ISSN: 2319-5967
ISO 9001:2008 Certified
International Journal of Engineering Science and Innovative Technology (IJESIT)
Volume 2, Issue 5, September 2013

Effect of Temperature on Strength of Concrete Strengthening With CFRP

H. Shehab El – Din, Heba A. Mohamed
hshehabeldin@yahoo.com, hebawahbe@yahoo.com
Dean & Professor of Reinforced Concrete, Lecturer, Department of Structural Engineering, Faculty of Engineering, Zagazig University, Egypt.

Abstract— ***This paper investigates the effect of different temperature on concrete strength when Fiber Reinforced Polymer (FRP) is used to strengthen concrete structures. Concrete structures are submitted to various temperature changes during its time life. In this work, the heat degradation is measured in terms of compressive and tensile strength of cylindrical concrete specimens 100 mm in diameter and 200 mm in height, also flexural strength of concrete prisms 100 x 100 x 500 mm are investigated. Carbon fiber reinforced polymer (CFRP) is wrapped into specimens with different shapes and values of strengths are determined after exposed the cured specimens to three temperature 100 ^{0}c, 150 ^{0}c, and 200 ^{0}c. Results and conclusions which are useful for structural engineering practice are drawn from the research.***

Index Terms— **Fiber reinforced polymer; temperature effect; Externally bonded reinforcement; Concrete strength.**

I. INTRODUCTION

Among various retrofitting techniques, use of carbon fiber reinforced polymer (CFRP) is the one that is becoming quite popular. It was found out that the use of FRP wrapping technique caused an increase in the capacity of concrete column depending on the number of FRP plies applied, concrete grade, type of FRP and the properties of the matrix material [1 , 2]. Reinforced concrete normally offers high fire resistance at low cost [3]. The use of FRP reinforcement materials is, therefore, an issue which must be looked into seriously. The engineer during the design of a structure can withstand high temperatures as well as fire exposures. It was well known that all FRP materials were susceptible to degradation of mechanical properties at high temperature [4].
The success of the FRP strengthening technology has been due to advantages that arise from the high strength – to – weight ratio and excellent corrosion resistance of FRP composites [5 , 6]. However, the technology also suffers from one major limitation when employed for indoor applications in buildings : FRP composites have a poor resistance to fire as organic polymers (normally epoxies) used both as the matrix material and the bonding adhesive soften quickly around their glass transition temperature T_g (^{o}c) [generally in the range of 45 ^{o}c to 82 ^{o}c [7 , 8]].
It has been shown by Gamage et al. [9] that rapid strength loss appears when epoxy reaches the temperature around 73.6 ^{o}c. Although most of the advanced resin systems that are cured at high temperatures produce high quality and high performance even under elevated temperatures, the construction adhesives (epoxy) show poor characteristics at elevated temperature.
Di Tommaso et al. [10] tested several concrete specimens externally bonded with CFRP at four temperatures, - 100 ^{o}c, - 30 ^{o}c, 20 ^{o}c and 40 ^{o}c. The tests indicated that at 40 ^{o}c the failure load was lower than that at room temperature and also in this case the authors reported cohesive failure in the adhesive layer. Klamer et al. [11], found contradictory results compared to Di Tommaso et al. [10]. The failure load increased at 40 and 50 ^{o}c and suddenly decreased above a threshold temperature of 65 ^{o}c. This behavior was correlated to the fact that the T_g of the glue used was 62 ^{o}c. As expected above the T_g temperature of the adhesive, the failure load dropped dramatically because the adhesive suddenly softened.

II. RESEARCH SIGNIFICANCE

In the present study, the main objective is to determine the effect of temperature on compressive, tensile, and flexural strength of concrete strengthening with CFRP. Therefore temperature changes are expected to affect the mechanical properties of concrete, FRP, and adhesive. When the glass transition temperature (T_g) is exceeded, the increase in temperature has a negative effect on the adhesive

ISSN: 2319-5967
ISO 9001:2008 Certified
International Journal of Engineering Science and Innovative Technology (IJESIT)
Volume 2, Issue 5, September 2013
properties. Also, the research aims to identify the best shape of CFRP wrapping under the used temperature.

III. EXPERIMENTAL PROGRAM

In this experimental study, cylinders with 100 mm in diameter and 200 mm in length are cast to investigate compressive and tensile strength. After 28 days of curing, Carbon Fiber Reinforced Polymer (CFRP) is used as the strengthening material. At the first, the surface of the cylinders is cleaned then the epoxy is applied on concrete as shown in figure (1 – a). CFRP sheets are cut in a desired length as cylinder length, as well as strips. Finally, concrete are wrapped with a single layer of CFRP as shown in figure (1 – b, c), so there were three different forms of CFRP wrapping into cylinders as that totally wrapped, wrapped with 2 strips, and wrapped with 3 strips moreover these without CFRP as shown in figure (2). To investigate flexural strength, the experimental program contains prisms 100 x 100 x 500 mm wrapped with CFRP as the same way mentioned above to have different forms of wrapping as totally wrapped between two point loads, wrapped with U shape between two point loads, and wrapped with strips between two supports moreover these without CFRP as demonstrated in figure (3). To obtain the effect of temperature, the specimens are exposed to different temperature inside a high capacity controlled oven as can be seen in figure (4). In the absence of flames, the parameter used in this case was the amount of heat that the specimen was exposed to, in this study three different temperature 100 ^{o}c , 150 ^{o}c , and 200 ^{o}c are used for compressive and tensile test while 100 ^{o}c , and 200 ^{o}c are used for flexural test.

(a)

(b)

(c)

Fig 1. Strengthening process

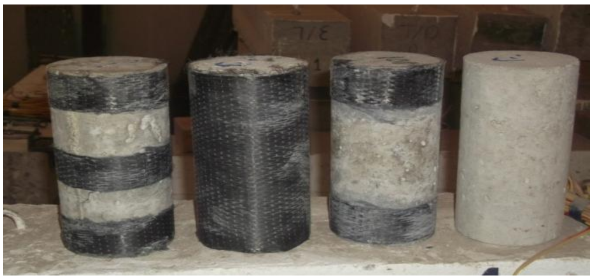

Fig 2. Different forms of CFRP wrapped around cylinders

ISSN: 2319-5967
ISO 9001:2008 Certified
International Journal of Engineering Science and Innovative Technology (IJESIT)
Volume 2, Issue 5, September 2013

Fig 3. Different forms of CFRP wrapping on prisms

Fig 4. The Oven used in the research

A. *Materials Properties*

Cement

The cement used throughout this work was Ordinary Portland Cement (OPC). Cement is tested and the test results satisfied the requirement of Egyptian Code of Practice, the physical test results of the used cement are given in table (1).

Table (1): Properties of cement

Tests	**Results**	**ECP 203 – 2007 Specification limits**
Initial setting time	1 hours and 10 minutes	Not less than 45 min.
Final setting time	4 hours and 30 minutes	Not more than 10 hr
3 days compressive strength	19.5 N/mm^2	Not less than 18 N/mm^2
7 days compressive strength	29 N/mm^2	Not less than 27 N/mm^2

Aggregates

10 mm nominal maximum size dolomite is used as coarse aggregates and natural sand of maximum size < 5 mm is used for concrete mixes of this investigation. The sieve analyses of both natural sand and coarse aggregate are shown in table (2).

Table (2): Grading of fine and coarse aggregates

Sieve size (mm)	37.5	20	14	10	5	2.36	1.18	0.60	0.33	0.15	0.075
% passing (dolomite)	100	99.2	97.5	95	20	-	-	-	-	-	-
% passing (sand)	-	-	-	-	99.6	94.5	85.2	64	27	2.5	0.6

Strengthening materials

The unidirectional woven fabrics used were the Sikawrap 300 C, the properties are given by the manufacturer: tensile strength = 3.900 N/mm^2, tensile E – modulus = 230.000 N/mm^2, and elongation at break = 1.5 %. The adhesive used was SikaDur - 32, it has a compressive strength = 50 – 60 N/mm^2,

ISSN: 2319-5967
ISO 9001:2008 Certified
International Journal of Engineering Science and Innovative Technology (IJESIT)
Volume 2, Issue 5, September 2013
flexural strength = 30 – 35 N / mm^2, tensile strength = 18 – 20 N / mm^2, and bond strength to concrete = 2.5 – 3 N / mm^2.

B. *Mix Proportions*

For this study, The same mix is adopted for all specimens, the quantities of materials used for this mix are illustrated in table (3). Quantity of cement used was equal to 300 Kg / m^3 with a water / cement ratio (W / C) = 0.55 and the ratio of fine to coarse aggregates was 30 % to 70 %.

Table (3): Mix proportions

Cement content (Kg /m^3)	300
Water content (Kg /m^3)	165
Coarse aggregate (Kg /m^3)	1372.3
Fine aggregate (Kg /m^3)	588.1
W / C ratio	0.55

IV. TESTS OF HARDENED CONCRETE

A. *Compressive and Spitting Tensile Strengths*

The compressive and splitting tensile strengths of concrete are measured using a 2500 KN capacity testing machine. The compressive and tensile splitting tests are carried out on cylinders strengthening with CFRP and those without CFRP after 28 – day of curing and exposing to different temperatures then left on the room temperature. The test setup for the compressive and tensile splitting tests are shown in figures (5) and (6) respectively.

B. *Flexural Strengths*

The flexural strength of concrete is measured using a same testing machine as used in the previous tests. The flexural test is carried out on prisms strengthening with CFRP and without strengthening as control specimens under two – point symmetric top loading. The test setup for the beam is shown in figure (7).

V. RESULTS AND DISCUSSIONS

In order to understand the effects of temperature on the mechanical properties of concrete with CFRP wrapping, all specimens are tested as mentioned above until failure and the results are discussed as follows:

A. *Concrete Compressive Strength*

According to the different used temperatures the values of compressive strength are obtained of specimens confined with different shapes of CFRP and unconfined specimens. The values of compressive strength are plotted versus temperature as shown in figure (8). This figure demonstrated that the higher the temperature the lower the values of compressive strength, this was probably caused by softening of the adhesive and as a result strain and stresses along the interface adhesive / concrete were more evenly distributed. The percentage of decrease in values of compressive strength are shown in table (4). From this table, one can be noticed that when temperature increased from 0 ^{o}c to 200 ^{o}c the lowest value of decrease is obtained in case of wrapped with 3 strips and is estimated by about 20.52 % . However, in general the highest values of compressive strength are obtained when the specimens are wrapped totally with CFRP followed by specimens wrapped with 3 strips then wrapped with 2 strips and in the rear these without CFRP as can be seen from figure (9), which represents the relationship between the values of compressive strength and CFRP wrapping. The percentage of increase in the values of compressive strength due to CFRP wrapping are listed in table (5).

Fig 5. Setup of the compressive test

ISSN: 2319-5967
ISO 9001:2008 Certified
International Journal of Engineering Science and Innovative Technology (IJESIT)
Volume 2, Issue 5, September 2013

The table demonstrated that the values of compressive strength are significantly increased as the specimen area wrapped with CFRP increases and the highest percentage of increase is achieved at 200 °c in cases of totally wrapped and wrapping with 3 strips. Where the percentages of increase in cases of totally wrapping, and wrapped with 3 strips are estimated by about 248.56 %, and 121.45 % respectively than that without wrapping at 200 °c.

Fig 6. Setup of the spilliting tensile test.

Fig 7. Setup of the flexural test

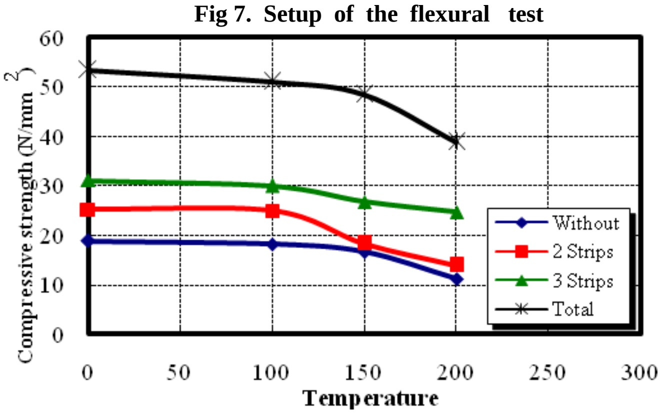

Fig 8. Effect of temperature on compressive strength.

Table (4) : Effect of increase in temperature on compressive strength

Temp.	compressive strength (N/mm^2)							
	Without	% decrease	2 Strips	% decrease	3 Strips	% decrease	Total	% decrease
0	18.78	-	25.15	-	31.04	-	53.32	-
100	18.14	3.4	24.83	1.27	29.92	3.6	50.93	4.48

ISSN: 2319-5967
ISO 9001:2008 Certified
International Journal of Engineering Science and Innovative Technology (IJESIT)
Volume 2, Issue 5, September 2013

0	18.78	-	25.15	-	31.04	-	53.32	-
150	16.55	11.87	18.3	27.24	26.74	13.85	48.38	9.26
0	18.78	-	25.15	-	31.04	-	53.32	-
200	11.14	40.68	13.85	44.9	24.67	20.52	38.83	27.2

B. *Concrete Tensile Strength*

The values of tensile strength are plotted against different temperatures as shown in figure (10). This figure observed the same behavior as mentioned above, where the values of tensile strength decreases as the temperature increases that due to the higher temperature, the stiffness of the adhesive decreased. The percentages of decrease in tensile strength are listed in table (6). Also as effect of CFRP on compressive strength, wrapped with 3 strips gives the lowest percentage of decrease in values of tensile strength when temperature increased from 0 ^{o}c to 200 ^{o}c by about 18 %. Figure (11) gives the effect of CFRP wrapping on the values of tensile strength at different temperature. This figure indicated that the highest values of tensile strength at each temperature are obtained when the specimen totally wrapped followed by that wrapped with 3 strips, then wrapped with 2 strips. Table (7) shows the percentage of increase in tensile strength from specimen without wrapping to that wrapped with different shapes at each temperature. The percentages of increase were 204.54 %, 142.32 %, and 100.1 % from without wrapping to totally wrapped, wrapped with 3 strips, wrapped with 2 strips respectively at 200 ^{o}c.

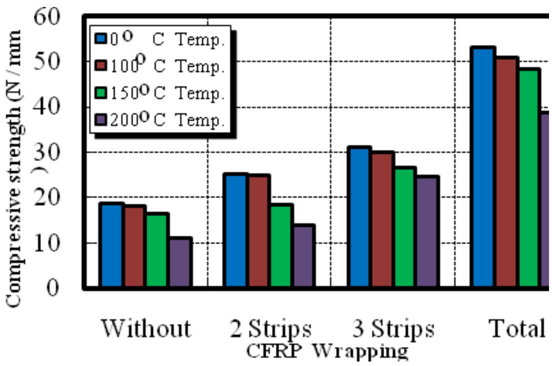

Fig 9. Effect of CFRP wrapping on compressive strength

Table (5): Effect of CFRP on compressive strength

CRFP Wrapping	compressive strength (N/mm^2)							
	0 ^{o}C	% increase	100 ^{o}C	% increase	150 ^{o}C	% increase	200 ^{o}C	% increase
Without	18.78	-	18.14	-	16.55	-	11.14	-
2 Strips	25.15	33.92	24.83	36.88	18.3	10.57	13.85	24.3
Without	18.78	-	18.14	-	16.55	-	11.14	-
3 strips	31.04	65.28	29.92	64.94	26.74	61.57	24.67	121.45
Without	18.78	-	18.14	-	16.55	-	11.1438	-
Total	53.32	183.92	50.93	180.76	48.38	192.33	.83	248.56

ISSN: 2319-5967
ISO 9001:2008 Certified
International Journal of Engineering Science and Innovative Technology (IJESIT)
Volume 2, Issue 5, September 2013

Fig 10. Effect of temperature on tensile strength.

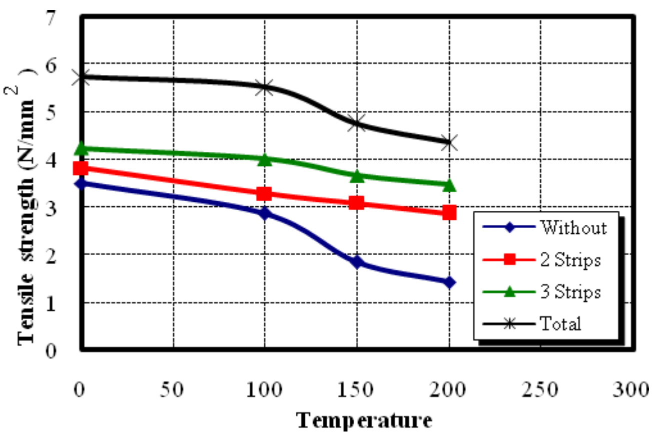

Table (6) : Effect of increase in temperature on tensile strength

Temp.	Tensile strength (N/mm^2)							
	Without	% decrease	2 Strips	% decrease	3 Strips	% decrease	Total	% decrease
0 100	3.5 2.865	- 18.1	3.82 3.28	- 14.14	4.234 4.011	- 5.27	5.73 5.51	- 3.84
0 150	3.5 1.846	- 47.26	3.82 3.088	- 19.16	4.234 3.661	- 13.53	5.73 4.743	- 17.23
0 200	3.5 1.432	- 59.1	3.82 2.865	- 25	4.234 3.47	- 18	5.73 4.361	- 23.9

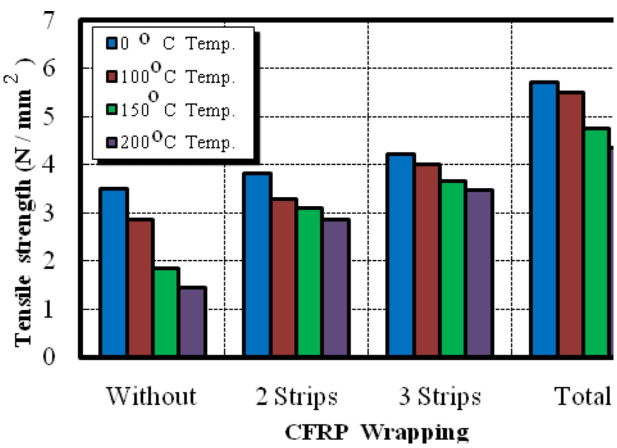

Fig 11. Effect of CFRP wrapping on tensile strength.

ISSN: 2319-5967
ISO 9001:2008 Certified
International Journal of Engineering Science and Innovative Technology (IJESIT)
Volume 2, Issue 5, September 2013

Table (7): Effect of CFRP on tensile strength

CRFP Wrapping	Tensile strength (N/mm^2)							
	0 °C	% increase	100 °C	% increase	150 °C	% increase	200 °C	% increase
Without	3.5	-	2.865	-	1.846	-	1.432	-
2 Strips	3.82	9.14	3.28	14.5	3.088	67.28	2.865	100.1
Without	3.5	-	2.865	-	1.846	-	1.432	-
3 strips	4.234	20.97	4.011	40	3.661	98.32	3.47	142.32
Without	3.5	-	2.865	-	1.846	-	1.432	-
Total	5.73	63.71	5.51	92.32	4.743	156.93	4.361	204.54

C. *Flexural Strength*

Figure (12) gives the values of flexural strength according to different temperatures, one can be noticed that the values of flexural strength decreased as the temperature increased. The percentages of decrease in flexural strength of confined and unconfined specimens are listed in table (8). The lowest rate of decrease in flexural strength is obtained in case of specimens wrapped with strips of CFRP where the percentage is estimated by about 6.29 % and 30.82 % when the temperature increased from 0 °c to 100 °c and from 0 °c to 200 °c respectively. The best shape of CFRP wrapping in case of prisms was wrapped with strips between two supports as clearly shown in figure (13) and table (9) where the values of flexural strength increased by high rate in this case. The percentages of increase were 185.7 %, 16.88 %, and 3.9 % from without wrapping to wrapped with strips, wrapped with U shape, totally wrapped between two point loads respectively at 200 °c.

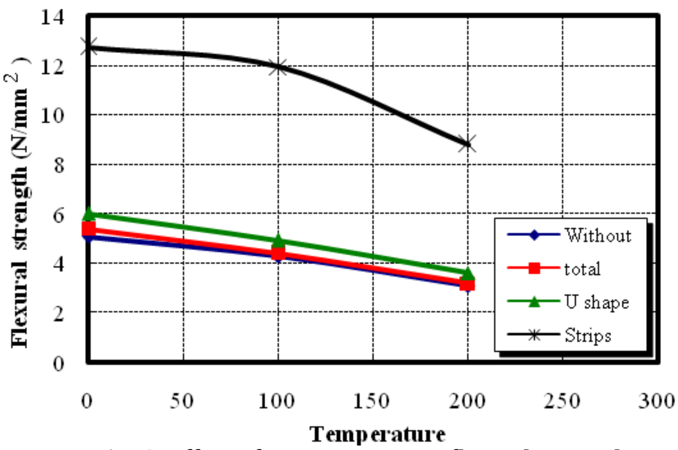

Fig 12. Effect of temperature on flexural strength

Table (8) : Effect of increase in temperature on flexural strength

Temp.	Flexural strength (N/mm^2)							
	Without	% decrease	Total	% decrease	U Shape	% decrease	Strips	% decrease
0	5.08	-	5.4	-	6	-	12.72	-
100	4.28	15.75	4.4	18.52	4.92	18	11.92	6.29
0	5.08	-	5.4	-	6	-	12.72	-
200	3.08	39.4	3.2	40.74	3.6	40	8.8	30.82

ISSN: 2319-5967
ISO 9001:2008 Certified
International Journal of Engineering Science and Innovative Technology (IJESIT)
Volume 2, Issue 5, September 2013

VI. CONCLUSION

This paper presents an experimental program to describe the effect of different temperature on concrete strength when Fiber Reinforced Polymer (FRP) is used to strengthen concrete structures. The following conclusions can be drawn from the experimental results:

- The higher the temperature the lower the values of compressive strength, when temperature increased from 0 ^{o}c to 200 ^{o}c the lowest value of decrease is obtained in case of wrapped with 3 strips and is estimated by about 20.52 %
- The values of compressive strength are significantly increased as the specimen area wrapped with CFRP increases. The percentages of increase in cases of totally wrapping, and wrapped with 3 strips are estimated by about 248.56 %, and 121.45 % respectively than that without wrapping at 200 ^{o}c.
- Specimens wrapped with 3 strips gives the lowest percentage of decrease in tensile strength when temperature increased from 0 ^{o}c to 200 ^{o}c by about 18 %.
- The percentages of increase in tensile strength were 204.54 %, 142.32 %, and 100.1 % from without wrapping to totally wrapped, wrapped with 3 strips, wrapped with 2 strips respectively at 200 ^{o}c.
- The lowest rate of decrease in flexural strength is obtained in case of specimens wrapped with strips of CFRP.
- The percentages of increase in flexural strength were 185.7 %, 16.88 %, and 3.9 % from without wrapping to wrapped with strips, wrapped with U shape, totally wrapped between two point loads respectively at 200 ^{o}c.

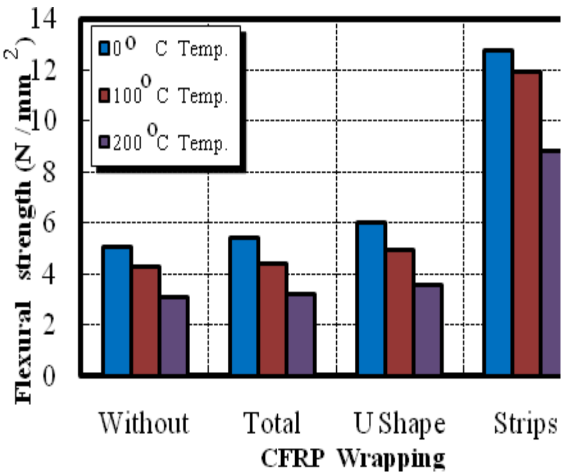

Fig 13. Effect of CFRP wrapping on flexural strength.

Table (9): Effect of CFRP on flexural strength

CRFP Wrapping	Flexural strength (N/mm^2)					
	0 ^{o}C	% increase	100 ^{o}C	% increase	200 ^{o}C	% increase
Without	5.08	-	4.28	-	3.08	-
Total	5.4	6.3	4.4	2.8	3.2	3.9
Without	5.08	-	4.28	-	3.08	-
U Shape	6	18.11	4.92	14.95	3.6	16.88
Without	5.08	-	4.28	-	3.08	-
Strips	12.72	150.4	11.92	178.5	8.8	185.7

ISSN: 2319-5967
ISO 9001:2008 Certified
International Journal of Engineering Science and Innovative Technology (IJESIT)
Volume 2, Issue 5, September 2013

REFERENCES

[1] Lam L., and Teng J. G., "Design-oriented stress - strain model for FRP- confined concrete" , Construction and Building Materials. 17, PP. 471- 489 (2003).

[2] Ilki A., Kumbasar N., and Koc V., " Strength and deformability of low strength concrete confined by carbon fiber composite sheets", 15th ASCE Engineering Mechanics Conference (2002).

[3] Weber, A., and Witt, C., " Composite rebars in RC members in case of fire ", Proc., Advanced Composite Materials in Bridges and Structures, Canadian Society of Civil Engineering, Winnipeg, Manitoba Canada (2008).

[4] Kodur, V. K. R., Bisby, L. A., and Green, M. F. , " Guidance for the design of FRP – strengthened concrete members exposed to fire " , J. Fire Prot. Eng., 17(1), PP. 5 – 26 (2007).

[5] Teng, J. G., Chen, J. F., Smith, S. T., and Lam, L. , " FRP - strengthened RC structures " , John Wiley and Sons Ltd., Chi Chester, UK (2002).

[6] Hollaway, L.C., and Teng, J. G. Strengthening and rehabilitation of civil Infrastructures using FRP composites. Wood head Publishing Limited, Cambridge, UK (2008).

[7] Féderation International du Béton (fib)., " Externally bonded FRP reinforcement for RC structures ", fib Bulletin 14, fib Task Group 9.3, fib, Lausanne, Switzerland (2001).

[8] American Concrete Institute (ACI). , " Guide for the design and construction of externally bonded FRP systems for strengthening concrete structures.", ACI 440.2R-08, Farmington Hills, Michigan, America (2008).

[9] Gamage,J.C.P.H., Wong, M.B., and Al-Mahaidi, R., " Bond performance of CFRP plated concrete members at elevated temperatures", Proceedings of Australian Structural Engineering Conference (ASEC), Newcastle, Australia (2005).

[10] Di Tommaso, A., Neubauer, U., Pantuso, A. and Rostasy, F.S., " Behavior of adhesively bonded concrete – CFR joints at low and high temperatures", Mechanics of Composite Materials, 37, 4, PP. 327- 338 (2001).

[11] Klamer, EL, Hordijk, DA, Janssen, HJM., " The influence of temperature on the debonding of externally bonded CFRP", Proceedings of the 7th International Symposium on Fiber Reinforced Polymer (FRP) Reinforcement for Concrete Structures (FRP7RCS), Kansas City, PP. 1551-1570 (2005).