to the vaporization of moisture not bound by the hydrated compounds (free moisture) leaving voids behind in the concrete mass ^[7]. In addition, the heating process leads to find cracks resulted from volume changes, which take place due to the thermal movements between cement paste and aggregate, which attributed to the differential thermal expansion between the cement past and aggregate. The chemical and physical effects of the heating process at higher temperature (dehydration of calcium silicate at about 400°C) ^[8] leads also to volume changes which play the main role in the cracking and deterioration of concrete at higher temperatures. These voids retard the ultrasonic pulse leading to increase the travel time and consequently decrease the velocity.

3-2-3 Effect of Original Strength

By comparison between the UPV-temperature curve for the two groups with different original strengths related to the presence of steel fiber as shown in **Figs.(3)** and **(4)** it can be noticed that in the studied range the UPV for group (A) is lower than those of group (B), except that the UPV in the direction parallel to the direction of casting for temperature levels above (300°C) and the UPV in the direction perpendicular to the costing direction for temp

level (400 °C). Thus it can be concluded that original strength has no significant effect on UPV after explosive to high temperatures. The observation of **Fig.(6)** confirms the conclusion that the influence of original strength (in the studied range) is very limited and insignificant.

4. Statistical Analysis

Statistical analyses are made using (SPSS) program version 10 to find many relationships between the results obtained in the present experimental work to find some of them as a function of the others. These Results are presented in **Table (2)** and the coefficients of correlation (R) and coefficients of determination (R^2) are also presented in the same table. Linear relationships are selected for simplicity and for its good correlation and determination coefficients. The variables used in that table mean:

t = temperature degree in (°C).

F_{cu} = compressive strength of non fibered concrete in (MPa).

F_{cu_f} = compressive strength of fibered concrete in (MPa).

V_p = ultrasonic pulse velocity of non fibrous concrete parallel to the compacted layers direction in (km/sec.)

V_{pf} = ultrasonic pulse velocity of fibrous concrete parallel to the compacted layers direction in (km/sec.).

V_n = ultrasonic pulse velocity of non fibrous concrete perpendicular to the compacted layers direction in (km/sec.).

V_{nf} = ultrasonic pulse velocity of fibrous concrete perpendicular to the compacted layers direction in (km/sec.).

Table (2) Statistical relationships

Variables	Equations	R (%)	R ² (%)
$F_{cu_f}=f(t)$	$F_{cu_f}=60.208-0.0908t$	95.3	89.3
$F_{cu_f}=f(t, F_{cu})$	$F_{cu_f}=8.639-0.0122t+0.941F_{cu}$	99.8	99.4
$F_{cu_f}=f(t, V_{pf}, V_{nf})$	$F_{cu_f}=-50.05+0.01793t+32.948 V_{pf}-13.049 V_{nf}$	98.9	96.1
$V_{pf}=f(t)$	$V_{pf}=5.455-5.99 \times 10^{-3}t$	98.1	95.7
$V_{nf}=f(t)$	$V_{nf}=5.324-6.8 \times 10^{-3}t$	98	95.4
$V_{pf}=f(t, V_p)$	$V_{pf}=0.804-6.66 \times 10^{-4}t+0.846V_p$	99.9	99.7
$V_{nf}=f(t, V_n)$	$V_{nf}=-1.86 \times 10^{-3}+3.824 \times 10^{-5}t+0.966 V_n$	99.9	99.6
$F_{cu}=f(t)$	$F_{cu}=54.808-0.0835t$	94.1	86.7
$F_{cu}=f(t, V_p, V_n)$	$F_{cu}=-54.88+0.03555t+28.534 V_p-8.565 V_n$	99.3	97.6
$V_p=f(t)$	$V_p=5.499-6.3 \times 10^{-3}t$	97.8	94.9
$V_n=f(t)$	$V_n=5.315-7.0810^{-3}t$	98.2	95.7

5. Conclusions

1. The concrete compressive strength for the steel fibrous concrete is higher than that of non fibrous concrete before heating with a percentage of (17%) and with a maximum percentage after heating of (56.9%) at temperature level (500°C).
2. The values of the compressive strength between temperature levels (300 and 400°C) for the fibrous and non fibrous concrete are convergent.
3. The residual compressive strength of the non fibrous concrete is higher than those of steel fibrous concrete for temperatures less than or equal to (400°C) but the results are reversed for temperatures higher than that value.
4. The ultrasonic pulse velocities for the fibrous concrete and non fibrous concrete are convergent.
5. The percentage residual velocities in the direction parallel to the direction of compacted layers for steel fibrous concrete is higher than those of fibrous concrete with a maximum percentage of increase of (15%) at temperature level (500 °C)
6. The distribution of the percentage residual velocities in the direction perpendicular to the direction of compacted layers at each temperature level differs than that of other level.
7. The effect of the original strength on the concrete compressive strength and (UPV) after exposure to high temperatures is insignificant for the steel fibrous concrete and non fibrous concrete.

6. References

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