The Effect of Elevated Temperature of Compressive Strength of Steel Fiber Concrete

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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) cubes. 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 that 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 a temperature level of (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

Key Words: steel fiber reinforced concrete, compressive strength, elevated temperatures.

الخلاصة

الدراسة الحالية تسلط الضوء على الفائدة الحاصلة من تسليح الألياف الفولاذية في تكنولوجيا الخرسانة حيث بحث تاثير الحرارة على مقاومة انضغاطها.اجري نوعان من الفحص احدهما لااتلافي وهو فحص سرعة الأمواج فوق الصوتية (UPV)والأخر إتلافي باستعمال نماذج مكعبة بطول ضلع(10سم).تم تسخين(48) نموذج (نصفها مقواة بألياف الفولاذ بنسبة حجمية للالياف الفولاذية إلى الخرسانة مقدارها(0.01)والنماذج الأخرى المتبقية غير مقواة) إلى مستويات من درجات الحرارة هي(100و200و300و400و500و600و700)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 باعلى 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 الاصلية يقل باضافة الالياف الفولاذية عند كل مستويات درجات الحرارة الأقل من (400)درجة سيليزية ولكنها تزداد بعد تلك الدرجة .

1. Introduction

The fibrous reinforced concrete is a composite material essentially consisting of concrete reinforced by random placement of short discontinuous and discrete fine fibers of specific geometry [Mugume R.&Takashi H.2011,Ramakrishnan V.1987,Ramesh K.&Prabhakar M.2003,Mahasneh B.2005]. When concrete members including these 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 [Al-Owaisy S.&Al-Ghalabi N.2004]. 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 the 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.

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 cube samples. Non destructive test (UPV) is taken on the same samples.

1.1 Aim of the Study

The aim of this work is to provide an understanding of the behavior of the steel fibrous reinforced concrete when exposed to high temperatures.

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/m^3). Steel fibers, of specifications given in Table (1) as supplied by the manufacturer, added with a steel fiber/concrete ratio of (0.01) by volume.

Table (1) Steel fiber specifications

Fiber Type	Density (kg/m^3)	Ultimate tensile strength (MPa)	Modulus of Elasticity (MPa)	Poission's ratio	Length (mm)	Nominal diameter (mm)
Hooked steel fibers	7860	1130	200000	0.28	25	0.2

The water/cement ratio used for both groups is (0.45) by weight and the slump of the mix is (100±5)mm. The specimens are divided into two groups, each group consisted of twenty-four cubes. Group A specimens were cast with the addition of steel fiber with the percentage mentioned above, while group B specimens were 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) factofy according to Iraqi Standards (1QS 5:1984) is used as shown in table 2.

Table (2) Chemical & Physical Properties of Cement

Chemical Analysis		Physical Properties
Oxides	% by weight	
CaO	58.30	Fineness (Blain) (cm^2/gm) 6624
SiO_2	22.50	
Al_2O_3	4.55	Initial setting time(min) 73
Fe_2O_3	2.95	Final setting (min) 140
MgO	1.68	
SO_3	1.45	Compressive Strength (N/mm^2)
Na_2O	0.18	3 days 10.6
K_2O	0.67	7 days 16.3
L.O.I	8.85	Soundness(Le Chatelier) mm 1.2

Fine aggregate from Rahhalia (Anbar) region with grading limits in zone (3),with specific gravity of (2.6)&fineness modulus of (2.43), and crushed river gravel from (Al-Niba'ai) region with a maximum size of 10 mm& specific gravity of (2.63) are used as shown in table 3.

Table (3) %Passing of Coarse Aggregate

Sieve Size(mm)	%Passing
20	99.6
10	70.46
5	4.72
2.36	2.51

After about 24 hours from casting, the specimens are stripped from their moulds, and placed in water containers to be cured for 28 days. Then after, the specimens were stripped out from the containers, and were left in the laboratory environment for 24 hours to be dried then tests were 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 [Holschemacher et.al.2010]. 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 Figures (1) and (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 Figure (2).

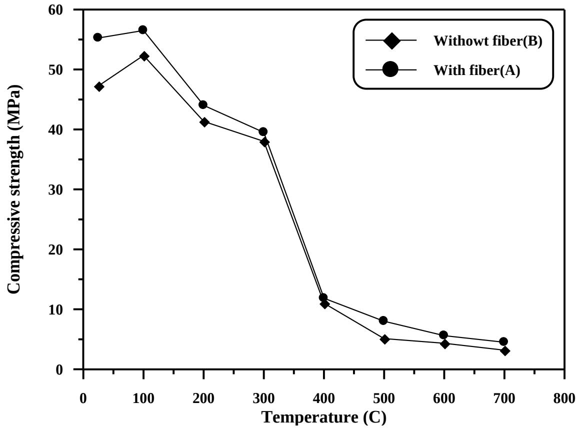

Figure (1) Compressive strength- temperature relationship for fibrous and non fibrous concrete.

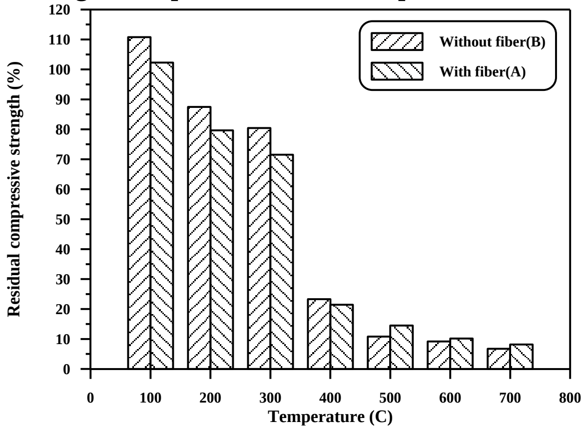

Figure (2) Residual compressive strength - temperature relationship for fibrous and non fibrous concrete.

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 is similar that of non fibrous concrete, but with slightly higher value

This is an expected result, since exposure to elevated temperatures makes a lot of physical and chemical changes in concrete, [Lau A.&Anson M.2006]. 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 microcracking 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 is related to the presence of steel fiber reinforcement and have original concrete compressive strength of about (55.2 and 47.2 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 lead 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 2 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 temperatures higher than (400°C) differs from that of lower temperature. For the temperature levels of (100,200,300 and 400°C), the residual compressive strengths for group A (fibrous specimens) are (102.2%, 79.6%, 71.4% and 21.4%) from its original strength while for group B (non fibrous specimens) the values are (110.7%, 87.4%, 80.4% and 23.2%).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%,10.1% and 8.1 %) from its original strength while for group B the values are (10.7%,9.1% and 6.7%). It can be noticed that the reduction in the compressive strength of 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 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 Figures (3, 4, 5 and 6) in the direction parallel and perpendicular to the direction of compacted layers.

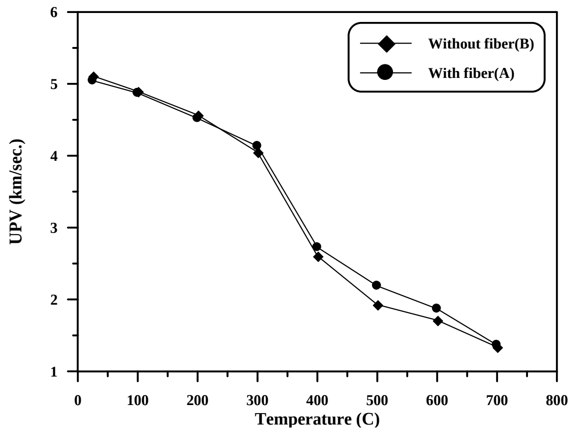

Figure (3) UPV parallel to the direction of compacted layers - temperature relationship for fibrous and non fibrous concrete.

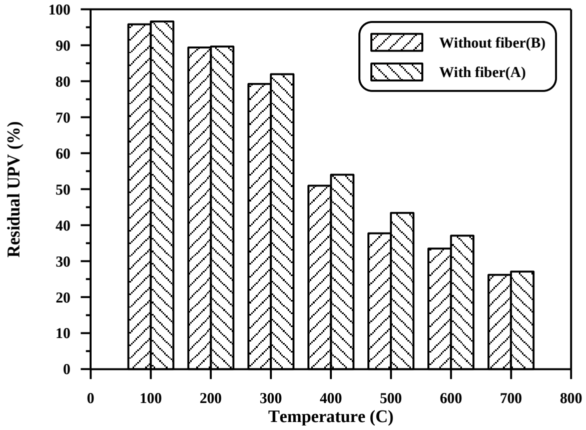

Figure (4) Residual UPV parallel to the direction of compacted layers - temperature relationship for fibrous and non fibrous concrete.

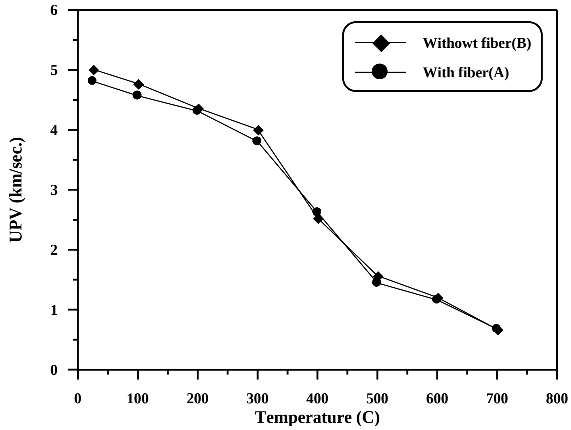

Figure (5) UPV perpendicular to the direction of compacted layers - temperature relationship for fibrous and non fibrous concrete.

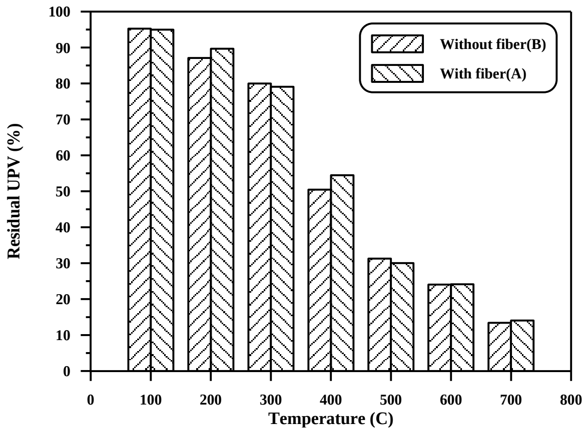

Figure (6) Residual UPV perpendicular to the direction of compacted layers - temperature relationship for fibrous and non fibrous concrete.

-UPV parallel to the direction of compacted layers

The results are shown in Figures (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 temperatures levels (100,200,300,400,500,600 and 700°C) the UPV for group A are (4.8, 4.5, 4.1, 2.7, 2.1,1.8 and 1.3 km/sec.), respectively. For group B the UPV are (4.9, 4.5, 4.05, 2.6, 1.9, 1.7 and 1.3 km/sec.), respectively.

From these results it can be noticed that the UPV for group A is lower than those for group B 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.

-UPV perpendicular to the direction of compacted layers

The results are shown in Figures(5 and 6) the recorded velocities for group A and B before heating are(4.8and 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 (4.5, 4.3, 3.8, 2.6, 1.4, 1.1 and 0.6 km/sec.), respectively, but for group B the UPV are(4.7, 4.3, 4.0, 2.5, 1.5, 1.2 and 0.6 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 Figures (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 [Lau A.&Anson M.2006]. 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) [Sofren L.&Takashi H.2006] 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.

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

4. 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 similar.
3. The residual compressive strength of the non fibrous concrete is higher than these of steel fibrous concrete for temperatures less than or equal to (400°C) but the results are reversed of temperatures higher than that value.
4. 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)
5. The distribution of the percentage residual velocities in the direction perpendicular to the direction of compacted layers at each temperature level differ than that of other level.

6. 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.

References

Mugume Rodgers Bangi & Takashi Horiguchi, (Pore Pressure Development in Hybrid Fiber Reinforced High Strength Concrete at Elevated Temperature). Magazine of Cement and Concrete Research, Vol.41, Issue 11, November 2011, PP.1150-1156.

Ramakrishnan,V.,(Materials and Properties of Fiber Reinforced Concrete).Proceedings of International Symposium on Fire Reinforced Concrete, Madras, India, SERC, 1987,PP.2.3-2.23.

Ramesh, K., Seshu, D.R. and Prabhakar, M., (Constitutive Behavior of Confined Fiber Reinforced Concrete under Axial Compression). Elsevier Journal, Cement and Concrete Composites, No.25, 2003, PP.343-350.

Mahasneh, B. Z., (The Effect of Addition of Polymeric Fiber Reinforcement on Fire Resistant Composite Concrete Material). Journal of Applied Sciences Vol.5, No .2, 2005, PP. 373-379.

Al-Owaisy, S.R., Al-Chalabi, N. N, (Non Destructive Tests on Concrete Exposed to Temperatures up to 700°C). Journal of Engineering and Development, Vol. 8, No.1, 2004, PP. 29-37.

Holschemacher K., Mueller T..& Ribakov Y., (Effect of Steel Fibres on Mechanical Properties of High Strength Concrete). Magazine of Materials &Design , Vol.31, Issue5, May 2010, PP.2604-2615.

Lau A. & Anson M., (Effect of High Temperature on High Performance Steel Fiber Reinforced Concrete). Magazine of Cement and Concrete Research, Vol.36, Issue 9, September 2006, PP.1698-1707.

Sofren Leo Suhaendi &Takashi Horiguchi., (Effect of Short Fiber on Residual Permeability and Mechanical Properties of Hybrid Fibre reinforced High Strength After Heat Exposition) . Magazine of Cement and Concrete Research, Vol.36, Issue 9, September 2006, PP.1672-1678.