Fire Flame Influence on the Behavior of reinforced Concrete Beams Affected by Repeated Load

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ABSTRACT

The influence and hazard of fire flame are one of the most important parameters that affecting the durability and strength of structural members. This research studied the influence of fire flame on the behavior of reinforced concrete beams affected by repeated load. Nine self- compacted reinforced concrete beams were castellated, all have the same geometric layout (0.15x0.15x1.00) m, reinforcement details and compressive strength (50 Mpa).

To estimate the effect of fire flame disaster, four temperatures were adopted (200, 300, 400 and 500) ^{o}C and two method of cooling were used (graduated and sudden). In the first cooling method, graduated, the tested beams were leaved to cool in air while in the second method, sudden, water splash was used to reduce the temperature. Eight of the tested beams were divided in to four groups, each were burned to one of the adopted temperature for about half an hour and cooled by the adopted cooling methods (one by sudden cooling and the other by graduated cooling). After burning and cooling the beams were tested under the effect of repeated load (loading – unloading) for five cycle and then up to failure.

As a compared with the non- burned beam, the results indicated that the ultimate load capacity of the tested beams were reduced by (16, 23, 54 and 71)% after being burned to (200, 300, 400 and 500) ^{o}C , respectively, for a case of sudden cooling and by (8, 14, 36 and 64)% , respectively, for a case of graduated cooling. It was also found that the effect of sudden cooling was greater than that in a case of graduated cooling.

Regarding the failure mode, there was a different between the non-burred beam and the other ones even that all of them had the same geometric layout, compressive strength and reinforcement details. The failure mode for all burned beams was combined shear- flexure failure which was belong to the reduction in the compressive strength of the concrete due to the effect of the temperature rising , while the failure mode of the non-burned beam was flexure failure which was compatible with the preliminary design. It was also detected that the residual deflection proportion directly with the temperature, as the temperature increase to (200, 300, 400 and 500) ^{o}C the residual deflection compared with the non-burned beam increased by (32, 48, 326 and 358)% for a case of sudden cooling and by (13, 29, 303 and 332)% for a case of graduated cooling. Another effect was appear represented by the method of cooling, the results showed that the sudden cooling had more effect on the residual deflection than the graduated cooling by (15-6)% approximately. To vanish the residual deflection, numbers of cycle (loading-unloading) were required. It was found that this number increase as the temperature of burning increased and it's also larger in a case of sudden cooling.

Key words: concrete beam, self- compacted, fire flame, repeated load.

تأثيراللهب على سلوك العتبات الخرسانية المسلحة الخاضعة لتاثير الاحمال الدورية

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الخلاصة

يعتبر تاثير ومخاطر لهب النيران من اكثر العوامل المؤثرة على ديمومة ومقاومة العناصر الإنشائية . يدرس هذا البحث تأثير لهب النيران على تصرف العتبات الخرسانية المسلحة الخاضعة لتأثير الأحمال الدورية. إشتمل برنامج البحث صب تسعة من العتبات الخرسانية المسلحة باستخدام خرسانة ذاتية الرص بمقاومة انضغاط (50 Mpa) جميعها تتطابق في الابعاد الهندسية (0.15x0.15x1.00) م وتفاصيل التسليح.

لتخمين تإثير مخاطر لهب النيران تم إعتماد اربع درجات حرارة مختلفة هي على التوالي (200, 300, 400 and 500) درجة سيليزية كما تم إعتماد طريقتين للتبريد ، التبريد التدريجي والفجائي. في الطريقة الاولى للتبريد (التدريجي) يترك النموذج بعد حرقه في الهواء الطلق ليبرد اما في الطريقة الثانية (التبريد المفاجئ) فيستخدم الماء للتبريد إذ يرش النموذج بكمية كافية من الماء لتبريده. قسمت ثماني من النماذج المستخدمة الى اربعة مجاميع كل مجموعة تم حرقها الى واحدة من درجات الحرارة المعتمدة في البحث ولمدة نصف ساعة وتم تبريد نموذجي كل مجموعة بواحدة من طرق التبريد المعتمدة (التبريد التدريجي او الفجائي). بعد إتمام عملية الحرق والتبريد تم فحص النماذج تحت تاثير الاحمال الدورية ولخمس دورات ومن ثم الى مرحلة الفشل.

مقارنة مع النموذج غير المحروق، بينت النتائج إنخفاض قيمة الحمل الأقصى للنماذج المفحوصة بمعدل %(71 , 54 ,23 ,16) لدرجات الحرق المعتمدة (500 , 400 ,300 ,200) على التوالي لحالة التبريد الفجائي و بمعدل %(64 , 36 ,14 ,8) لحالة التبريد التدريجي. كما بينت النتائج بان تأثير التبريد الفجائي أكبر من تأثير التبريد الفجائي وان هذا التباين بين الطريقتين يقل بزيادة درجة حرارة الحرق.

فيما يخص طور الفشل، كان هناك إختلاف بين النموذج غير المحروق وبقية النماذج المحروقة بالرغم من تطابق الأبعاد الهندسية ، مقاومة الإنضغاط وتفاصيل التسليح لجميع النماذج المفحوصة. بالنسبة للنماذج المحروقة . كان طور الفشل في جميع النماذج المحروقة مركبا (قص – انحناء) نتيجة لإنخفاض مقاومة الانضغاط في الخرسانة بفعل تاثير حرارة الحرق في حين كان طور الفشل في النموذج غير المحروق (انحناء) وهو ما صمم عليه النموذج. فيما يتعلق بالاحمال الدورية تبين بان الهطول المتبقي يتناسب طرديا مع درجة حرارة الحرق كما تبين تأثر مقدار الهطول المتبقي بطريقة التبريد فللتبريد الفجائي تاثير اكبر على مقدار الهطول المتبقي بنسبة تتراح بين %(6-15) تقريبا.

الكلمات الرئيسيةّ: العتبات الخرسانية، خرسانة ذاتية الرص، اللهب ، الاحمال الدورية.

1. INTRODUCTION

Exposure to high temperatures resulting from the fires is one of the common things in concrete and steel buildings. In such case, concrete composition will suffer from self-deterioration due to the difference in the thermal expansion of its components. Fletcher et al 2007, stated that, the free water evaporates when concrete heated, and above 100 ^{o}C, approximately, there will be a releasing of water that chemically bonds in the hydrated calcium silicate. In some cases, the surface layer of concrete specimen is not able to resist the pressure of the water and steam, and spalling occurs. Shrinkage of the hydrated cement paste will accurse due to the released water if the concrete dose not spall, while both the reinforcing bars and the coarse aggregate will subject to thermal expansion. Consequently, stresses will develop in the composite material and form micro cracks through the matrix. Above approximately 400 ^{o}C the crystals calcium hydroxide begin decomposing into calcium oxide and water process reaching its highest intensity at above 535 ^{o}C.

Venkatesh, K. 2014, indicated that the compressive strength of the concrete decrease slightly up to 400 ^{o}C, then it decreased rapidly when it reached about 600 ^{o}C then it began to diminish continuously as temperature increased more and more till approximately disappeared at 1000 ^{o}C.
Many theoretical researches or finite element models have been conducted to study the behavior of different structural elements exposed to high temperature, **Obaidat and Haddad 2016, Lakhani et. al. 2014, Neno et. al. 2013**, but a very little experimental works were carried out to investigate the behavior of burred beams under the effect of repeated load, therefore an experimental program was performed to find the behavior, ultimate load and the residual deflection of self-compacted concrete beams subjected to fire flame under the effect of repeated load.

2. EXPERIMENTAL PROGRAM:

Three stages were included in the program of the experimental work. In the first stage, nine beams were castled and cured using self-compacted concrete of (50 Mpa) compressive strength and mix proportion as illustrated in **Table 1,** the properties of the consuming materials were illustrated in **Table 2** up to **Table 10.** All the tested beams had the same geometric layout and reinforcement details (0.15x0.15) m as cross section and (1.00) m total length, **Fig. 1**.
Burning the beams was the second stage of the experimental program, eight of the tested beams were divided into four groups each were burned to one of the adopted temperature (200, 300, 400 and 500) ^{o}C using a steel furnace that manufactured by 3mm thick plate bents like two L-shape with a capacity of two specimens, **Fig. 2**. The clear space around the beam was 500mm height by 400mm width and 2600mm length. These dimensions provide enough space around the beam to reach the fire flame from the sources and to ensure that the flame are not concentrated on a limited area but distributed on a wide area of the beam bottom and sides. Fire sources were designed as a network of methane burners nozzles, the nozzles were allocated, four in each side of the furnace. Two thermocouples were used, one for each beam, to monitoring the temperature. The rate of temperature increasing was adopted to be the same for all burning possess (3-5^{o}C /min), approximately, and after reaching the adopted temperature of 200, 300, 400 and 500 ^{o}C, the beams kept at the same temperature for half an hour. During the burning process time-deflection was measured by a dial gauge of 0.01 mm sensitivity placed at the mid-top point, **Fig. 2**.Then after the burned beams of a cetin group were cooled by the adopted methods (one gradually by leaving at lab temperature and the other suddenly by using water splash). The last stage was the repeated loading test. Each beams was tested under the effect of repeated load for five cycle then after up to failure. The adopted peak load of each cycle was (2500 kN), approximately.

3. RESULTS AND DISCUSSION

Results discussion considered two main items. The first focus on the output data of the burning stage. In this stage, cracks were generated on all beam surfaces with an intensity increased with the increasing of burning temperature, **Fig. 4** up to **Fig. 11**. For an individual beam the generated cracks were more distributed in the bottom surface (tension zone) due to the deflected shape produced by increasing the temperature and these cracks were mostly extended towered the side surfaces of the beam **Fig. 4** up to **Fig. 11**.There was also an increasing in the maximum crack width with the increasing of the fire temperature to reach 0.45 mm in a case of 500 ^{o}C and sudden cooling, **Table 11.** The results of this stage also improve the effect of the cooling method on the intensity of the generated cracks. Sudden cooling had more effect to generate cracks due to the variation in the rate of temperature rising and rate of temperature reducing (sudden cooling) which had a damage effect on the bond between concrete composite materials. Another phenomena was appeared in this stage this is the spalling of the concrete surfaces, all the beams that burned up to 400 ^{o}C and greater in addition to the beam that burned up to 300 ^{o}C with sudden cooling were spalled, **Fig.6** up to **Fig. 11**. This is usually belong to the rapid varying in the interior temperature caused by sudden cooling and/or high burning temperature that expand the consuming materials of the concrete (sand and gravel) and steel reinforcement, **DeHaan, John D, 2006, NFPA 921, 2004, Lentini, John J.,2006.**

During this stage, middle deflection of the tested beams was recorded versus the measured temperature. The trend of the deflection-temperature curves, **Fig. 12**, showed the compatibility between the curves in a case of individual temperature (same temperature and different method of cooling) and between cases of different temperature. This improve the control of the temperature rising rate that adopted in the test.

Repeated-load test was the second stage to be discussed. The results of this stage improved the effect of both temperature rise and method of cooling on the ultimate load capacity of the burned beams. Regarding the burning temperature, there was indirect proportion with the ultimate load capacity, increasing the temperature to (200, 300, 400 and 500) ^{o}C produced a reduction in ultimate load capacity by (16, 23, 54 and 71)% in a case of sudden cooling and by (8, 14, 36 and 64)% in a case of graduate cooling. While the effect of cooling method demonstrate that sudden cooling had more influence on the reduction of ultimate load capacity.

Even that the preliminary design of all the tested beams was checked to be flexure failure, the failure mode of all the burned beams was combined shear-flexure mode with different degree of participation between shear and flexure failure. As the burning temperature increase the percentage of shear failure increase and shear cracks began to generate in earlier stage of loading, **Fig. 13**. This is belong to the decrease in the compressive strength of concrete due to the breakdown of interfacial bond which is caused by the incompatible volume change between the concrete components during heating and cooling , **Georgali, B. and Tsakiridis, P. 2005, Koksal, et. al. 2011**.

Regarding the residual deflection, there was a variation in the behavior of the tested beams during the repeated-load. It was detected that the increasing in the burning temperature cause an increasing in the residual deflection by (32, 48, 326 and 358)% as the temperature increase to (200, 300, 400 and 500) ^{o}C for a case of sudden cooling and by (13, 29, 303 and 332)% for a case of graduated cooling and number of cycle that required to vanish the residual deflection.

4. CONCLUSIONS:

1. As a compared with the non- burred specimen, the results indicated that the ultimate load capacity of the tested specimens were reduced by (16, 23, 54 and 71)% after being burned to (200, 300, 400 and 500) ^{o}C , respectively, for a case of sudden cooling and by (8, 14, 36 and 64)% , respectively.
2. The effect of sudden cooling on the ultimate load capacity was greater than of that in a case of graduated cooling and this variance was reduced as the temperature increased.
3. There was a different in the failure mode between the non-burred specimen and the other ones even that all of them had the same geometric layout, compressive strength and reinforcement details. The failure mode for all burred specimens was combined shear- flexural failure which is belong to the reduction in the compressive strength of the concrete due to the effect of the

temperature, while the failure mode of the non-burred specimen was flexural failure which was compatible with the design.

4. It was detected that the residual deflection proportion directly with the temperature, as the temperature increase to (200, 300, 400 and 500) ^{o}C the residual deflection compared with the non-burned beam will be increased by (32, 48, 326 and 358)% for a case of sudden cooling and by (13, 29, 303 and 332)% for a case of graduated cooling.
5. Method of cooling affected the residual deflection. The result showed that the sudden cooling had more effect on the residual deflection than the graduated by (15-6)%, approximately.
6. After burning, cracks were performed on the concrete surface of the beams especially in tension zone (bottom surface), and these cracks increase in length, width and depth as the fire flame temperature increase.
7. Method of cooling had an effect on the intensity and width of the generated cracks, the sudden
8. The required number of cycles to vanish the residual deflection proportion directly with the fire temperature and sudden cooling method.

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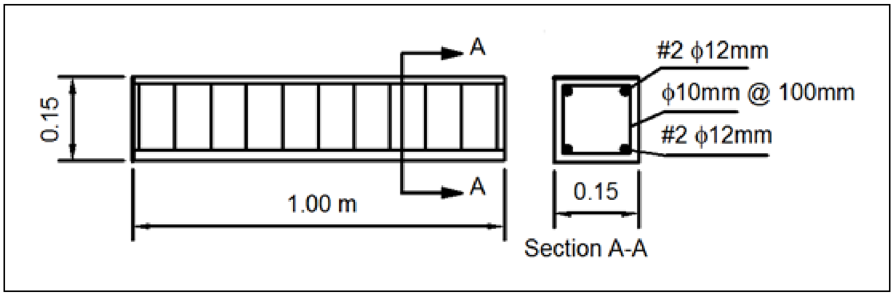
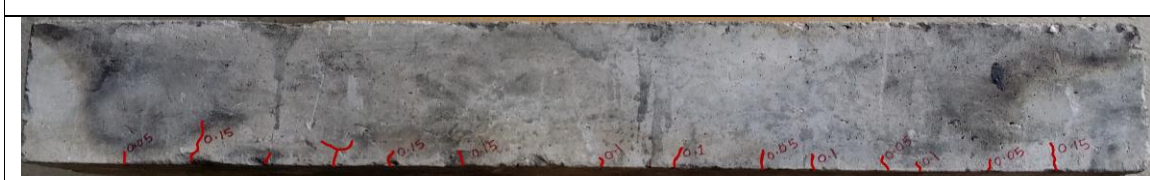


Figure 2. Steel finance setup.

Figure 3. Test Setup.

Figure 1. Geometric layout and reinforcement details of the tested beams.



S.V 1

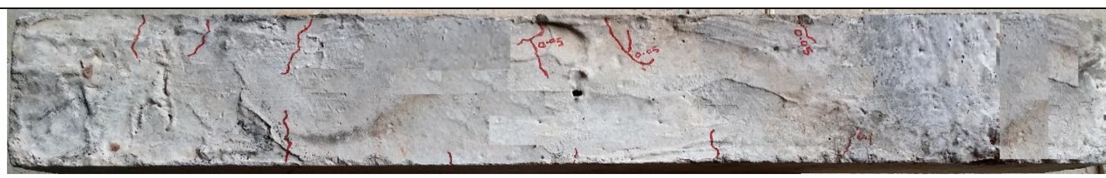
S.V.2

B.V.

Figure 4. Surface of specimen T200S after fire test.

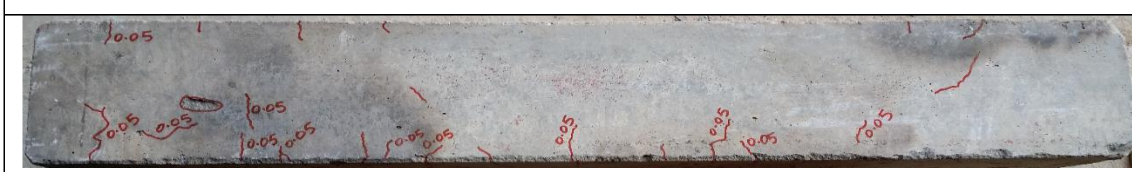
S.V. 1

S.V.2

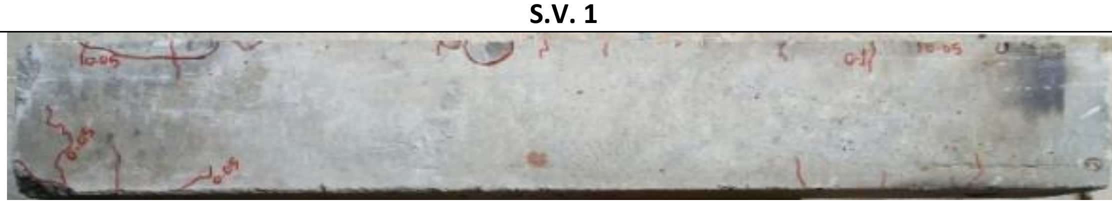


B.V.

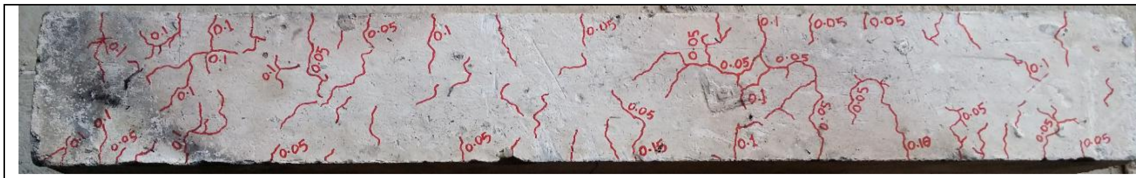
Figure 5. Surface of specimen T200G after fire test.



S.V. 1

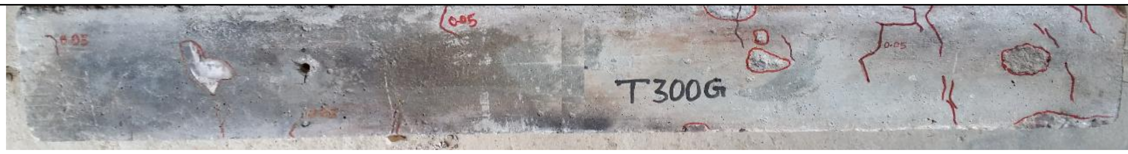


S.V.2



B.V.

Figure 6. Surface of specimen T300S after fire test.

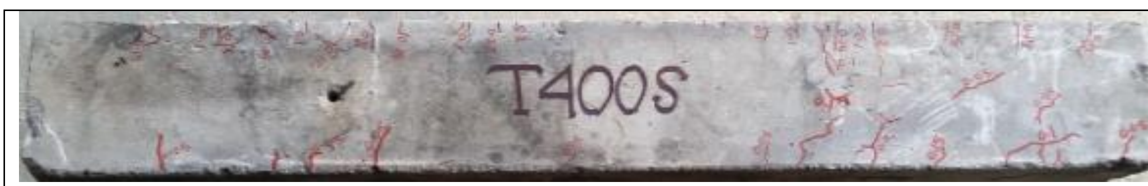


S.V. 1

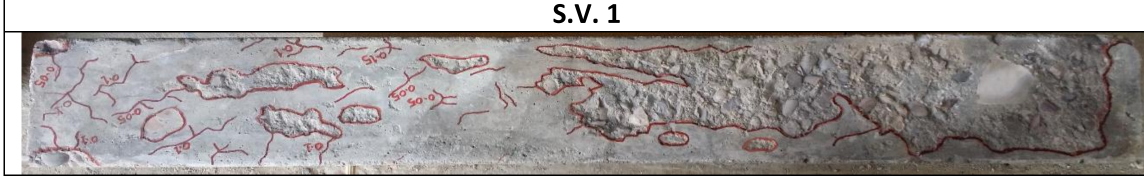
S.V.2

B.V.

Figure 7. Surface of specimen T300G after fire test.



S.V. 1



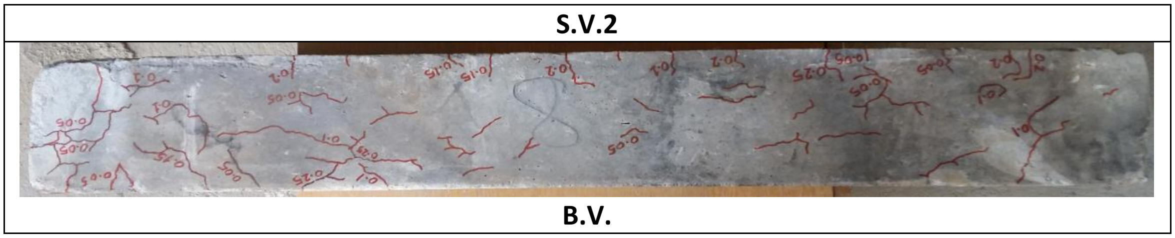


Figure 8. Surface of specimen T400S after fire test.

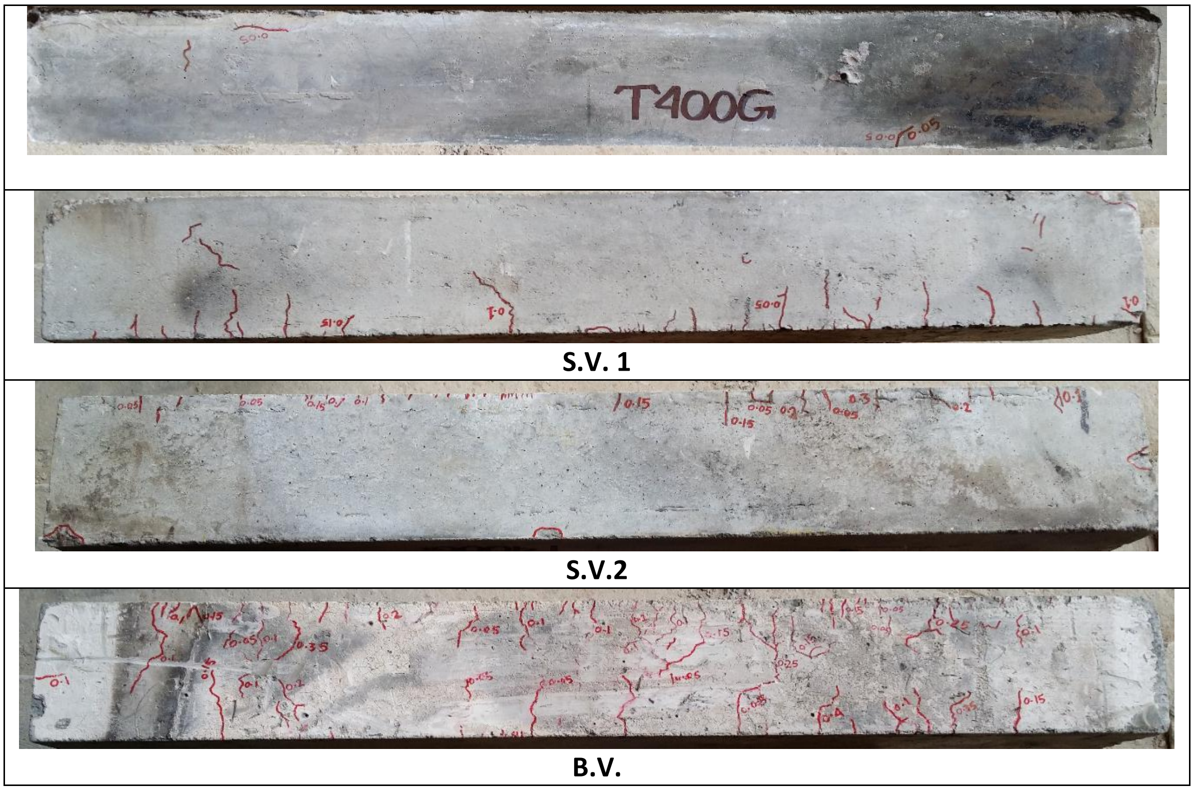


Figure 9. Surface of specimen T400G after fire test.

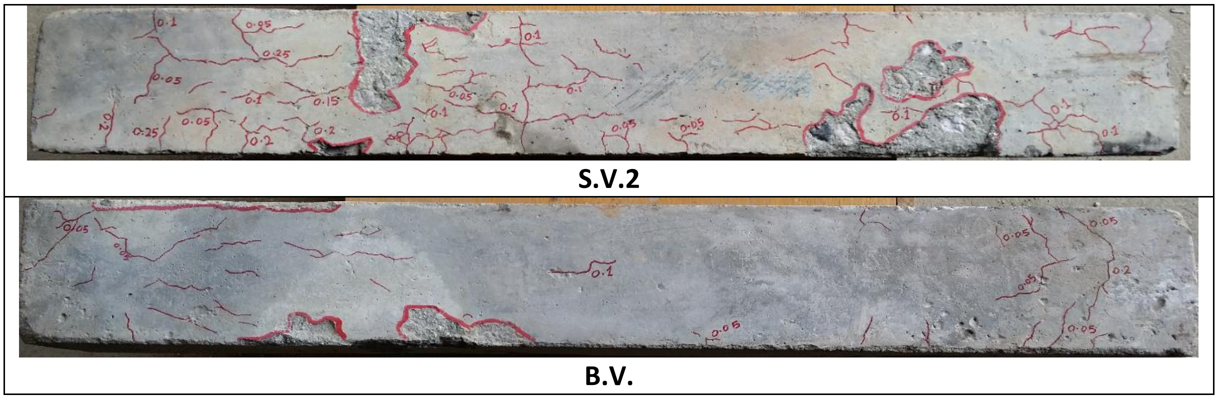


Figure 10. Surface of specimen T500G after fire test.

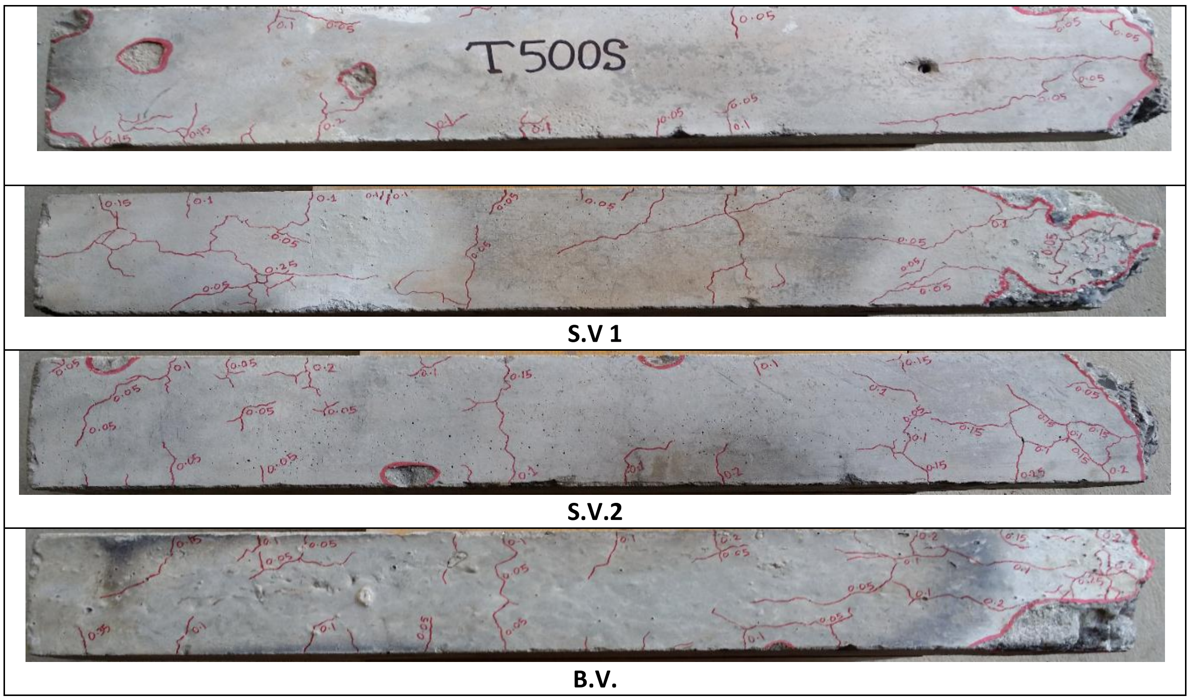
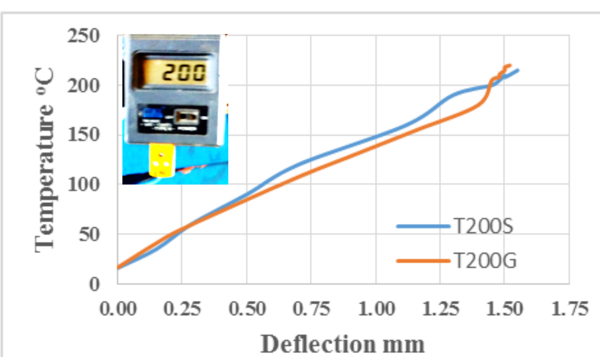
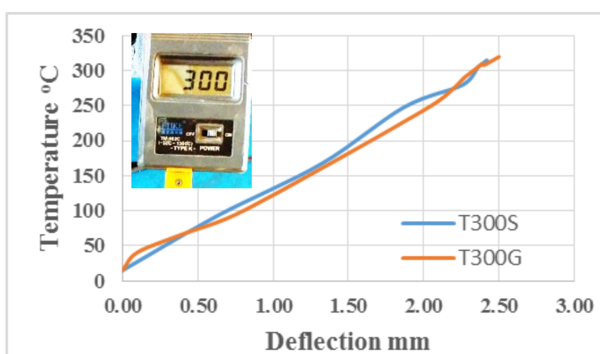
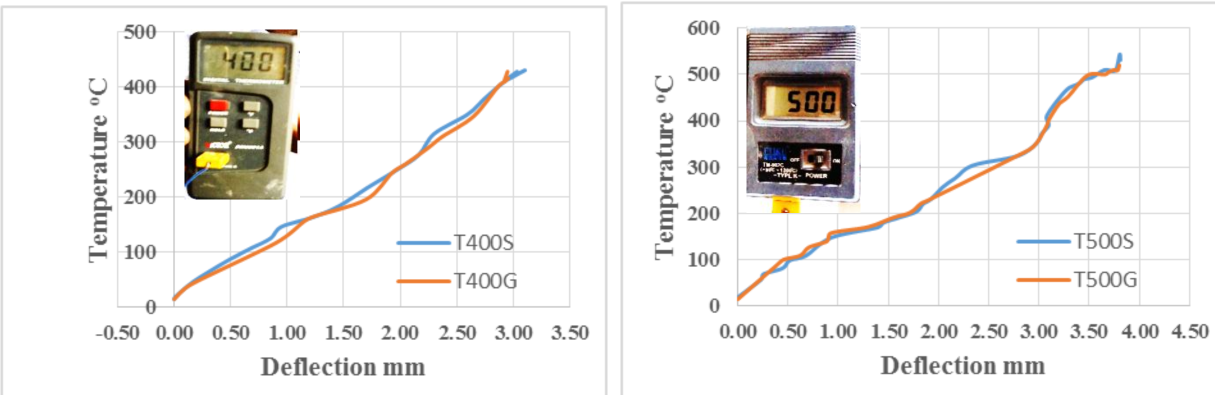


Figure 11. Surface of specimen T500S after fire test.



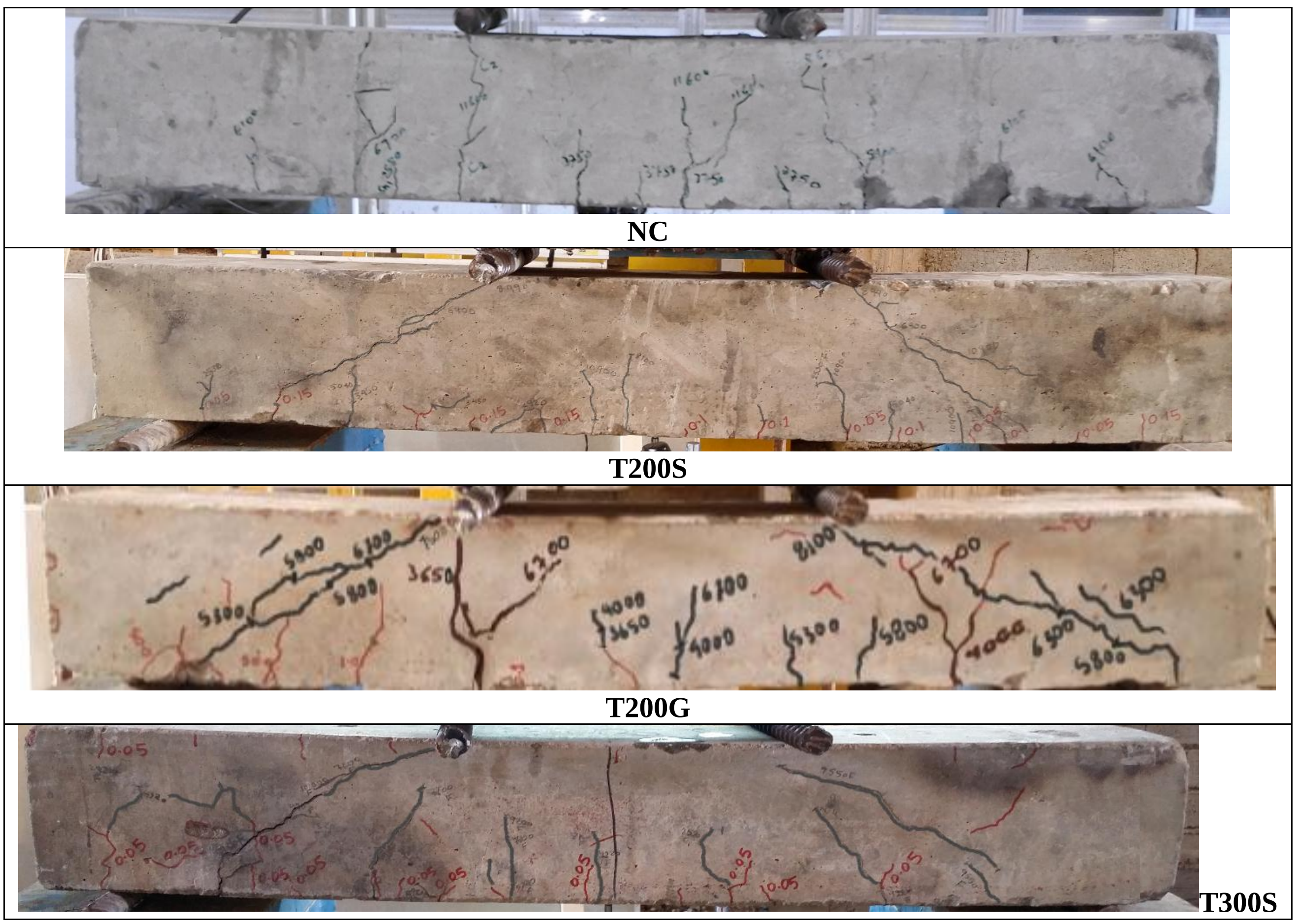


(a) Temperature = 200 °C **(b) Temperature = 300 °C**



(c) Temperature = 400 °C (d) Temperature = 500 °C

Figure 12. Deflection – temperature curves at burning test.

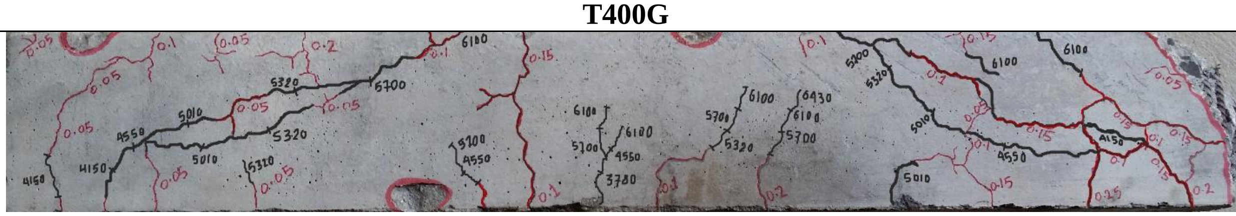


T300G

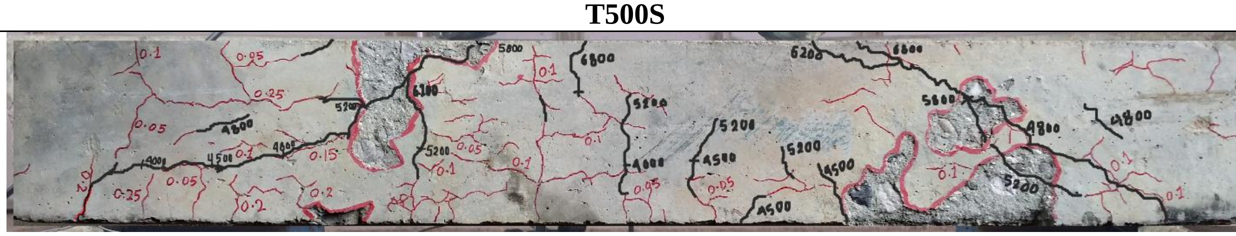
T400S

Figure 13. Crack pattern of specimens after repeated – load test.

T400G



T500S



T500G

Figure 13. Crack pattern of specimens after repeated – load test (Continue).

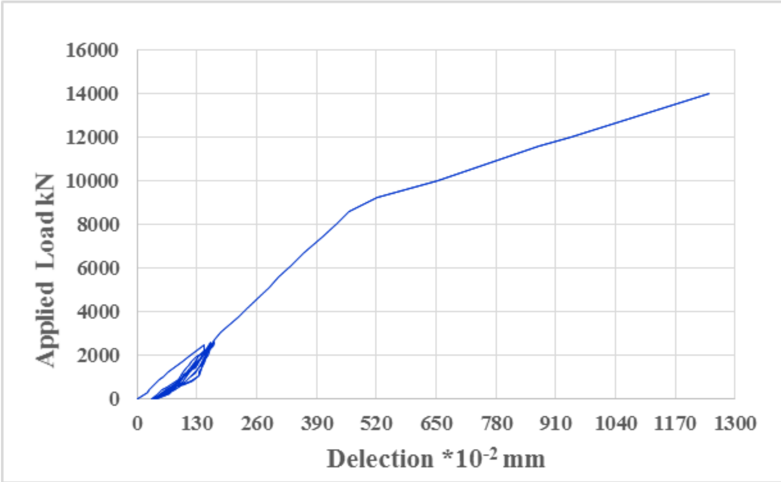


Figure 14. Load- central deflection of specimen WOF tested under repeated load

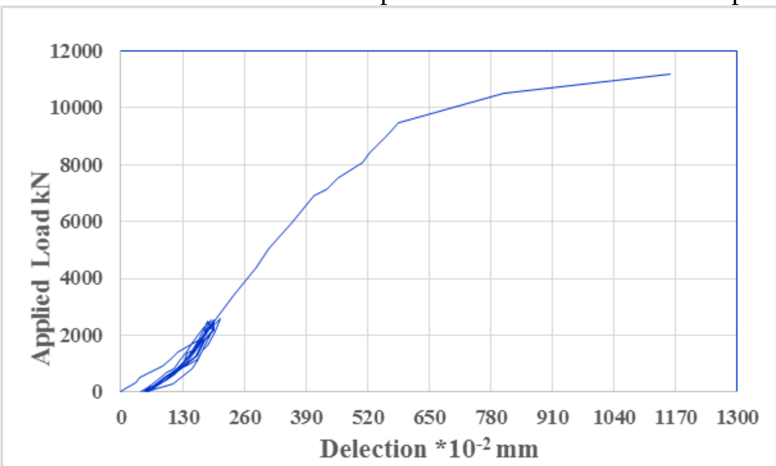


Figure 15. Load- central deflection of specimen T200S tested under repeated load.

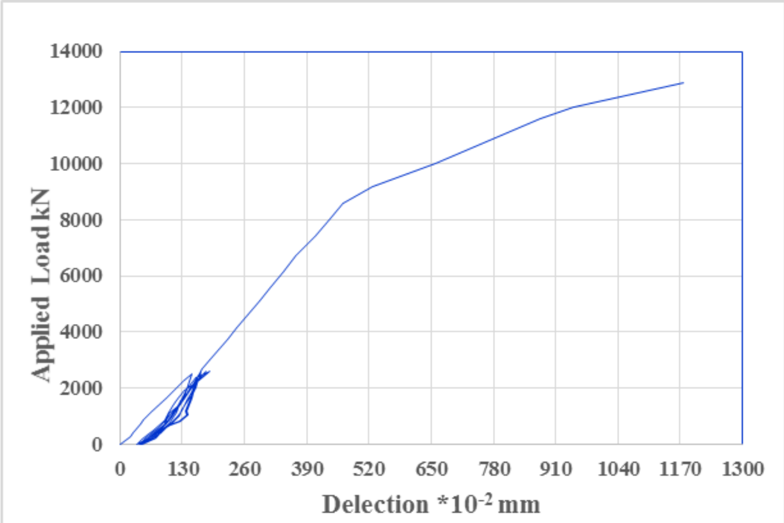


Figure 16. Load- central deflection of specimen T200G tested under repeated load

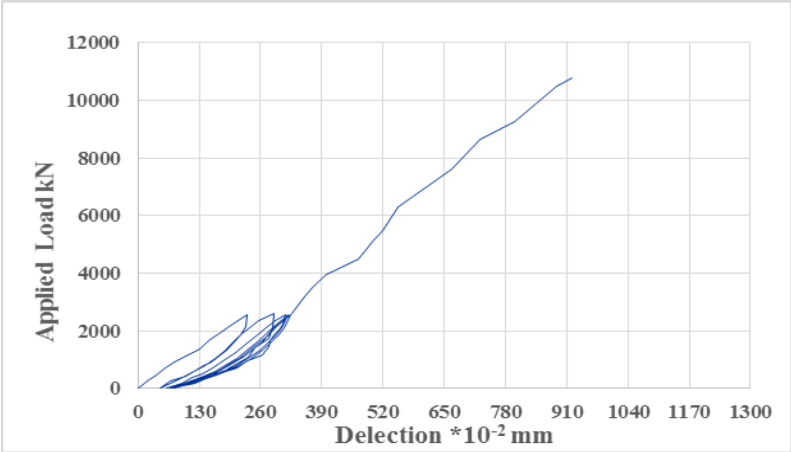


Figure 17. Load- central deflection of specimen T300S tested under repeated load

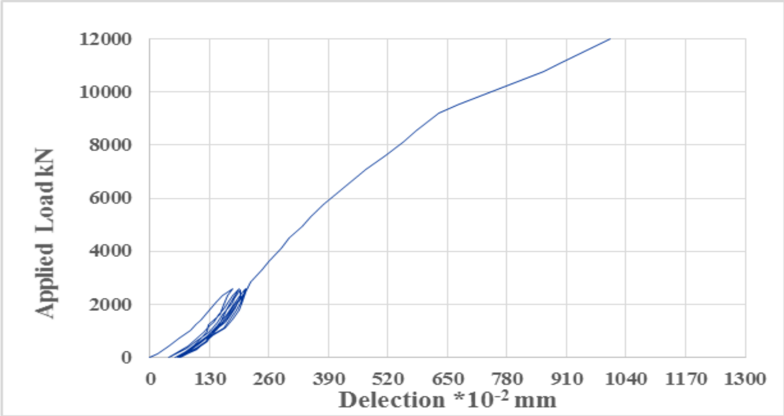


Figure 18. Load- central deflection of specimen T300G tested under repeated load

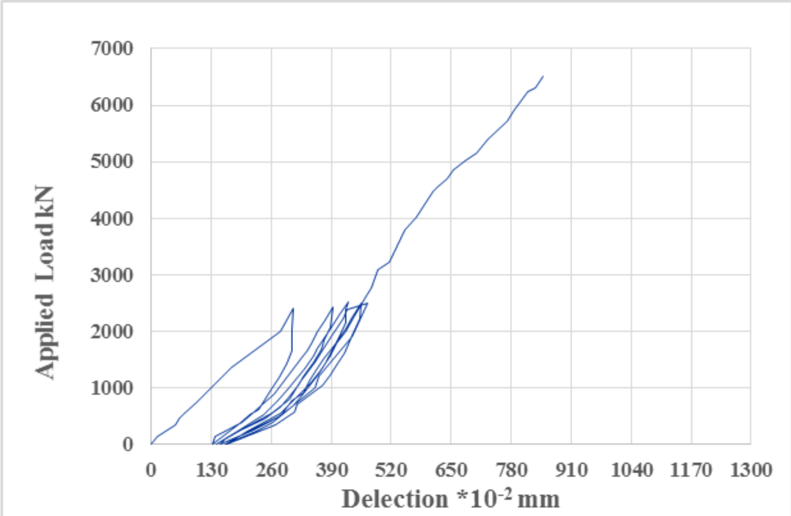


Figure 19. Load- central deflection of specimen T400S tested under repeated load

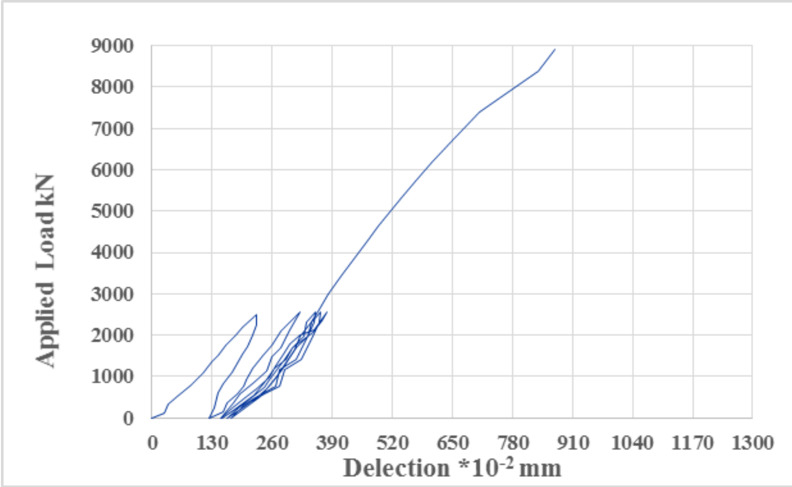


Figure 20. Load- central deflection of specimen T400G tested under repeated load

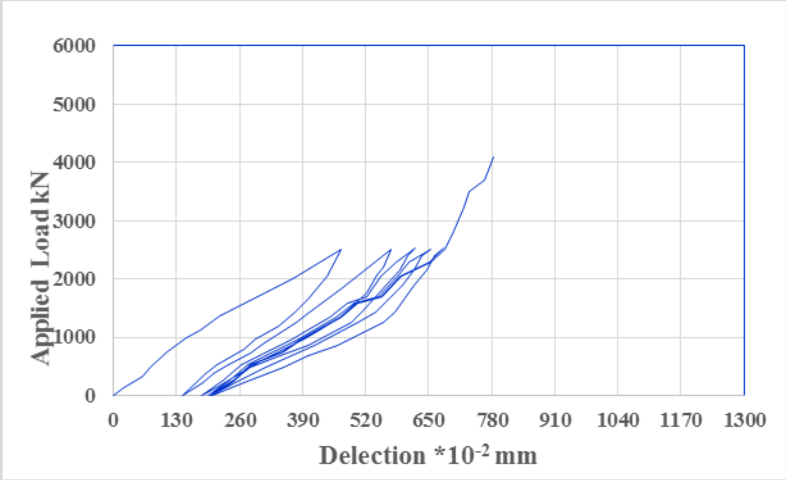


Figure 21. Load- central deflection of specimen T500S tested under repeated load

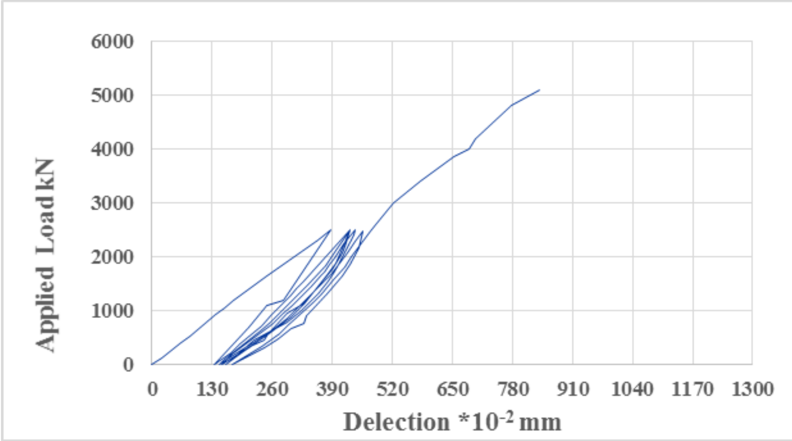


Figure 22. Load- central deflection of specimen T500G tested under repeated load

Table 1. Details of the adopted mix .

Mix Ratio (by weight)	w/c	Mix Proportion (kg/m^3)				SP*	SF**
		Water	Cement	Sand	Gravel		
1:2.35:2.59	0.29	163.3	563	750	883	2.4	3%

*lt /100 kg of cement (Max limit is 2.7).
** Replacement by weight of cement.

Table 2. Chemical composition of cement.*

No.	Compound Composition	Chemical Composition	% Weight	Iraqi Specification No. 5 / 1993
1	Silica	SiO_2	20.28	---
2	Alumina	Al_2O_3	5.00	---
3	Iron Oxide	Fe_2O_3	3.44	---
4	Lime	CaO	63.80	---
5	Magnesia	MgO	2.33	5 (max)
6	Sulfate	SO_3	2.4	2.8 (max)
7	Insoluble residue	I.R	1.27	1.5 (max)
8	Loss on ignition	L.O.I	3.00	4.0 (max)
9	Tricalcium aluminates	C_3A	0.58	---
10	Lime saturation factor	L.S.F	0.93	0.66 – 1.02
11	Tricalcium alumina ferrite	C_4AF	Not available	---
12	Tricalcium silicate	C_3S	Not available	---
13	Dicalcium silicate	C_2S	Not available	---
14		Fe_2O_3- Al_2O_3	Not available	---

*All the test were conducted by the National Center of Laboratories and Researches (Baghdad).

Table 3. Physical properties of cement.*

No.	Physical Properties	Test Result	Iraqi Specification No. 5 / 1993
1	Specific surface area (Blaine Method) m^2/kg	392	230 (min)
2	Setting time (Yicale's Method) Initial time setting : (hour: mint) Final time setting : (hour: mint)	 2:25 3:50	 00:45 (min) 10:00 (max)
3	Autoclave Expansion %	0.08	0.80 (max)
4	Compressive Strength, Mpa 7 days 28 days	 21.41 27.81	 15.00 (min)\ 23.00 (min)

*All the test were conducted by the National Center of Laboratories and Researches (Baghdad).

Table 4. Physical properties of the fine aggregate.*

No.	Physical Properties	Test Result	Iraqi Specification No. 45 / 1993
1	Specific gravity	2.63	---
2	Sulfate contained %	0.22	0.5 (max)
3	Absorption	0.50	---

*All the test were conducted by the National Center of Laboratories and Researches (Baghdad).

Table 5. Grading of the fine aggregate.

Sieve size (mm)	% Passing by Weight	Limit of Iraqi Specification No. 45 / 1993			
		Zone 1	Zone 2	Zone 3	Zone 4
10	100	100	100	100	100
4.75	100	90-100	90-100	90-100	95-100
2.36	91.8	60-95	75-100	85-100	95-100
1.18	76.5	60-90	55-90	75-10	90-100
0.60	51	30-70	35-59	60-79	80-100
0.30	12.2	5-34	8-30	12-40	15-50
0.15	2.7	5-20	0-10	0-10	0-15
$75x10^{-3}$	2.66	5 max			

Table 6. Grading of the coarse aggregate.

Sieve Size (mm)	% Passing by Weight	Limit of Iraqi Specification No. 45 / 1993
37.5	100	100
19	97.1	95-100
9.5	51.4	30-60
4.75	6.8	0-10

Table 7. Physical properties of the coarse aggregate.*

No.	Physical Properties	Test Result	Iraqi Specification No. 45 / 1993
1	Specific gravity	2.63	---
2	Sulfate contained %	0.04	0.1 (max)
3	Absorption	0.7	---

*All the test were conducted by the National Center of Laboratories and Researches (Baghdad).

Table 8. Chemical composition of silica fume.*

No.	Compound Composition	Chemical Composition	% Weight
1	Silica	SiO_2	92.03
2	Alumina	Al_2O_3	0.18
3	Lime	CaO	0.70
4	Iron Oxide	Fe_2O_3	1.10
5	Magnesia	MgO	2.10
6	Sulfate	SO_3	0.85
7	Loss on ignition	L.O.I	3.78

*All the test were conducted by the S. C. Geological Survey and Mining.

Table 9. Chemical requirements of SF according to ASTM C1240-03.

Chemical Composition	Test Result	Limit of ASTM C 1240-03
Silica (SiO_2), min	92.03	85.00
Loss on ignition (L.O.I) , max	3.78	6.00

Table 10. Technical description of GLENIUM51*.

Form	Viscous liquid
Color	Light brown
Relative density	1.1
PH	6.6
Viscosity	128 +/- 30 CPS
Transport	Not classified as dangerous
Labelling	No hazard label required

*Data sheet of the Manuscript.

Table 11. Details of the tested beams.

Beam Sample	Temp. ^oC	Cooling	Ultimate load kN	Residual deflection mm	Max. crack width after burning mm	Max. burning deflection mm
NC	-----	-----	14000	0.31	-----	------
T200S	200	Sudden	11700	0.41	0.25	1.55
T200G	200	Graduated	12900	0.35	0.10	1.52
T300S	300	Sudden	10800	0.46	0.30	2.42
T300G	300	Graduated	12000	0.40	0.20	2.5
T400S	400	Sudden	6500	1.32	0.40	3.05
T400G	400	Graduated	8900	1.25	0.35	2.95
T500S	500	Sudden	4100	1.42	0.45	3.81
T500G	500	Graduated	5100	1.34	0.35	3.80