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Experimental Investigation on Bending Behavior of Textile Reinforced Concrete (TRC) Plates at High Temperatures

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***Keywords*:**

Textile reinforced concrete TRC; flexural behavior; High temperatures; Dry carbon fibers.

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A B S T R A C T

Textile Reinforced Concrete (TRC) can be used as independent structural elements due to its high loading capacity and proper to product light weight and thin walled structural elements. In this study, the bending behavior of TRC plates that reinforced with dry carbon fiber textile and exposed to high temperatures was experimentally studied under 4-points bending loading. The examined parameters were; (a) number of textile fiber reinforcements layers 1, 2 and 3 layers; (b) level of high temperatures 20°C, 200°C, 300°C, and 400°C. Firstly, the mechanical properties of the cementitious matrix and the tensile properties of TRC coupons at each predefined temperature were evaluated. The results showed that the ultimate tensile stress of the TRC coupons did not affect up to 200°C, however, a significant reduction observed at 300°C and 400°C by 19% and 24% respectively. Regarding the compressive strength and flexural strength of the cementitious matrix, the degradation was not severe until 200°C, while it became critical at 400 °C (23% and 22% respectively). The result of the bending of TRC plates showed that doubling and tripling textile fiber reinforcements layers improved the flexural loading. In general, increasing the level of temperatures resulted in decrease in the flexural capacity of TRC plates. The highest decrease recorded for the specimen reinforced with 1-layer of carbon fiber textile subjected to 400 °C and was 33%.

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دراسة تجريبية لخصائص الانثناء للصفائح الخرسانية المسلحة بالالياف النسيجية والمعرضة لدرجات حرارة عالية.

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عاصم هجران عارف قسم الهندسة المدنية/ كلية الهندسة/ جامعة تكريت/ العراق.

الخلاصة

اصبح استخدام الخرسانة المسلحة بالالياف النسيجية كجزء انشائي مستقل شائع جدا وذلك بسبب قدرتها على تحمل الاحمال العالية وكذلك امكانية انتاج اجزاء انشائية بسمك قليل.في هذه الدراسة تم دراسة تصرف الانثناء لصفائح مصنعة من الخرسانة المسلحة بالالياف الكاربونية الجافة ومعرضة لدرجات حرارة عالية مع الاخذ بنظر الاعتبار المحددات التالية :(أ) عدد طبقات الالياف الكاربونية (1,2,3) طبقة,(ب) مستوى درجات الحرارة (20م°,200م°,300م°,400م°). بدايةً تم تقييم تأثير درجات الحرارة العالية على الخصائص الميكانيكية للخلطة الاسمنتية و على خصائص الشد للكوبونات ال (TRC) التي تتضمن طبقة واحدة من الالياف الكاربوينة الجافة ومن ثم تم اختبار خصائص الانثناء لصفائح ال(TRC) .بينت النتائج بأن خصائص الشد للكوبونات والخصائص الميكانيكية للخلطة الاسمنتية لم تتاثر بشكل ملموس لغاية درجة حرارة 200م°,بينما عند التعرض لدرجة حرارة 300م° و 400م° تم ملاحظة تدهور في الخصائص المذكورة عند المقارنة مع نفس الخصائص في درجة حرارة المحيط.كذلك بينت النتائج بأن زيادة عدد طبقات الالياف الكاربونية النسيجية من طبقة واحدة الى طبقتين وثلاثة طبقات يؤدي الى زيادة قابلية الانثناء لصفائح ال(TRC) عند المقارنة مع النموذج بطبقة واحدة وفي نفس درجة الحرارة.بشكل عام, ان زيادة درجة الحرارة يؤدي الى نقصان في قابلية الانثناء لصفائح ال TRC(النسيجية) وان اعلى نسبة نقصان تم تسجيلها عند درجة حرارة 400م° للنموذج المتضمن طبقة واحدة من الالياف الكاربونية وكانت 33%.

الكلمات المفتاحية: خرسانة مسلحة بالالياف النسيجية, خصائص انثناء, صفائح خرسانية, الياف كاربونية جافة نسيجية.

1. Introduction

Over the recent decades, Textile Reinforced Concrete (TRC) was used for external strengthening as a promising alternative to Fiber Reinforced Polymers (FRP) due to its favorable properties such as: low-cost materials, high tensile strength, convenient and safe for manual works, and acceptable performance at high temperatures. Research on TRC as external strengthening showed the effectiveness of TRC for: Confinement of RC columns [1,2,3], Flexural Strengthening of RC slabs and beams [4,5,6,7,8,9], Shear strengthening of RC beams [10,11], Seismic retrofitting of masonry-infilled RC frames and Strengthening of masonry members [12]. Today, there is a big challenge to produce and construct a unique structure with complex shapes and thin concrete element which is not possible for conventional reinforced concrete. Examples of such structures are exterior cladding systems and facades, slender pedestrian bridges, thin walled shell structures, and sandwich elements [13,14]. Therefore, researchers thought to embedded continuous fibers in form of textile with inorganic binders in the construction of new structures. The first case study was made in Germany in 1990 [15], leading to the product a composite known as textile reinforced concrete (TRC) [1,9,15]. This new composite has the following advantages [9,16]: Low-cost materials, high tensile strength, convenient and safe for manual works, acceptable performance at high temperatures, high quality of finished surface and aesthetics, free form design possibilities and reduced product thicknesses, enhanced durability characteristics, low environmental impact, and resistance to corrosion.

The new modern design codes have put into consideration the performance of structural elements at high temperature [9,16]. As TRC a new material in the field of construction, it's important to understand it's performance at high temperatures. Up to date a few studies are available in the previous studies on the performance of TRC structural elements exposed to high temperature [9]. In the next paragraphs, a briefly description on the previous studies.

Colombo et al., 2011[21]; De Andrade Silva et al. 2014[22]; Rambo et al., 2015[23] examined the residual strength of TRC coupons after being subjected to high temperatures. Different parameters were investigated, namely: the textile materials (glass textile) and level of high temperatures of 20°C, 200 °C, 400 °C, and 600 °C [21], (carbon textile) and level of high temperatures of 20 °C,100 °C,150 °C, 200 °C, 400 °C, and 600 °C [22], (basalt textile) , level of high temperatures of 20 °C,75 °C,150 °C, 200 °C, 400 °C, 600 °C,1000 °C and the number of textile layers (1,3 and 5) layers of basalt fibers textile [23].They concluded that exposure of 200°C has no effect on tensile strength of TRC coupons. Whereas, above that temperature, the tensile strength was progressively decreased. In specific, the residual tensile strength was 33% ,75%,37% at 400 °C for glass, carbon and basalt textile respectively compared to control specimens. However, they concluded that after 600 °C, the cementitious matrix and textile fiber showed significant reduction in the tensile strength. Also, the results showed that the use of 3 and 5 layers of basalt fabric provided great improvements on tensile strength by 120% and 260% respectively in comparison to the unreinforced specimen [23]. Linghua Shen et al., 2015[24], studied the effect of high-temperature on the performance of TRC thin-plates. Fourteen- thin plates with dimensions of (500 × 100 ×16) mm in length, width and thickness fabricated and reinforced with three-layer of hybrid textile made of carbon and glass fiber textile. Four specimens reinforced with textile impregnated with epoxy resin and the other specimens reinforced with dry textile. They give name type 1 for the epoxy impregnated textile reinforcement while the others non- impregnated textile reinforced specimens had the name type 2. The specimens subjected to heating level up to (200 °C, 400 °C, 600 °C, and 800°C) using a furnace and then cooled down to ambient temperature. All specimens were subjected to four-points bending loading. The test results for type1 specimens showed that no significant change in ultimate load with brittle failure mode till 200 °C, but after 300 °C, the specimens destroyed and the burst ratio of these specimens reached to 100% due to the weak thermal resistance of epoxy under high temperature leading to a decrease in interfacial bonding performance between the textile fiber. The ultimate load of type 2 specimens was lower than type1 at the same high temperature and showed a high ductility failure during the damage process till 800 °C. Failure mode of type 2 specimens characterized by crack opening followed by pulling out the textile filaments from the matrix. A comparison between the ultimate load of type 2 at room and high temperatures sowed that, the ultimate load decreased by 12.5%, 52.4% and 80% at (400 °C, 500 °C and 800 °C) respectively.

According to above literature, a few studies are available on the performance of TRC coupons at high temperatures. In the current study, the researchers went further steps by study the influence of high temperatures on the flexural performance of TRC plates. Also, evaluating the influence of high temperatures on the mechanical properties of the cementitious matrix and the tensile properties of TRC coupons.

2. Experimental program

The experimental program included testing of thirteen TRC plates with dimensions of (1000× 300 ×50) mm in length, width and thickness. One specimen was un-reinforced as a control specimen. Whereas the rest twelve specimens were reinforced with carbon fiber textile. The examined parameters were; (a) number of textile fiber reinforcements layers 1, 2 and 3 layers; (b) level of high temperatures 20°C, 200°C, 300°C, and 400°C. Firstly, the mechanical properties of cementitious matrix and the tensile properties of TRC coupons at predefined temperatures was evaluated. Then, the flexural behavior of the TRC plates at ambient and high temperature was assessed using 4-points bending test.

2.1.Specimens details

Thirteen specimens with dimensions of (1000 × 300 × 50) mm in length, width and thickness were fabricated, reinforced with 1,2, and 3-layers of dry carbon fiber textile fiber. All specimens were subjected to different high temperatures, cooled down to ambient temperature and then tested under 4-point bending loading. The cover of all specimens was 5 mm. A 5-mm spacing between the reinforced layers was left for the specimens that reinforced with more than one layer as shown in Fig.1. Also Table 1 shows the details and notation of TRC plates. Specimen's notations include N-C-Y, where N refers the number of layers, C refers dry carbon textile fiber and Y the level of temperature.

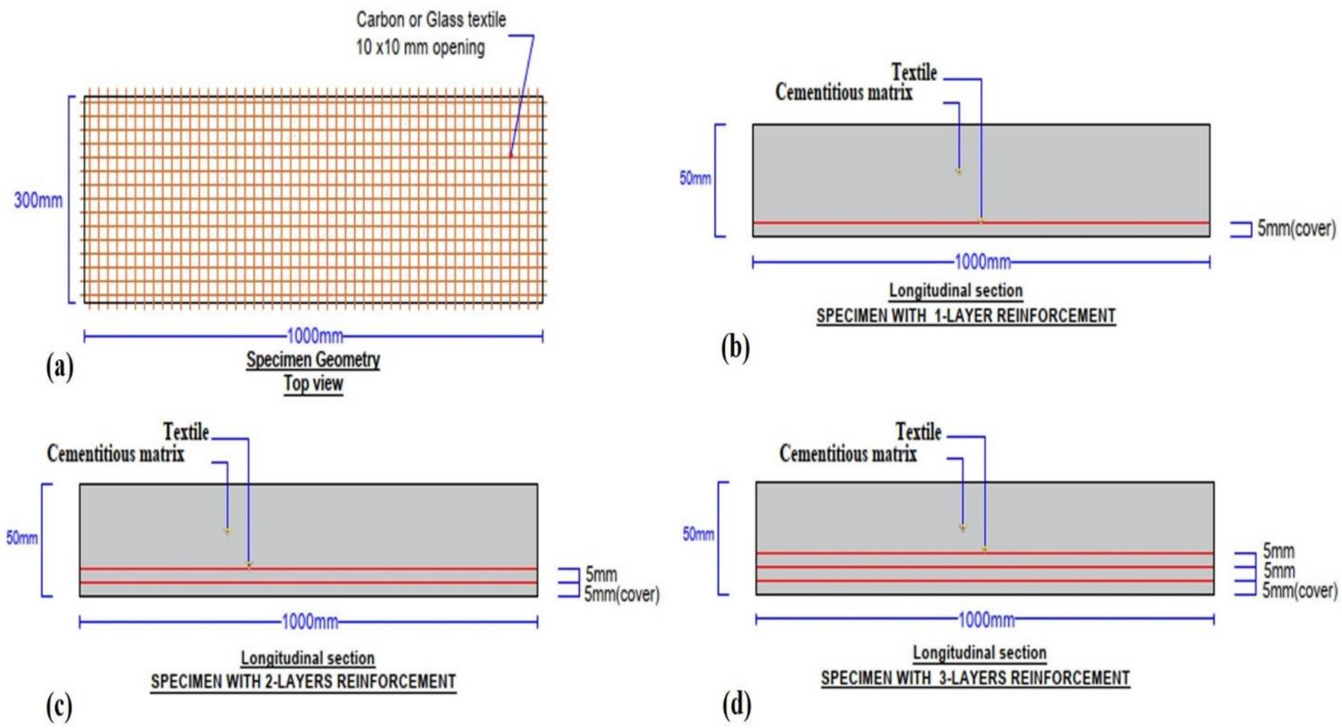


Fig.1: Details of tested TRC plates and internal reinforcement.

Table 1:
TRC plates details with dimensions (1000mm ×300mm ×50mm).

Specimen Name	No. of Textile Layers	Target Temperature Level (°C)
Non-Reinforced	0	Ambient temperature (20 °C)
1-C-20	1	Ambient temperature (20 °C)
1-C-200	1	200 °C
1-C-300	1	300 °C
1-C-400	1	400 °C
2-C-20	2	Ambient temperature (20 °C)
2-C-200	2	200 °C
2-C-300	2	300 °C
2-C-400	2	400 °C
3-C-20	3	Ambient temperature (20 °C)
3-C-200	3	200 °C
3-C-300	3	300 °C
3-C-400	3	400 °C

2.2. Cementitious matrix

The cementitious matrix used to produce TRC is generally composed of cement, fine-grained particles, cement replacement materials such as (fly ash, silica fume) and superplasticizer. Ordinary Portland cement and fine aggregate (sand) with maximum aggregate size 2 mm were used in this study. The flexural and compressive strength of the cementitious matrix at the predefined temperatures were calculated experimentally according to BS EN 1015-11 (1999) [25], and the results presented in next section. A flow-table test was conducted to assess the workability and flow able properties of the fresh matrix. The test was performed according to ASTM C 1437 - 15 Standard test method for flow of hydraulic cement mortar [26]. Table 2 shows a detailed description of the materials used for the matrix.

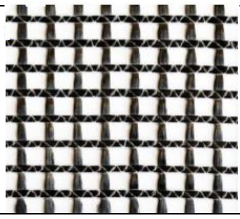
Table 2:
Cementitious matrix details.

Cement Kg/m³	Sand Kg/m³	Fly ash Kg/m³	Silica Kg/m³	W/C	Super plasticizer Kg/m³	Percentage of flow
500	1400	150	27.5	0.4	15	110%

2.3. Textile fiber materials

Dry carbon fiber textile was used in this study. The geometry of the roving of textiles were distributed equally in two directions orthogonally. Details of the textiles according to the manufacturer datasheets given in Table 3.

Table 3:
Details of the textiles according to the manufacturer datasheets

	Dry Carbon Fiber Textile	
Nominal thickness (mm)	0.095	
Weight: (g/m²)	170	
Mesh size (mm)	10×10	
Density: (g/cm³)	1.75	
Tensile strength (MPa)	4800	
Elastic modulus (GPa)	>240	

2.4. Tensile test on bare textile and TRC coupon

Uniaxial tensile tests were performed on bare textile in order to determine the tensile properties of textile fiber at ambient temperature and to determine the tensile properties of TRC coupons at ambient and high temperature. The test conducted according to (ACI 549-Guide for the design, construction and repair of Ferro cement) [27]. A universal testing machine of 30-kN capacity was used in this test. The tensile test of bare textile conducted on three coupons comprised one layer of dry carbon textile with dimensions of 520mm length ,50mm width. Whereas, the tensile test for TRC coupons conducted on three coupons for each temperature with dimensions of (520×50×6) mm in length, width and thickness reinforced with one layer of dry carbon textile. The coupons gripped to the machine using aluminum plates glued at the ends of the specimens with dimensions 50mm×60mm. Figs.2 and 3 shows the test details. The test results are presented in the next section.

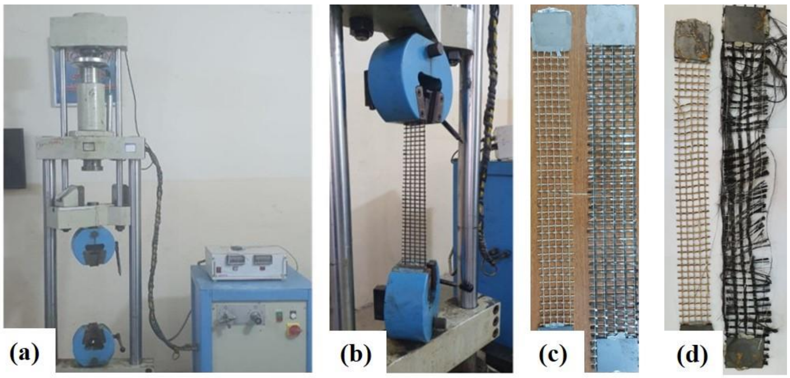


Fig.2: Details of tensile tests on Bare Textiles, (a) universal testing machine of 30-kN capacity, (b) specimen's setup, (c) Bare Textiles specimen, (d) failure mode.

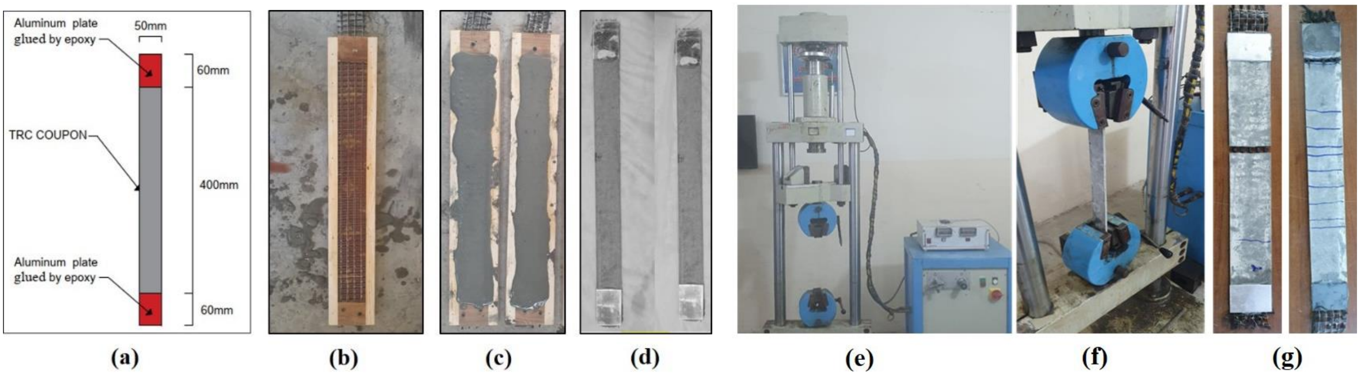


Fig.3: Details of TRC coupons test, (a) geometric of coupon, (b) details of the mold, (c) casting stage, (d) TRC coupons glued with Aluminum plates after heating, (e) universal testing machine used, (f) test set up, (g) failure mode.

2.5. Casting procedure of TRC plates

Fig.4 shows casting procedure of TRC plates specimens. The mold designed with movable plate parts 5mm thickness at the two ends to stretching and fixing the textile mesh. The textile reinforcement was placed in the mold prior to placing mortar as shown in (Fig.4.b). To hold the textile reinforcement layers in their specific location, high tensile wires were extended in the short direction of the mold (see Fig.4 d and e). This was achieved by making holes in the longitudinal sides of the mold. The distance between each raw of hole was equal to 5 mm. The wires were pass through these holes to hold the reinforcement in the specific location and to maintain spacing between the textile reinforcement layers (5 mm). The cementitious matrix was poured in the mold in three layers. A shacking table was used to compact each layer to ensure a good penetration through the textile openings. During casting, a thermocouples type J-800°C was embedded at the core of the specimens as shown in (Fig.4 b) to measure the temperature at the core of the specimens during heating process. The surface of the specimens was then leveled and finished with a trowel. Cubes with dimensions of 70×70×70 mm and prisms with dimensions 160×40 ×40 mm were also taken from each casting stage. After 24 hrs., the specimens were taken off from the mold and cured by wrapping the specimens with wet fabrics for 28 days. After the 28 days and before the heating test, all specimens were dried in an electric furnace for 24 hours.

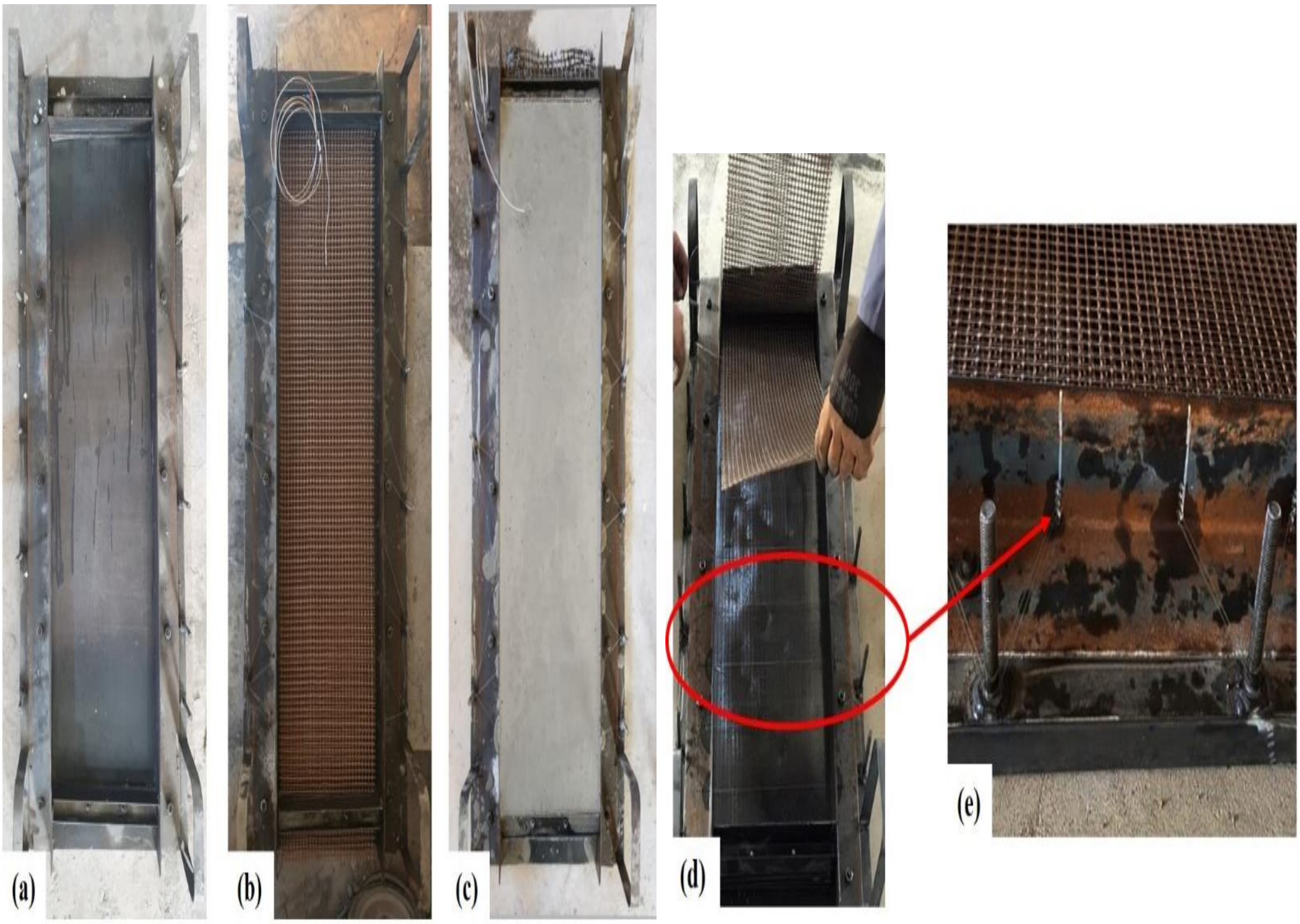


Fig.4: Casting procedure of TRC plates, (a) steel mold preparation, (b) placing textile layers and fixing the thermocouple, (c) placing mortar in the mold, (d) details of holding the textile reinforcement layers by wires, (e) enlarge details for holding details.

2.6. Heating procedure

The heating procedure were conducted according to ASTM E119[28]: "standard test methods for fire tests of building construction and materials" (see Fig.5). An electric furnace with maximum temperature of 1200 °C was designed by the researchers and manufactured specifically for this study. The dimension of the chamber room of the furnace were (1500 × 600 ×600) mm in length, width and height. Fig.6. a, b, c shows the details of furnace. The heating procedure was as follows: the specimens were dried using the furnace. The drying procedure included exposing the specimens to a temperature of 100 °C for 24 hours before being subjected to the pre-defined temperature. This was applied to reduce the moisture content to avoid evaporation which might lead to explosion. Thereafter, heating was applied to the specimens at a rate of 10°C /min till the core of the specimens reached the targeted temperature. A data logger was used to monitor the temperature to ensure that the temperature at the core of the specimens reached the targeted temperature. After reaching the targeted temperature, the specimens were kept at this temperature for 30 minutes, and then left to cool down to the ambient temperature. At the same time, TRC coupons, mortar cubes and prisms exposed to heating for each target temperature in order to evaluate tensile properties of TRC coupons and matrix mechanical properties at each pre-defined temperature. (Fig.6. d, e, f, g) shows the heating procedure.

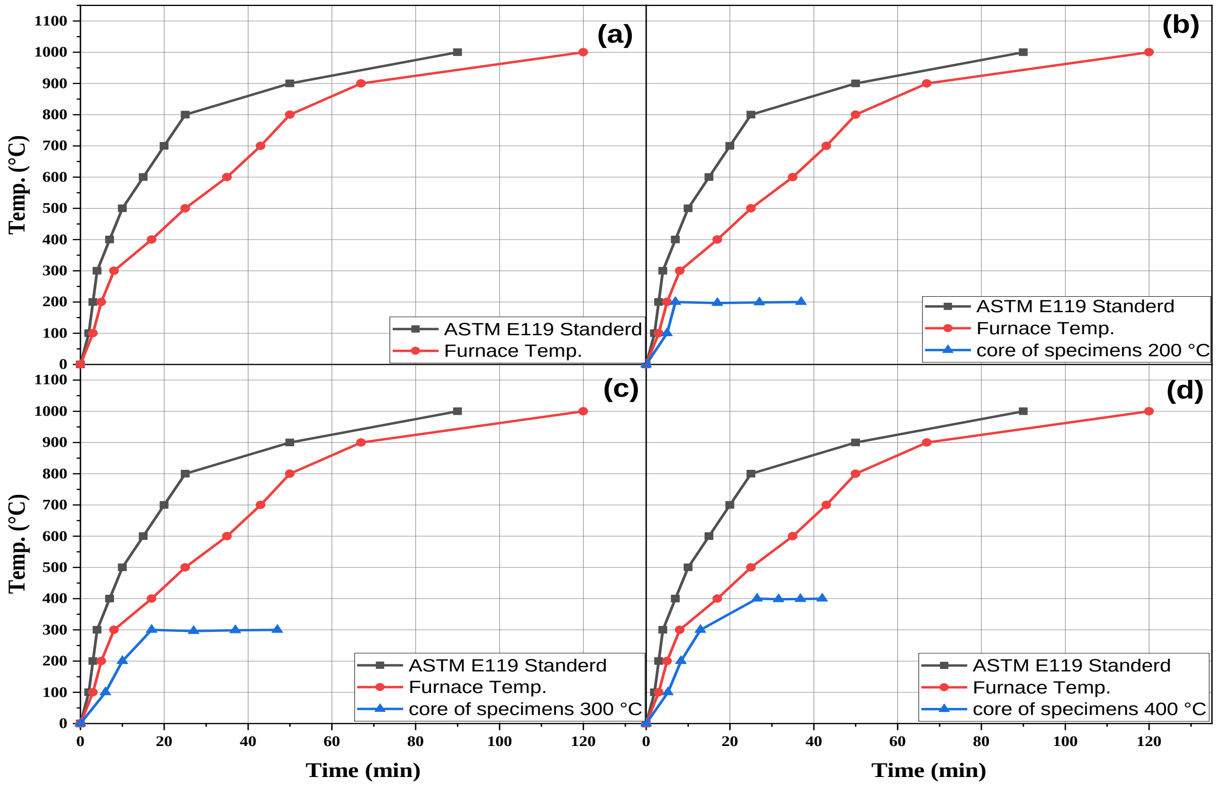


Fig.5: Temperature evolution during heating procedure.

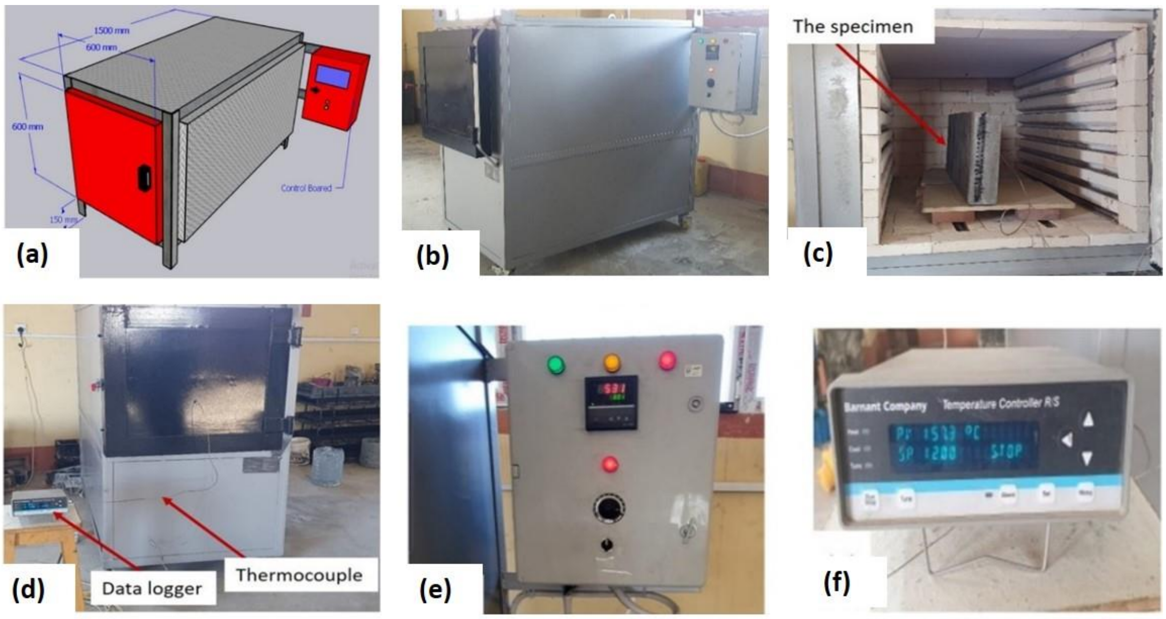


Fig.6: Heating procedure, (a)furnace dimensions, (b) furnace after manufacturing, (c) specimen inside the furnace room, (d) monitoring the specimens core temperature, (e) monitoring the furnace temperature (f) data logger used for monitoring specimens core temperature.

2.7. Four-point test setup

The specimens were tested in flexural using four-point bending tests. The specimen was installed in a loading frame that fixed in the universal machine. The load was applied to the specimens under a displacement rate of 1.25 mm/sec using a universal machine with capacity 2000 kN. An LVDT (Linear Variable Differential Transformer) was mounted on top of the TRC specimen to record the mid-span deflection. The deflection and the applied load on the specimen were recorded by using a data logger. Fig.7 shows the test procedure.

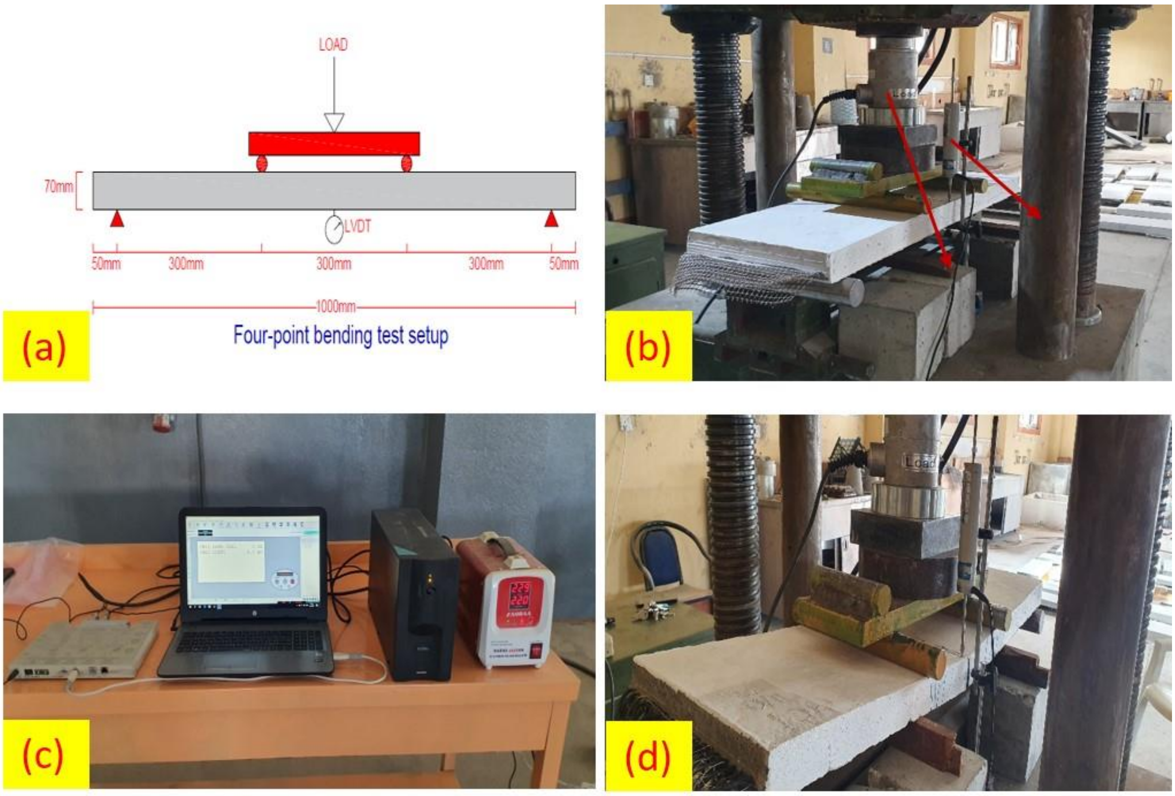


Fig.7: (a) four-point test details, (b) specimen instrumentations, (c) load and deflection monitoring by data logger, (d) Failure of specimen.

3. RESULTS AND DISCUSSION

3.1. Compressive and flexural strength of cementitious matrix

The results of the compressive strength and flexural strength of the cubes and prisms are shown in Table 4. These results represent the average of three cubes and prisms that were tested at the day of testing for each temperature. This table also provides the percentage of the residual compressive and flexural strength of the cementitious matrix due to exposure to high temperatures. As shown in the Table, the reduction in the compressive and flexural strength was not significant up to 200 °C recording 5% and 4%. However, above this temperature, the reduction in the strength sharply increased. In specific, at 300 °C, and 400 °C the reduction in the compressive strength recorded 18% and 23% while the reduction in the flexural strength recorded 11% and 22% respectively. The flexural strength (F) is calculated from the equation: $F=\frac{3PL}{2bd^2}$, where (b) and (d) are the internal dimensions of the prism, (L) is the distance between the supporting rollers, and (P) is maximum flexural load. The residual of the compressive and flexural strength at each high temperature calculated according to the following equation : : $[1-(\frac{X_\circ - X}{X_\circ})]\times 100\%$, where ($X_\circ$) is the compressive or flexural strength at ambient temperature ,(X) is the compressive or flexural strength at high temperature.

Table 4:

Residual compressive strength of cubes and residual flexural strength of prisms at high temperature.

Level of temperature (°C)	Compressive strength (MPa)	Flexural strength (MPa)	Residual Compressive strength	Residual Flexural strength
20°C*	64.1	15.2	-	-
200°C	60.8	14.6	95%	96%
300°C	52.3	13.5	82%	89%
400°C	49.3	11.8	77%	78%

*Reference specimen.

3.2. Tensile test of bare textile and TRC coupon

The results of the tensile tests are presented in Table 5. These results are reported in terms of ultimate tensile stress. The percentage of residual ultimate tensile stress was also reported. As shown in this table, the ultimate tensile stress of the TRC coupon did not affect up to 200 °C. However, above this temperature the residual ultimate tensile stress at 300°C and 400°C were 81% and 76% respectively. All TRC coupons failed due to rupture of the fibers at the central region (Fig.8). The residual of the compressive and flexural strength at each high temperature calculated according to the following equation : $[1-(\frac{T_o-T}{T_o})]\times100\%$, where ($T_o$) is the ultimate tensile stress at ambient temperature ,(T) is the ultimate tensile stress at high temperatures.

Table 5:

Summary of results of the tensile tests.

Coupon Name	No. of layers	Ultimate tensile Strength (MPa)	Residual Ultimate tensile Strength (%)
		Tensile Test Results on Bare textile at 20 °C	
Bare textile	1	3044	-
		Tensile Test Results on TRC Coupons at (20°C, 200°C, 300°C and 400°C).	
1-C-20*	1	3389	-
1-C-200	1	3167	93%
1-C-300	1	2756	81%
1-C-400	1	2578	76%

*Reference specimen.

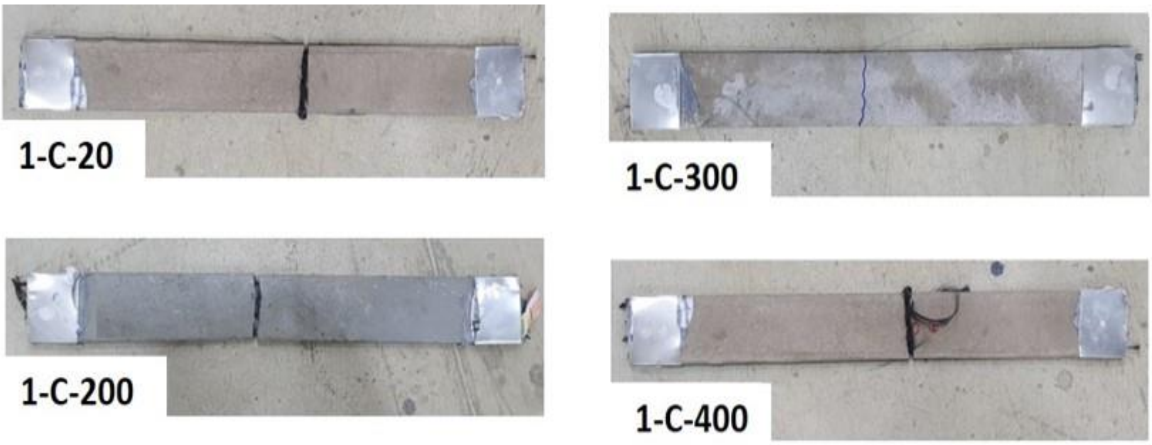


Fig.8: Failure mode of TRC coupons at the predefined temperatures

3.3. Four-point test

The results of all tested specimens are presented in Table 6. These results include; (1) The maximum ultimate load, (2) The deflection at ultimate load, (3) The percentage of the residual bending capacity due to effect of high temperatures, (4) The flexural increases at ambient temperature, (5) Specimen's failure mode**.** The residual of ultimate load at each high temperature calculated according to the following equation : $[1-(\frac{P_o-P}{P_o})]\times100\%$, where ($P_o$) is the ultimate load at ambient temperature ,(P) is the ultimate load at high temperature. Also, the increasing in the ultimate load at ambient temperature calculated according to the following equation : $(\frac{Pr-Pc}{Pc})\times100\%$, where ($P_r$) is the ultimate load of reinforced specimen at ambient temperature ,(P_c) is the ultimate load of non-reinforced specimen.

Table 6:

Summary of Four- point bending test results

Specimen Name	Ultimate Load (kN)	Ultimate Deflection (mm)	Residual Ultimate Load (%)	Flexural Increases at Ambient Temperature (%)	Failure Mode**
			Non-Reinforced Specimen		
Non-Reinforced	5.78	0.405	-----		F
			Specimens Reinforced By Dry Carbon Fiber Textile		
1-C-20*	10.7	0.94	-	85%	R+F
1-C-200	9.03	0.96	84%		R+F
1-C-300	7.37	0.85	69%		R+F
1-C-400	7.13	0.97	67%		R+F
2-C-20*	13.76	1.38	-	138%	R+F
2-C-200	11.25	1.24	82%		R+F
2-C-300	10.54	7.4	77%		R+F
2-C-400	10.33	6.55	75%		R+F
3-C-20*	14.3	1.37	-	148%	R+F
3-C-200	12.07	4.15	84%		R+F
3-C-300	11.47	6.8	80%		R+F
3-C-400	10.74	9.9	74%		R+F

*Reference specimen.

**(F): Flexural failure, (R+F): Flexural failure due to rupture of textile fiber.

3.4. Load –mid span deflection

(Fig.9, a) represents the flexural load versus mid-span deflection curve of the specimens tested at ambient temperature and (Fig.9. b, c, and d) represents the flexural load versus mid-span deflection curve of control specimens (specimens tested at ambient temperature) related to specimens exposed to high temperatures. The non-reinforced specimens were involved in these curves for the sake of comparison. The load-mid span deflection for non-reinforced specimen was characterized by one stage, namely; linear behavior up to failure due to absence of reinforcement, whereas, for the reinforced specimens with textile fiber, the load- displacement curves had two different stages;

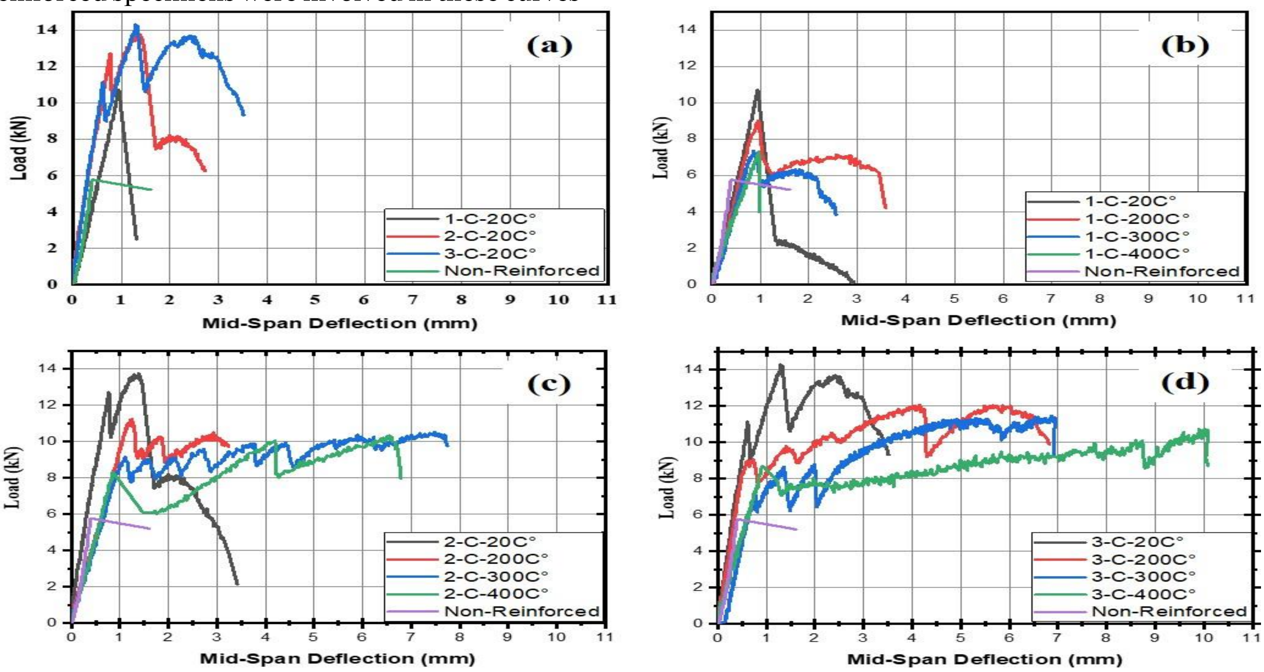


Fig.9:(a) Load – mid span deflection curves at ambient temperature, (b, c, and d) Load – mid span deflection curves at high temperatures.

Stage1: (un-cracked stage) the behavior was primarily governed by the stiffness of cement matrix up to cracking and stage2: (cracked stage) non-linear with fluctuation, due to progressive of the transformation of stresses to the layers of the textile with continuous decrease in the stiffness until the failure occurred. From the load-deflection curves a compression between non reinforced specimen and reinforced specimen showed the effect of applying the reinforcement using textile fiber. The second stage of load-deflection curves clearly showed increasing in bending capacity of reinforced specimens. After reaching the ultimate load, a significant change in ultimate load with brittle failure occurred due to rupture or slippage of textile fiber. Thus, the reason why the ultimate load decreased will be discussed later.

3.5 Ultimate loads and failure modes

3.5.1. At ambient temperature.

The results of the ultimate load and the failure mode of the tested specimens are presented in Table 6. The ultimate load of the control specimens 1-C-20, 2-C-20, 3-C-20 which reinforced by 1, 2 and 3-layers of carbon fiber textile was 10.7 kN, 13.77 kN, and 14.31 kN respectively. Hence, the gain in the strength of the specimens reinforced with carbon textile was 85%,138%, and 148% respectively compared to non-reinforced specimen. The observed failure mode of these specimens was flexural failure due to rupture of fibers (Fig.10).

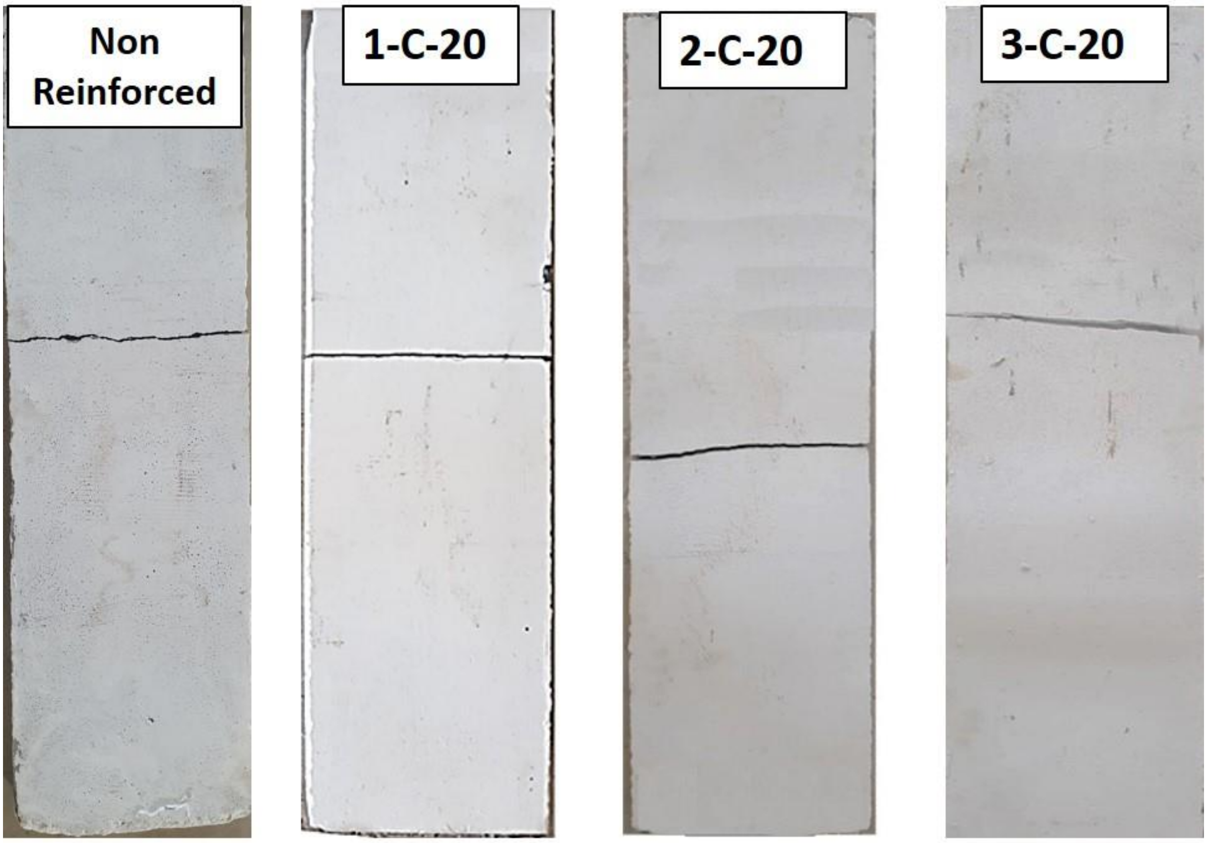


Fig.10: Failure mode of specimens tested at ambient temperature.

3.5.2. At high temperatures

Increasing the temperature from ambient to 200°C, 300°C and 400°C led to a decrease in the ultimate flexural load compared to the ambient load. When the Targeted Temperature (TR) reached 200°C, the residual ultimate load for specimens 1-C-200, 2-C-200, 3-C-200 were 84%, 82%, and 84% respectively. At 300°C, the residual ultimate load for specimens 1-C-300, 2-C-300, 3-C-300 was 69%, 77%, and 80% respectively. Finally, at target temperature 400°C, the residual ultimate load for specimens 1-C-400, 2-C-400, 3-C-400 were 67 %, 75%, and 74 % respectively. This dropped in ultimate load was due to reduction in tensile properties of carbon fiber textile and to the degradation of the cementitious matrix due to effect of high temperatures.

All Specimen failed identically to its counterpart tested at ambient temperature (flexural failure) due to rupture of the textile fiber roving (See Fig.11)

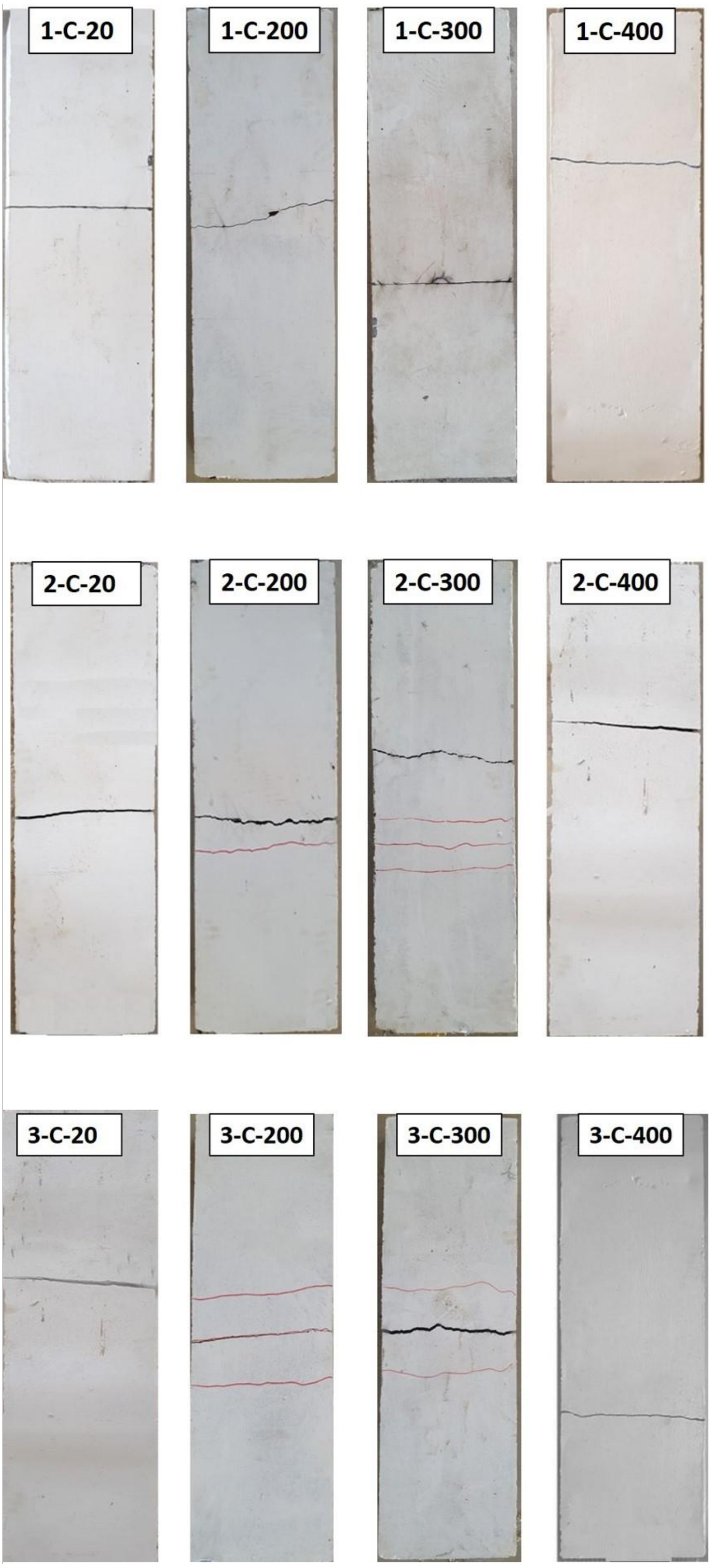


Fig.11: Failure mode of specimens tested at high temperature.

3.6 Effect of number of layers on flexural capacity

The effect of the number of layers on the specimen's flexural capacity is shown in Fig.12. For specimens tested at ambient temperature (i.e. 2-C-20, 3-C-20), doubling and tripling the number of layers led to in an increase in the flexural capacity by 1.28 and 1.33 times, respectively compared to specimen 1-C-20. The same trend was observed at high temperatures, in specific, at 200 °C for specimens (i.e. 2-C-200, 3-C-200) the improving in the flexural load were by 1.24 and 1.33 times respectively, compared to specimen 1-C-200. At temperature of 300 °C and for specimens 2-C-300, 3-C-300, the improving in the flexural load was by 1.43, and 1.55 times respectively, compared to specimen 1-C-300. Finally, at 400 °C for specimens (i.e. 2-C-400, 3-C-300), doubling and tripling the number of layers led to an improving in the flexural load by 1.44, and 1.49 times respectively compared to specimen 1-C-400.

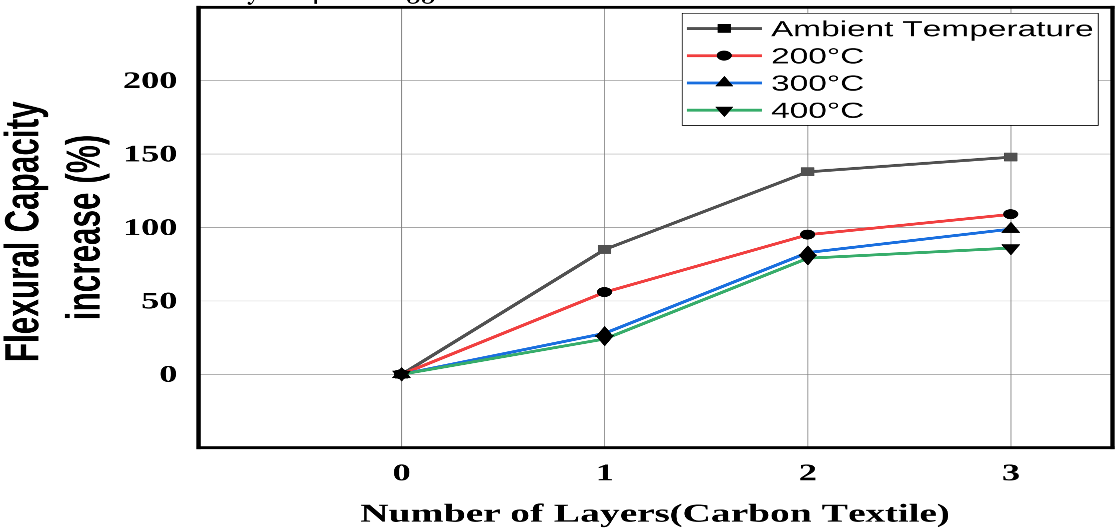


Fig.12: Effect of number of layers on the ultimate load response related to temperature level.

3.7. Effect of high temperatures on flexural capacity

The effect of high temperatures on the specimen's flexural capacity is shown in Fig.13. In general, increasing the temperature resulted in decrease in the flexural capacity of TRC plates. The curves show slight degradation in flexural capacity till 200 °C, while the turning point for ultimate load lies between 200°C and 400°C.Starting with one - layer of carbon fiber textile reinforced specimens, increasing the temperature from 20 °C to 200 °C, 300 °C and 400 °C resulted in a decrease in the flexural capacity of 16%, 31%, and 33% for specimens 1-C-200,1-C-300,1-C-400 respectively compared with control specimen 1-C-20. For 2-layers of carbon fiber textile reinforcement specimens increasing the temperature resulted in a decrease in the flexural capacity of 18%, 23%, and 25% for specimens 2-C-200, 2-C-300, 2-C-400 respectively compared with control specimen 2-C-20. Finally, for 3- layers of carbon fiber textile reinforcement specimens increasing the temperature resulted in a decrease in the flexural capacity of 16%, 20%, and 25% for specimens 3-C-200, 3-C-300, 3-C-400 respectively compared with control specimen 3-C-20.

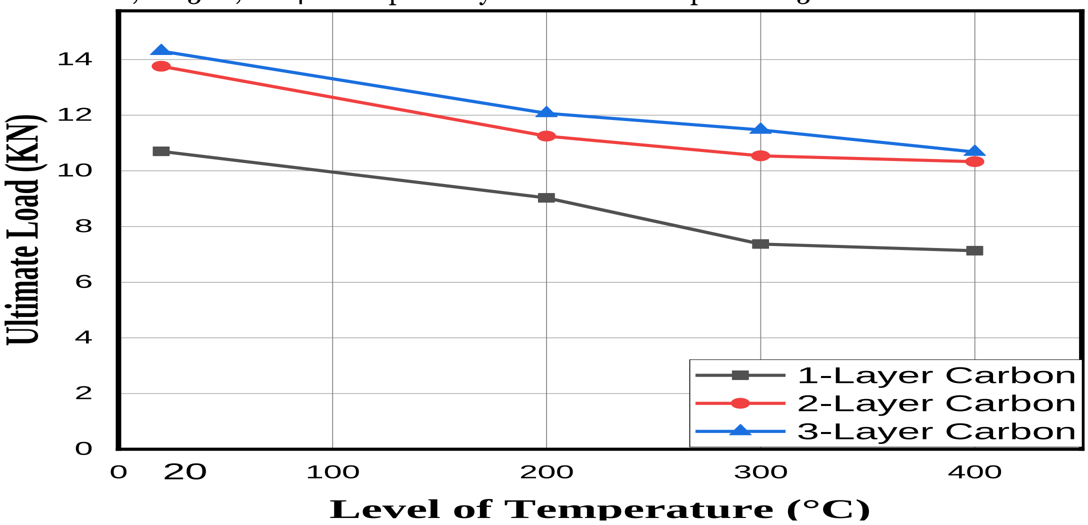
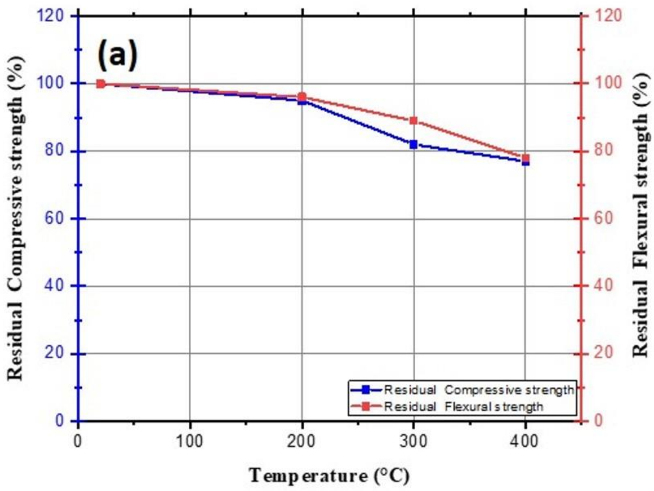


Fig.13: The relationship between ultimate load and level of high temperature.

This reduction in flexural capacity due to effect of high temperatures is related to:

(a) the reduction in mechanical properties of cementitious matrix. In specific, at 200 °C, 300 °C and 400 °C the degradation of the compressive strength was 5%, 18%, and 23% respectively compared with compressive strength at ambient temperature. Simultaneously, the degradation of the flexural strength was 4%, 11%, and 22% respectively (see Fig.14, a).

(b) the reduction in tensile properties as showed in TRC coupons results. particularly, the ultimate tensile strength for TRC coupons decreased by 7%, 19%, and 24% at 200 ° C, 300 ° C ,400 ° C respectively due to textile fibers tensile degradation (see Fig.14, b).



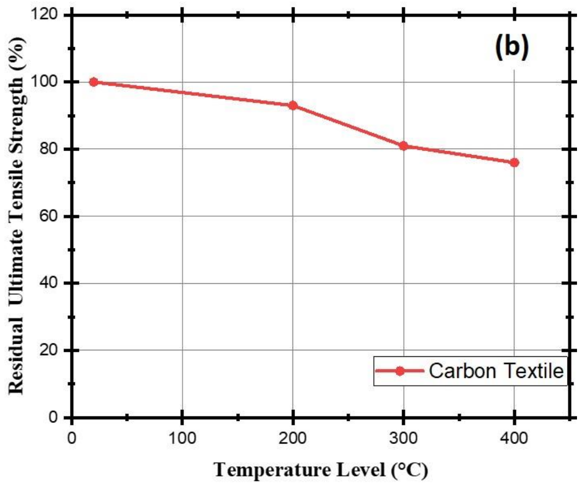


Fig.14: (a) Residual compressive strength (blue) and flexural strength (red) at high temperature, (b) Residual Tensile Strength for TRC coupons.

4. CONCLUSIONS

Based on the obtained results, the following conclusion can be highlighted:

1. Exposure of 200°C has no effect on tensile strength of TRC coupons. Whereas, above 200°C, the tensile strength was progressively decreased and the residual tensile strength was 81% ,76% at 300 °C and 400 °C respectively due to textile fibers tensile degradation.
2. The degradation of the cementitious matrix due to the high temperature was also significant and could be another dominant parameter. Regarding the compressive strength and flexural strength, the degradation was not severe until 200°C, while it became critical at 400 °C (23% and 22% respectively).
3. The flexural behavior of the TRC plates is strongly influenced by the number of textile layers. In specific, at ambient temperature, doubling and tripling the number of layers led to an increase in the flexural load by 28% and 33% respectively compared to one -layer reinforced specimen at the same temperature. The same observation was also noted at high temperatures. In specific, at 200 °C the flexural load increased by 24% and 33% respectively, at target temperature 300 °C the flexural load increased by 43%, and 55% respectively, finally, at 400 °C the flexural load increased by 44%, and 49% respectively.
4. Increasing the temperature from 20 °C to 200 °C, 300 °C and 400 °C resulted in a decrease in the flexural load of TRC plates compared to the ambient load. In specific, for TRC plates reinforced with 1-layer of carbon fiber textile the reduction was 16%, 31%, and 33%. For TRC plates reinforced with 2-layers of carbon fiber textile the reduction was 18%, 23%, and 25%. Finally, for TRC plates reinforced with 3-layers of carbon fiber textile the reduction was 16%, 20%, 25% respectively.

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