Journal of Engineering and Development, Vol. 13, No. 2, June (2009) **ISSN 1813-7822**

Effect of Elevated Temperatures on the Compressive Strength and Ultrasonic Pulse Velocity of Self Compacting Concrete

Lect. Sawsan Akram Hassan
Civil Eng. Dept., College of Eng.
Al-Mustansiriya University, Baghdad, Iraq

Lect. Mithaq A. Louis
Civil Eng. Dept., College of Eng.
Al-Mustansiriya University, Baghdad, Iraq

Asst. Lect. Mohammed Khachi Hatim
Civil Eng. Dept., College of Eng.
Al-Mustansiriya University, Baghdad, Iraq

Abstract

In this study, the effect of elevated temperature on the compressive strength of self compacting concrete 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 of conventional concrete and the other half are of self compacting concrete), 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 residual compressive strengths after high temperature exposure of the self compacting concrete is higher than that of conventional concrete at all tested temperature levels; for example, the residual compressive strength after exposure to temperature level of (700°C) for the former is (80.5%) while for the later is (53.1%) from their original strengths. Also, The percentage residual (UPV)-temperature relationships show similar behavior to that of compressive strength in conventional concrete, while they do not for the self compacting one.

الخلاصـــــــة

الدراسة الحالية تتضمن بحث تاثير الحرارة المرتفعة على مقاومة الانضغاط للخرسانة ذاتية الرص.اجري نوعان من الفحوصات احدهما لاتلافي وهو فحص سرعةالامواج فوق الصوتية (UPV)والاخر اتلافي باستعمال مكعبات طول ضلعها(١٠سم).تم تسخين(٤٨) نموذج (نصفها تقليدية والنصف الاخر ذاتية الرص)الى درجات من الحرارة هي (١٠٠ و٢٠٠ و٣٠٠ و ٤٠٠ و ٥٠٠ و ٦٠٠ و ٧٠٠)درجة سيليزية.فحصت النماذج لا اتلافيا بعد تبريدها بتعريضها للهواء ثم فحصت اتلافيا.بينت النتائج بان المقاومة المتبقية- بعد تعريض النماذج الى درجات الحرارة العالية- في النماذج ذات الخرسانة ذاتية الرص اعلى من تلك التقليدية، وكمثال على ذلك فان المقاومة المتبقية بعد تعريض النماذج الى (٧٠٠)درجة سيليزية للاولى هي(٨٠.٥%)و للثانية (٥٣.١%) من مقاومتهما الاصلية.بالاضافة الى ذلك فان منحنى السرعة النبضيةالمتبقية-درجة الحرارةتماثل تلك الخاصة بمقاومة الانضغاط المتبقية في الخرسانة التقليدية بينما لا تتماثل في الذاتية الرص.

Key Words: Self compacting concrete, Compressive strength, UPV, Elevated temperatures.

1. Introduction

Portland cement concrete is presently one of the most widely used materials in construction. Judging from world trends, the future of concrete looks even brighter because for most purposes it offers suitable engineering properties at low cost, combined with energy-saving and economical benefits. It is therefore desirable that engineers know more about the concrete mix design, method of mixing, placing, and curing problems [1,2]. One of these problems is placing of concrete. Placing the concrete requires skilled operative using slow, heavy, noisy, expensive and often dangerous mechanical vibration to ensure adequate compaction to obtain the full strength and durability of hardened concrete [2,3].

The use of self compacting (SCC) concrete is spreading world wide because of its very attractive properties in the fresh state as well as after hardening. The term self compacting concrete, refers to a special type of concrete mixture characterized by high resistance to segregation that can be cast without compaction or vibration. Therefore, this type of concrete can minimize the problem of concrete. The SCC differs from conventional concrete in the following three characteristics: appropriate flowability, non-segregation and non blocking tendency [4,5,6,7].

Many investigations on SCC have been carried out in the last several years and the mechanical behavior of this type of concrete is well understood by now. The fire behavior of this specialized concrete, however, is not fully understood [8].

In this work, an experimental program is directed to study the residual SCC compressive strength after exposure to high temperatures up to (700°C), using concrete cube samples. Non destructive test (UPV) is carried out on the same samples. The aim of this work is to provide an understanding of the behavior of the SCC 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 test.

A single concrete mix of (1:1.37:1.98) (cement: fine aggregate: coarse aggregate) in proportion by weight is used for the conventional concrete. The same mix is used for the SCC but the materials are (cement +limestone powder: fine aggregate: coarse aggregate). The w/c ratio is (0.38) for the two types and w/powder ratio of (o.34) for the SCC. Ordinary Portland cement (type I), which is manufactured in Kubaisa factofy according to Iraqi Standards (1QS 5:1984) is used. Fine aggregate from Rahhalia (Anbar) region, and crushed river gravel from (Al-Nibaa'ai) region with maximum size of (14 mm) are used. The cement content is (450 kg/m^3). The self compacting is obtained by using a superplasticiser which is (Glenium 51) with a dosage of 6 liter per cubic meter of concrete and limestone powder with a fineness of 3100cm^2/gm and content of 50 kg /m^3. For the SCC the slump flow is (755mm) and the T_{500} is (4 Sec.). The specimens are divided into two groups, each group consist of twenty-four cubes. Group (A) specimens are of conventional concrete, while group (B) specimens are of

SCC. 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.

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 taken out from the water containers and left in the laboratory environment for (6 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 (4 °C/min) to avoid steep thermal gradient [9]. 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 carried out to the specimens using the (UPV). The (UPV) test is made on three places two of them perpendicular to the direction of load application and the other parallel to it. After carrying out the non destructive test, the concrete compressive strength for each cube is tested (destructively).

3. Results and Discussions

3-1 Concrete Compressive Strength

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

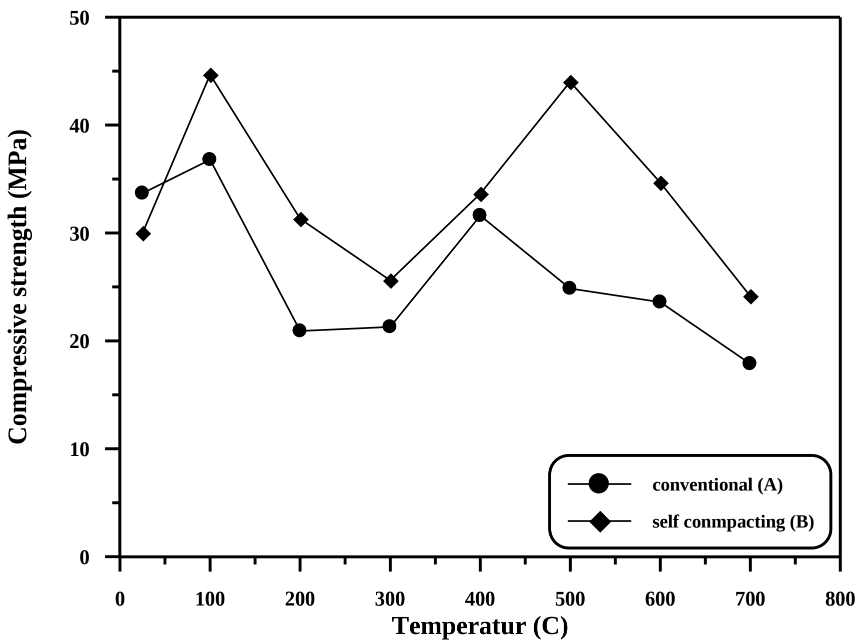

Figure (1) Compressive strength-temperature relationship for conventional and self compacting concretes

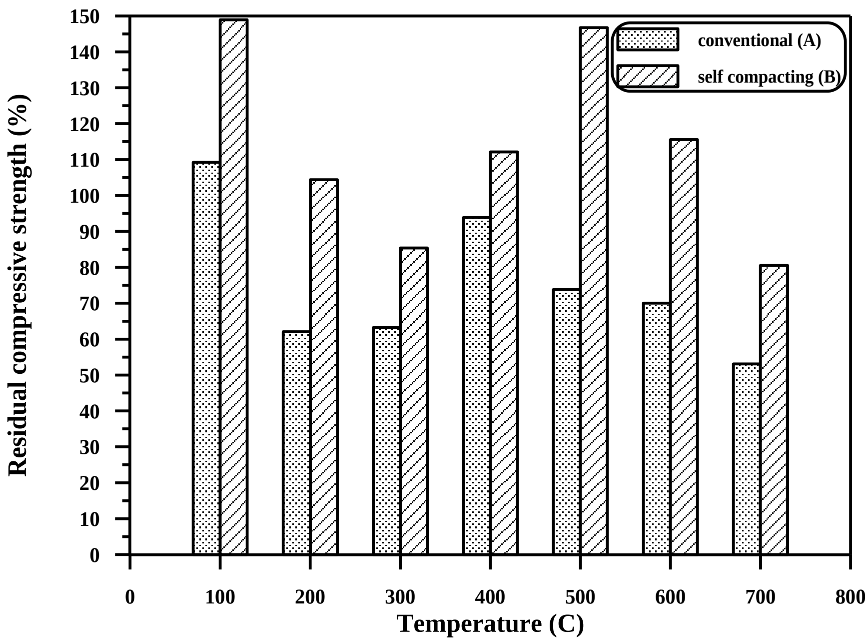

Figure (2) Residual compressive strength-temperature relationship for conventional and self compacting concretes

From the figures, it can be noticed that concrete compressive strength suffers a noticeable deterioration when exposed to high temperatures. This is an expected result, since exposure to elevated temperatures makes a lot of physical and chemical changes in concrete [10,11]. When temperature reaches about 300°C, interlayer C-S-H water and some of the 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. Such behavior leads 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 existed before heating (drying shrinkage cracks), and consequently leads to deterioration of concrete strength [12].

3-1-1 Effect of Original Strength

Figure (1) shows a comparison between concrete compressive strength-temperature relationships for the two groups of specimens (A & B) with original concrete compressive strengths of about 33.68 & 30 MPa, respectively. The compressive strength-temperature relationship of SCC has higher values than that of conventional concrete. The compressive strength-temperature relationship of the conventional concrete has two peaks at 100 and 400 °C , while that of the SCC has also two peaks but at 100 and 500 °C). It is observed that the compressive strengths of the SCC specimens are higher than those of conventional ones for the whole range of temperatures used in this study in spite of the fact that the SCC has lower original strength value before heating. This may lead to the conclusion that the influence of original strength on the percentage reduction in compressive strength after high temperature exposure results in a noticeable change in the compressive strength-temperature relationship curves.

This conclusion may be more clear and noticeable when **Fig.(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 percentage residual compressive strength has the same distribution for the two groups at all studied temperature levels. The percentage residual compressive strength of the SCC is higher than that of conventional concrete.

For the temperature levels of (100, 200, 300, 400, 500, 600, and 700°C), the residual compressive strengths for group (A) (conventional concrete specimens) are (109.2, 62.05, 63.18, 93.82, 73.75, 70.01, and 53.06%) from its original strength while for group (B) (SCC specimens), the values are (148.9, 104.37, 85.37, 112.1, 146.7, 115.57, and 80.5%). These observations confirm the conclusion that the original strengths (in the studied range) have a 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 directions perpendicular and parallel to the direction of load application.

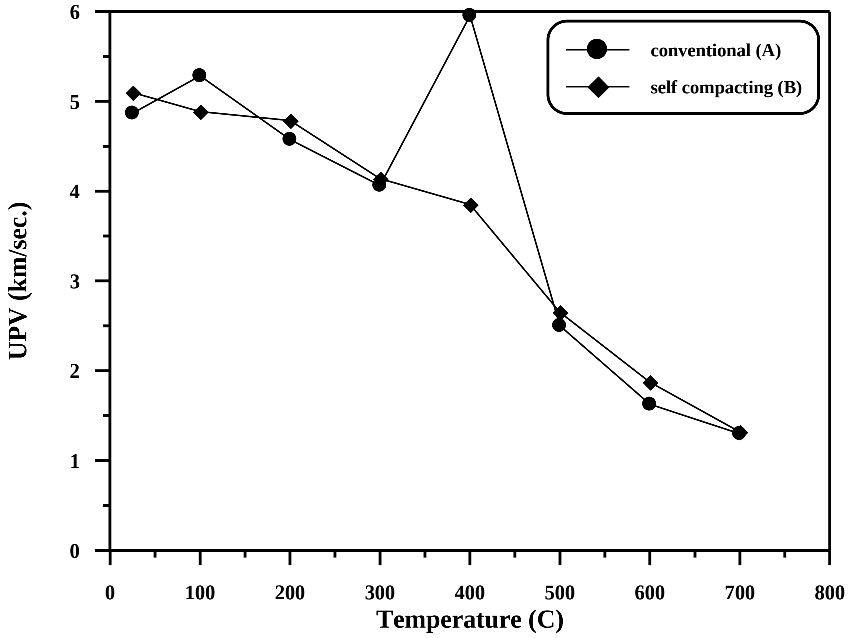

Figure (3) UPV perpendicular to the direction of load application-temperature relationship for conventional and self compacting concretes

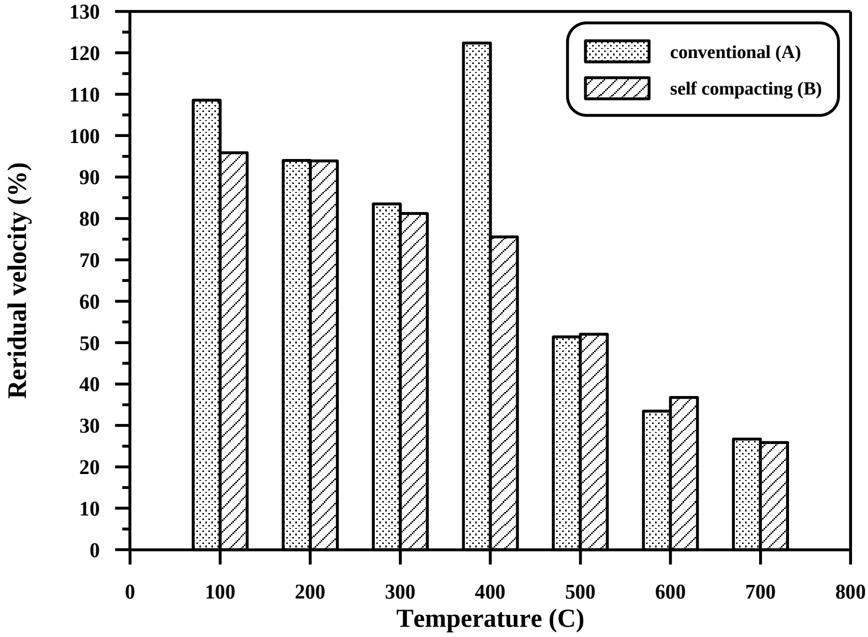

Figure (4) Residual (UPV) perpendicular to the direction of load application-temperature relationship for conventional and self compacting concretes

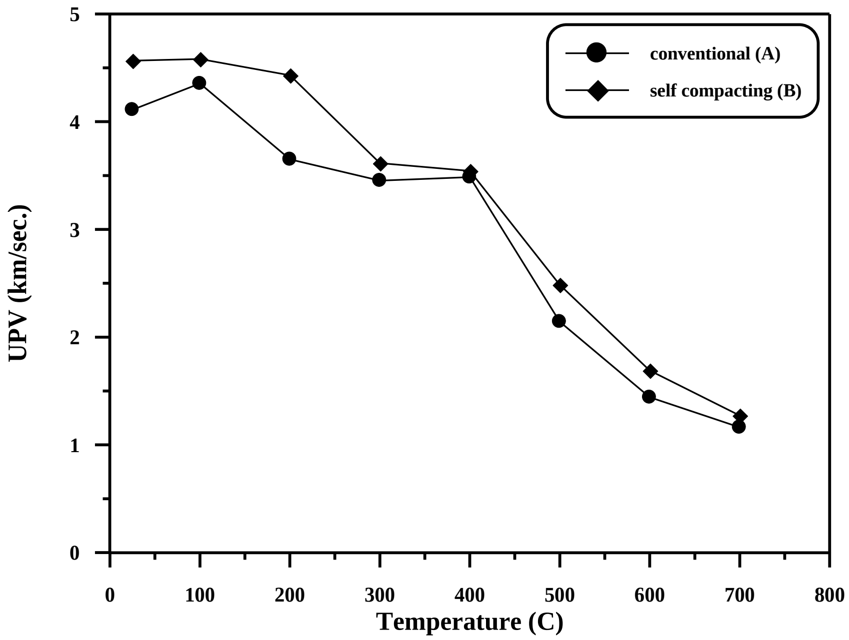

Figure (5) (UPV) Parallel to the direction of compacted layers-temperature relationship for conventional and self compacting concretes

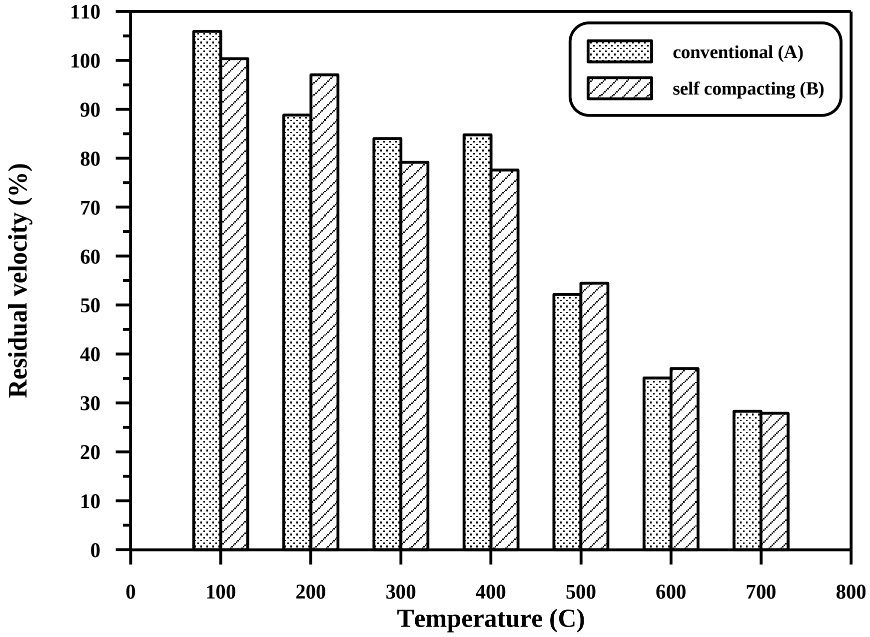

Figure (6) Residual UPV parallel to the direction of load application-temperature relationship for conventional and self compacting concretes

From the observation of **Figs.(3, 4, 5 & 6)**, it can be seen in general that the velocity shows a decrease with the temperature increases, since the exposure of concrete to high temperature leads to the evaporation of moisture unbound by the hydrated compounds (free moisture) leaving voids behind in the concrete mass [10,13,14]. In addition, the heating process leads to fine cracks resulting from volume changes, which take place due to the thermal movements between the cement paste and aggregate, which is attributed to the differential thermal expansion between the cement past and aggregate. Also, the chemical and physical effects of the heating process at higher temperature (dehydration of calcium silicate at about 400°C) [15] leads also to volume changes which play the main role in the cracking and deterioration of concrete at high temperatures. These voids retard the ultrasonic pulse leading to increase in the travel time and consequently a decrease in the velocity.

3-2-1 (UPV) Perpendicular to the Direction of Load Application

The results are shown in **Figs.(3)** and **(4)**. The recorded velocities for groups (A) and (B) before heating are 4.87 and 5.1 km/sec., respectively, while after heating to temperature levels of (100, 200, 300, 400, 500, 600, and 700°C), the (UPV) for group (A) are (5.28, 4.57, 4.06, 5.95, 2.5, 1.63, and 1.3km/sec.), respectively, and for group (B) the (UPV) are (4.89, 4.78, 4.14, 2.85, 2.65, 1.87, and 1.32 km/sec.), respectively.

Figure (4) shows the percentage residual (UPV) at each tested temperature level. From this figure, it can be seen that the percentage residual velocity loss is (73.31%) for conventional concrete and (74.31%) for SCC after exposure to (700°C).

3-2-1-1 Effect of Original Strength

From these results it can be noticed from **Fig.(3)** generally that the SCC velocities are slightly higher than those of conventional concrete at all tested temperature levels except at temperature levels of (100 and 400°C), they are lower with a maximum percentage of (54.5%) at temperature level (400°C). From **Fig.(4)** it can be noticed that the percentage residual velocities for the SCC is lower than that of conventional concrete between temperature levels (100 and 500°C) and slightly higher for temperature levels (500 and 700°C).

3-2-2 (UPV) parallel to the Direction of Load Application

The results are shown in **Figs.(5)** and **(6)** the recorded velocities for groups (A) and (B) before heating are (4.11 and 4.57 km/sec.), while after heating to temperature levels (100, 200, 300, 400, 500, 600, and 700°C) the (UPV) values for group (A) are (4.35, 3.65, 3.45, 3.48, 2.14, 1.44, and 1.16 km/sec), while for group (B) are (4.58, 4.43, 3.61, 3.54, 2.49, 1.69, and 1.27 km/sec), respectively.

Figure (6) shows the percentages residual velocities at each tested temperature levels for the two groups. From this figure it can be seen that the percentage residual velocity loss is (71.72%) for conventional concrete and (72.14%) for SCC after exposure to (700°C).

3-2-2-1 Effect of Original Strength

From the observation of these results, it can be seen that the velocities of the SCC are higher than those of conventional concrete for the all tested temperature levels.

From **Fig.(6)**, it can be seen that no clear conclusion can be made except that for the temperature levels higher than (400°C), the residual velocities of the SCC are higher than those of conventional concrete.

4. Comparison between Residual (UPV) and Destructive Compressive Strength

The behavior of both the concrete compressive strength and non destructive test (UPV) values after exposure to high temperatures are shown in **Figs.(7)** and **(8)**.

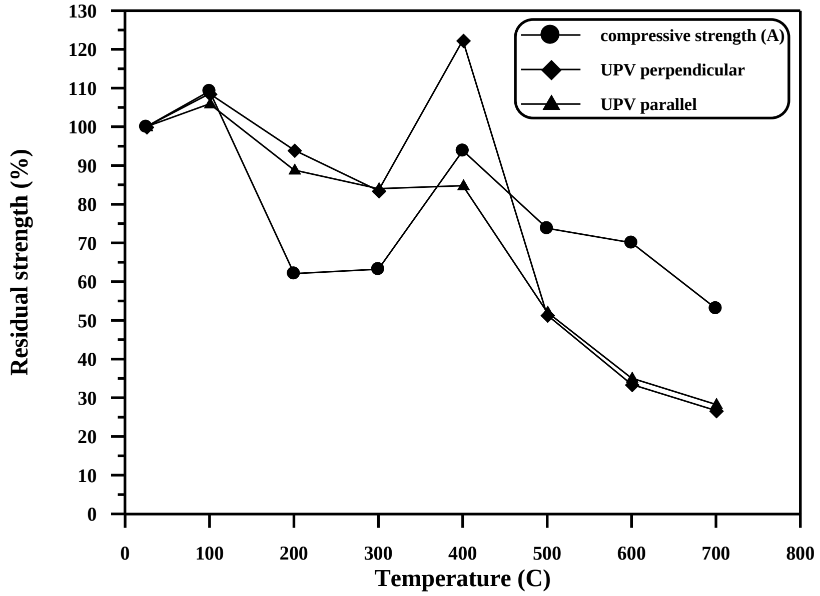

Figure (7) Residual compressive strength and UPV-temperature relationship for conventional concrete

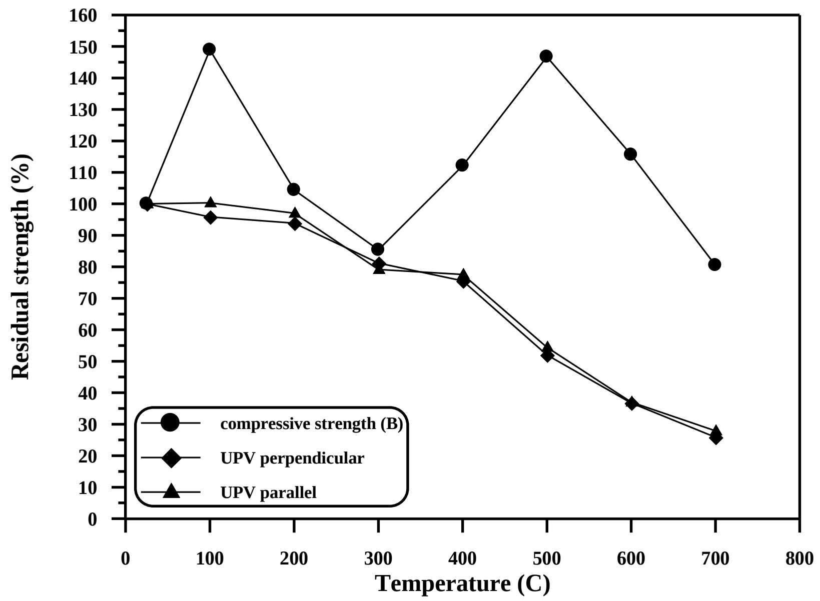

Figure (8) Residual compressive strength and UPV-temperature relationship for self compacting concrete

When these figures are studied problem can be discussed, which is the shape of percentage residual strength-temperature relationship. **Figure (7)** shows the comparison between the residual compressive strength and the (UPV) in two directions perpendicular and parallel to the direction of load application for the conventional concrete. As shown in the figure, the percentage residual compressive strength displays four different behaviors. First, a rising line between room temperature and (100°C) is noticed, which reflects the increase in the compressive strength at (100°C). Thereafter the specimens form a declined line, which reflects the loss in strength, occurring between (100 and 300°C), then a rising line between (300 and 400°C) which reflects the rising in the compressive strength then a decline line, which reflects the loss in strength between (400 and 700°C). The percentage residual (UPV)-temperature relationship shows similar behavior to that of concrete compressive strength. **Figure (8)** shows the same comparison but for SCC. As shown in the figure, the percentage residual compressive strength displays four different behaviors. First rising line between room temperature and (100°C) then, a decline line to (300°C), then a rising line after this temperature to(500°C) and finally, a decline line after this temperature. Also as in the same figure the percentage residual (UPV)-temperature relationship did not show similar behavior to that of compressive strength of SCC, since there is no significant strength recovery at any tested temperatures.

5. Conclusions

1. The compressive strengths of the SCC specimens after heating are higher than those of conventional ones for the whole studied range of temperatures in this study in spite of the fact that the SCC has lower original strength value. The compressive strength-temperature relationship of the conventional concrete has two peaks at (100 and 400 °C), while that of SCC has also two peaks but at (100 and 500 °C).
2. Both, the SCC and the conventional concrete, reach their maximum value at the same temperature level, which is (100 °C). The maximum compressive strength of the SCC is higher than its original value by (48.9%), while that of conventional concrete is higher than its original one by (9.2%).
3. The loss in strength resulting from exposure to high temperatures in SCC is smaller than that in conventional concrete in all the tested temperature levels (100 to 700°C), i.e. the residual compressive strength is higher. The loss in strength after exposure to (700°C) for the SCC is (19.5%) from its original strength, while for the conventional concrete is (49.9%).
4. After exposure to high temperatures, the (UPV) perpendicular to the direction of load application of SCC is higher than that of conventional concrete except at temperature levels (100 and 400°C) they are lower, with a maximum percentage (increase) of (54.5%) at temperature level (400°C). The percentage residual velocities of the SCC are lower than those of conventional concrete between temperature levels of (100 and 500°C) and higher for temperature levels (500 and 700°C). The percentage residual velocities for the SCC after exposure to temperature level (700°C) is (25.9%), approaches that of conventional concrete which is (26.7%), from their original velocities.
5. (UPV) parallel to the direction load application of SCC are slightly higher than that of conventional concrete for all the tested temperature levels. No clear conclusion can be made concerning residual velocities except that for the temperature levels higher than (400°C) the residual velocities of the SCC are slightly higher than that of conventional concrete. The percentage residual velocities for the SCC after exposure to temperature level (700°C) is (27.9%), approaches that of conventional concrete that is (28.3%), from their original velocities.

6. The percentage residual (UPV)-temperature relationships show similar behavior to that of compressive strength of conventional concrete, while the percentage residual (UPV)-temperature relationships do not show similar behavior to that of compressive strength of SCC, since there is no strength recovery at any tested temperature level, instead there is a continuous decrease as temperature increases.

6. References

1. Mehta, P. K., and Monteiro, P. J., ***"Concrete: Microstructure, Properties and Materials"***, 2nd and Final Edition, Englewood Clifts, New Jersey, USA, October 2001, 239 pp.

2. Ali, A. M., ***"Effect of Shape and Size of Specimen on Some Mechanical Properties of (20-80) MPa Self Compacting Concrete"***, M.Sc. Thesis, Al-Mustansiriya University, Iraq, March 2007.

3. ***"Measurement of Properties of Fresh Self-Compacting Concrete"***, European Union Growth, Final Report, September 2005, 62 pp.

4. Ravindrarajah, S. R., Farrokhzadi, F., and Lahoud, A., ***"Properties of Flowing Concrete and Self-Compacting Concrete with High Performance Superplasticier"***, Proceedings of the 3rd International RILEM Symposium, Iceland, Vol. 1, 17-20 August 2003, 1048 pp.

5. The European Guidelines for Self Compacting Concrete, European Red-Mix Concrete Organization (ERMCO), March 2005, pp. 68.

6. Al-Jabbri, L. A., ***"The Influence of the Mineral Admixtures and Steel Fibers on the Fresh and Hardened Properties of SCC"***, M.Sc. Thesis, Al-Mustansiriya University, Iraq, 2005.

7. Rahim, J. O., ***"The Influence of Volume Ratio and Size of Concrete Aggregate on the Properties of Self Compacting Concrete"***, M.Sc. Thesis, Iraq, 2005.

8. Reinhardt, H. W., and Stegmaier, M., ***"Self Consolidating Concrete in Fire"***, ACI Material Journal, Vol. 103, No .2, March-April 2006, pp. 130-135.

9. Moreley, P. D, and Royels, R., ***"Response of Bond in Reinforced Concrete to High Temperatures"***, Magazine of Concrete Research, Vol. 38, No.123, June 1983, pp. 67-75.

10. Lankard, D. R., Birkimer, D. L., Fondriest, F. F., and Snyder, M. J., ***"Effect of Moisture Content on the Structural Properties of Portland Cement Concrete Exposed to Temperatures up to 500F"***, ACI Special Publication, SP-25, Temperature and Concrete, Detroit, Michigan, USA, 1971, pp. 59-105.

11. Al-Sa'ady, M. A., ***"Effect of Previous Fire on Load-Slip Relationship at a Modified Push-Out Test"***, Journal of Engineering and Development, Vol. 9, No. 3, 2005, pp. 50-60.

12. Hassan, S. A., ***"Effect of Addition of Steel Fiber on the Compressive Strength of Composite Concrete Materials under High Temperatures (Experimental & Statistical Work)"***, Journal of Engineering and Development, Vol. 10, No. 3, September 2006, pp. 60-69.

13. Hassan, S. A., ***"Effect of High Elevated Temperature on the Compressive Strength and Ultrasonic Pulse Velocity of High Strength Concrete"***, Journal of Engineering and Development, Vol. 11, No. 1, March 2007, pp. 58-69.

14. Al-Owaisy, S. R., and 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.

15. Nikolai, G. Z., ***"Thermal Properties of Concrete under Sustained Elevated Temperatures"***, ACI Special Publication, SP-25, Temperature and Concrete, Detroit, Michigan, USA, 1971, pp. 1-31.