Durability of Concrete Cylinder Specimens Strengthened With FRP Laminates under Penetration of Chloride Ions

A. Gharachorlou[1] and A. A. Ramezanianpour [2,*]

Received: March 2009 Accepted: January 2009

Abstract: *The use of epoxy-bonded FRP composite for structural repair is emerging as an efficient and cost-effective technique for restoring and upgrading the capacity of concrete structures. Considerable researches have been reported in the last decades on the mechanical behavior and failure modes of the FRP strengthened RC elements but actual data on its durability are scarce. This study intends to examine the durability of concrete specimens strengthened with FRP laminates under accelerated laboratory conditions and mimic harsh environmental situation which is the penetration of chloride ions. In this study three groups of specimens were examined. Each of these groups includes several concrete cylindrical specimens full confined with FRP laminates for investigating different types of fiber (Glass and Carbon), number of fiber layers and temperature influences. Furthermore, an apparatus was fabricated to simulate wetting and drying cycles for the second group of specimens. Moreover group III specimens were placed in a marine environment for 3 years to monitor their performance. Test results show that addition of FRP laminates reduces chloride ions penetration up to 70 percent. Results also indicate that although chloride ions penetration decreased the ultimate strength of cylindrical specimens up to 11 percent but FRP strengthened specimens achieved their initial strengths. Moreover wetting and drying cycles reduced the strength of cylinder specimens up to about ten percent especially in the high temperature laboratory condition.*

Keywords: *fiber-reinforced plastic, chloride ions, durability, CFRP, GFRP*

1. Introduction

Existing reinforced concrete (RC) structures may, for a variety of reasons, be found to perform unsatisfactorily under service conditions. This could be attributed to ageing, poor initial design or construction, lack of maintenance, increased load demand, and environmentally induced degradation. Corrosion of reinforcing steel embedded in concrete is considered to be the major cause of deterioration in civil infrastructure facilities. RC structures in close vicinity to marine environments, industrial environments, and those subjected to the effects of road salt usage, are particularly prone to premature deterioration. The high concentration of chloride ions in aggressive environments, e.g., sea water combined with conditions of high temperature and humidity and exposure to tidal cycles make it possible for chloride ions to penetrate into concrete even for high quality concrete.

Considerable researches have been reported in the last decade on the mechanical behavior and failure modes of the CFRP strengthened RC elements [1…4] but only a few studies are available on durability of FRP strengthened concrete members. Beaudoin et al. [5] investigated FRP repaired beams and indicated that FRP strengthened concrete beams were not damaged significantly by exposure to wet and dry environments. In addition Lacasse et al. [6] used FRPs as external reinforcement, and preliminary results indicate that this technique can be quite effective in reducing the expansions due to alkali aggregate reactions. Homan [7] studied the durability of fiber-reinforced polymer composites subjected to freeze-thaw cycles, UV radiation, temperature variation, NaOH solutions and moisture. From his results, it appears that the tensile property of coupons subjected to freeze-thaw cycles in the controlled laboratory environments were not significantly affected for CFRP and GFRP. While the strength of GFRP coupons decreased by a maximum of 7 percent after 84 days of exposure to NaOH solutions, The effect of temperature variation between -20 °C

* *Corresponding Author: aaramce@aut.ac.ir*

1 *PhD. of civil engineering, Amirkabir University of Technology, Tehran, Iran*

2 *Professor of civil engineering, Amirkabir University of Technology, Tehran, Iran.*

and +40 °C presented no degradation in mechanical properties of CFRP. Micelli et al. [8] presented experimental results of FRP confined concrete cylinders subjected to accelerate environmental exposure. Two different conditioning agents were chosen. First, the specimens were immersed under a solution of NaCl. Second, the specimens were under freeze-thaw conditioning, high humidity, high temperature cycling and indirect UV exposure in an environmental chamber. Results show that GFRP and CFRP sheets wrapped on concrete cylinders increase the ultimate strength to 1.6 times that of plain concrete. GFRP wrapped cylinders under environmental cycles or immersion in NaCl solution showed a moderate decrease in ultimate strength and loss in ductility by about 40%. Moreover, Sangeeta et al. [9] presented the progression of corrosion of steel in concrete cylinders after it has been treated with surface bonded FRP. Pull out strength, mass loss, half cell potential of the steel have been reported as metrics of performance of the samples. Results show that wrapping dramatically slows down the rate of corrosion. Moreover, pullout strength increased due to FRP wrapping. Manuel et al. [10] studied bond degradation between FRP and RC beams. The study showed that temperature cycles and moisture cycles were associated with failure in the concrete substrate, while salt fog cycles originated failure at the interface of concrete–adhesive. Furthermore, no significant differences were detected in the ultimate load capacity of the systems strengthened with GFRP and CFRP probably due to fact that FRP sheets didn't achieved their ultimate strength.

However, most of the research studies, did not examined compressive straight loads effects or only investigated the durability of FRP strengthened concretes in freezing and thawing and low and high temperature cycles. Therefore, there are still concerns regarding the durability performance of these materials under severe environmental conditions, especially chloride ions penetration. Thus, an extensive experimental program was conducted by authors to evaluate the strength and durability of concrete cylinders strengthened with FRP laminates encountered with corrosive conditions. For this purpose the specimens tested in a harsh condition site of a marine environment and in accelerated laboratory condition. This paper shows the effect of wetting and drying cycles on the durability of specimens under corrosive environments.

2. Experimental Program

The testing program included long term test on fifty five (150*300 mm) cylinder specimens subjected to chloride exposure. These specimens were divided into three groups. Two of these groups were fabricated in laboratory and subjected to accelerated chloride ions penetration by 3% NaCl solution. The last group was cast and placed in a marine environment to investigate the effect of real corrosive conditions.

First group consists of twenty one strengthened and control cylinder specimens to investigate the effect of FRP layers and FRP types (GFRP and CFRP) parameters on reducing chloride ions penetration and increasing strength. Second group specimens were fabricated to investigate the effect of wetting and drying cycles in corrosive situations. This group of specimens were strengthened and exposed to 3% NaCl solution in a special apparatus which was assembled to apply wetting and drying cycles. Moreover, in this group, additional specimens were prepared to parametrically study the effect of FRP layers and types. Last group relates to in site specimens. These specimens were cast in the corrosive condition site of a marine environment under wetting and drying cycles for three years. In each group several control (consisted of salted and unsalted) specimens were used to compare with those strengthened with FRP under chloride ion penetration.

2.1. Specimens Fabrication

Construction of the specimens includes designing the type of concrete with the desired compressive strength, place the order, casting the concrete for the cylinder specimens and curing the specimens under controlled condition. For the experimental program of group I and II thirty nine cylinders with standard size of 150 by 300 mm were cast. In addition, for group III thirty

Table 1 concrete and FRP material properties

Condition	Concrete				FRP					
	E_c (GPa)	F_c (MPa)	n_c	g_c (KN/m^3)	Type	Thickness (mm)	E_f (Gpa) x	E_f (Gpa) y	n_f xy	Ultimate Strength (Mpa)
Lab	31	30	0.2	24	GFRP	0.2	75	10	0.2	2300
					CFRP	0.12	150	18	0.2	3800
Site	22	20	0.2	24	GFRP	0.2	75	10	0.2	2300
					CFRP	0.12	150	18	0.2	3800

^{x} Longitudinal direction (fiber direction)

^{y} Transverse direction (matrix direction)

$^n{}_{fxy}$ FRP major Poisson ratio

two specimens were fabricated in site in a marine environment. Half of these specimens were tested and presented in this paper and the others are remained for longer time durability tests.

2.2. Material Properties

The 28-day average compressive strength of the concrete was 30, 30 and 20 MPa with a standard deviation of 2 MPa for group I, II and III, respectively, and the splitting tensile strength was with the average of 3.3 MPa. Lower compressive strength was selected for group III specimens to accelerate the chloride ion penetration and to investigate the effect of concrete compressive strength on the rate of FRP strengthening technique. FRP composites are materials that consist of two constituents. The constituents are combined at a macroscopic level and are not soluble in each other. One constituent is the reinforcement, which is embedded in the second constituent, a continuous polymer called the matrix. The reinforcing material is in the form of fibers, i.e., carbon or glass, which are typically stronger and stiffer than the matrix. Therefore, FRP composites are anisotropic materials (usually modeled with transversely isotropic) and have different properties at their main direction. In this paper two types of glass and carbon FRP were used. Main properties of each type which were taken from the producer specification are shown in Table 1. Furthermore, a summery of concrete properties of all three groups of specimens is also depicted in that table.

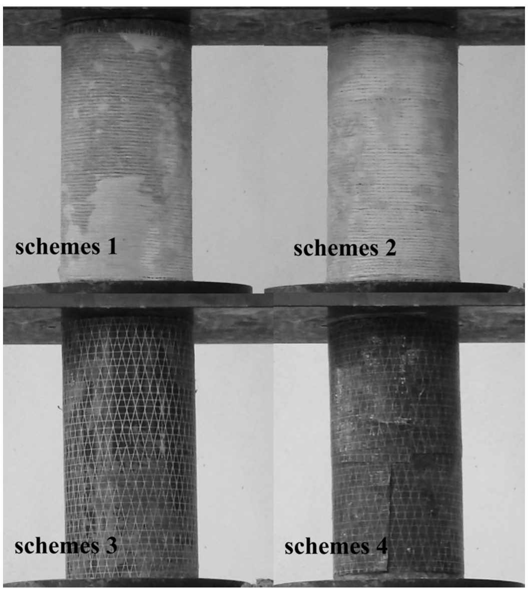

Fig. 1. FRP Strengthening schemes

2.3. FRP sheets

FRP sheets were used as the confinement. The high strength carbon and glass fibers which used were unidirectional and each cylinder was wrapped continuously, with the orientation of the fiber in the 0 direction. Four FRP repair schemes were utilized for the cylinders repair process. The first and second schemes were included specimens with one or two layers of GFRP sheets, respectively. While in the third and forth schemes one or two layers of CFRP sheets were used. FRP repair schemes 1, 2, 3 and 4 are shown in Figure 1. A two-part epoxy resin component A and B was used to impregnate the FRP sheets. The ratio of resin to hardener was 3:1 which was mixed in a graduated container by hand until there was uniform color between the resin and the hardener. FRP sheets were directly applied to the surface of the cylinder specimens after sandblasting concrete surfaces.

To ensure that there was a proper amount of FRP to keep the warp fully engaged during testing, the length of FRP laminates was extended by approximately 25% of the circumference, which was equal to about 100 mm. The wrapped specimens were allowed to cure under laboratory condition for 2 days.

2.4. Accelerated Corrosion Set Up

To induce corrosion damage within the test specimens in a reasonably short time, accelerated corrosion technique was employed by subjecting the specimens to 3% NaCl solution for group I and II. Group I specimens were placed in a large-scale corrosion chamber. This chamber was equipped with instrument consisted of two elements and a thermostat to maintain the water temperature at 23 ^{o}C for simulating normal temperature effect. The cylindrical specimens were placed in this chamber for three years. Special apparatus was fabricated to simulate wetting and drying cycles on FRP rehabilitation for the second group specimens. In this apparatus Electrical timer and pumps were used to create wetting-drying conditions (see Figure 2). Moreover, for investigating the effect of different temperatures, this apparatus was equipped with a temperature control system. Second group specimens were subjected to wetting and drying cycles at equal time intervals of 12 hours at 38 ^{o} Celsius for three years. Figure 3 shows group III specimens placed in the marine environment of Persian Gulf in especial position which encountered to wetting and drying cycles of salted water according to the sea tidal regime. Furthermore, for each type of FRP schemes one unsalted control specimens were tested.

After the corrosion period, specimens were brought out and transferred to laboratory environment. Compressive load tests were operated by universal testing machine as shown in Figure 4. specimens were tested at a deformation rate of 0.005 mm/sec. Load versus deflection graphs were plotted by this machine automatically for the cylindrical specimens.

3. Experimental Results and Discussion

3.1. Monitoring the Corrosion Activity

The corrosion activity within the test

Fig. 3. Bandar Abbas group III specimens

Fig. 2. wet and dry system instrument

Fig. 4. Universal testing machine

Table 2. chloride ions penetration for different specimens

Depth mm	Normal temperature					Wet and Drying System					Marine site				
	confined		control	Pen. Decrease		confined		control	Pen. Decrease		confined		control	Pen. Decrease	
	GFRP	CFRP				GFRP	CFRP				GFRP	CFRP			
	Chloride Pen. Ce. %			GFRP	CFRP	Chloride Pen. Ce. %			GFRP	CFRP	Chloride Pen. Ce. %			GFRP	CFRP
7.5	0.35	0.36	0.91	62%	60%	0.9	0.69	2.51	64%	73%	0.79	0.61	1.95	60%	69%
17.5	0.23	0.24	0.62	63%	61%	0.54	0.54	1.9	72%	72%	0.47	0.47	1.42	67%	67%
25	0.17	0.18	0.44	61%	59%	0.21	0.17	0.58	64%	71%	0.22	0.20	0.50	56%	60%

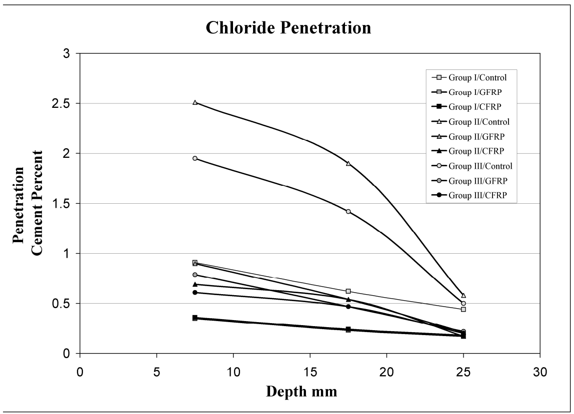

Fig. 5. Chloride ions penetration profile

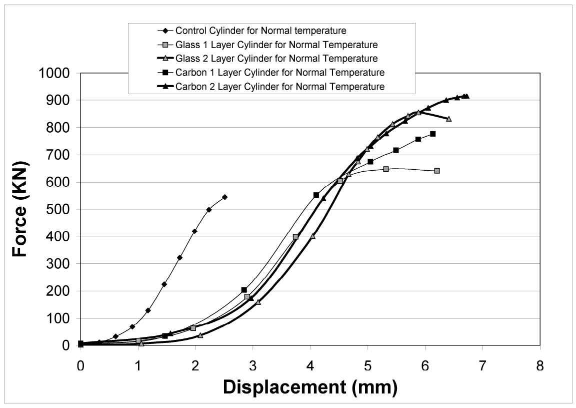

Fig. 6. Load-Deflection curve for group I specimens

specimens was monitored by using chloride measurement technique. In this method, chloride ions content was measured in accordance with ASTM C1152 [11] standard test method. Figure 5 shows that, group II and III specimens encountered with high chloride ions penetration in range of 2.51, 1.9 and 0.58 (group II) and 1.95, 1.42 and 0.5 (group III) percent of cement weight at 7.5, 17.5 and 25 mm depths, respectively. This results show that group II specimens approximately simulate group III site specimens while for group I cylinders chloride ions penetration were lower due to lower temperature. Moreover, results in cylindrical specimens showed effectiveness of using wrapped fiber sheets to decrease chloride ions penetration. Results performed that for group II and III specimens the chloride ions penetration decreased approximately 70 percent when compared with unwrapped specimens. The chloride penetration results corresponding to all three groups are summarized in Table 2.

3.2. Load Deflection Response

The load-deflection curve for the strengthened cylinder concrete specimens is linearly elastic up to about 10 percent of the maximum compressive strength as shown in Figure 6. After the maximum strength eventually crushing failure occurs abruptly and the curve descends into a softening region. The failure of both types of FRP strengthened cylinders was catastrophic with a sudden release of stored elastic energy (see Figure 7).

Fig. 7. Abrupt failure mode of FRP strengthened specimen

Table 3. ultimate load and deflection of group I specimens

No.	Description	Ultimate salted Displacement mm	Ultimate salted Force (KN)	unsalted Force (KN)	Average Displacement mm	Average Force (KN)	Increase Percent	Decrease percent to unsalted	Increase percent to unsalted control
1		2.5900	546.77						
2	Control	2.0810	497.09	551.84	2.28	521.54		5.5%	
3		2.1580	520.75						
4		5.3200	680.49						
5	Glass 1 Layer	5.8510	705.94	717.85	5.30	693.06	33%	3.5%	25.6%
6		4.3650	727.87						
7		5.6820	657.92						
8		6.2972	857.37						
9	Glass 2 Layers	6.1083	854.79	867.03	6.07	857.94	65%	1.0%	55.5%
10		5.7934	861.65						
11	Carbon 1 Layer	7.0900	784.22	791.20	6.61	780.64	50%	1.3%	41.5%
12		6.1330	777.05						
13		5.3150	901.66						
14	Carbon 2 Layers	4.1200	921.88	921.34	5.63	910.20	75%	1.2%	64.9%
15		6.3650	901.81						
16		6.7150	915.45						

3.2.1. Group I

Table 3 shows the result of ultimate strength of low temperature specimens. Results indicate that chloride ions penetration decreased 5.5 percent of the control specimen strength. Moreover, the strength of one and two layers of GFRP strengthened specimens, decreased 3.5 and 1 percent with respect of laboratory unsalted strengthened specimens. By using carbon fibers these values were reduced to 1.3 and 1.2 percent, respectively. Comparing strengthed salted specimens to unsalted control specimens results indicates that in column specimens not only chlorided strengthened specimens achieved their primary unsalted strength but also their strength increased by 25.6, 55.5, 41.5 and 64.9 percent for one and two layers of GFRP and CFRP sheets, respectively. Due to neglible chloride ions penetration at low temperature, reduction in compressive strength of all specimens was not considerable. However, FRP confinement reduced the magnitude of deterioration and specimens' strength decreased only by 3.5, 1, 1.3 and 1.2 percent for 1 to 4 FRP schemes, respectively.

3.2.2. Group II

Figure 8 gives an indication of the severity of wetting and drying system. In the figure, the compressive load versus axial deflection for all schemes is shown. Also, it is evident from table 4 that chloride ions penetration decreased the ultimate strength of control specimens by 11.6 percent. Moreover, significant losses in compressive strength of strengthened specimens were measured. It appears from the results that scheme 4 has the best overall performance by only 6.1 percent reduction in strength. Schemes 2, 3 and 1 place in the next orders by 7.2, 11 and 16.8 percent decrease in their strength in respect of unsalted strengthened specimens. Similar to group I strengthened specimens exceeded from their unsalted control strength but as we expected in this group the ultimate strength decreased, especially for schemes 1 which achieved only 8.2 percent more strength than unsalted control specimen. Schemes 2, 3 and 4 behave better and

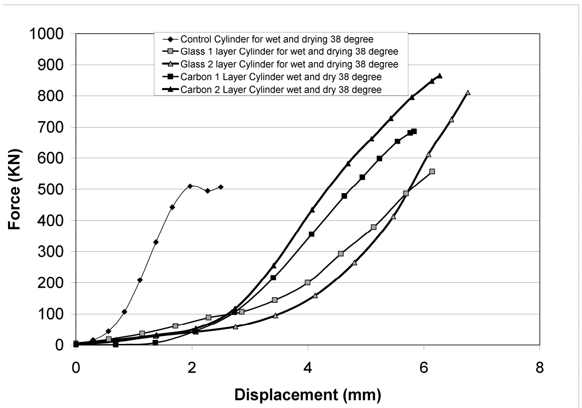

Fig. 8. Load-Deflection curve for group II specimens

Table 4. ultimate load and deflection of group II specimens

No.	Description	Ultimate			Average		Increase percent	Decrease percent to unsalted	Increase percent to unsalted control
		salted		Unsalted					
		Displacement mm	Force (KN)	Force (KN)	Displacement mm	Force (KN)			
1	Control	2.8790	435.96	551.84	2.40	487.64		11.6%	
2		2.5000	507.57						
3		1.8230	519.40						
4	Glass 1 layer	5.2270	651.62	717.85	6.17	597.12	22%	16.8%	8.2%
5		6.1440	557.37						
6		7.1490	582.37						
7	Glass 2 layers	5.3440	842.48	867.03	6.36	804.59	65%	7.2%	45.8%
8		6.7590	811.23						
9		6.9670	760.06						
10	Carbon 1 Layer	7.0390	729.91	791.20	6.06	704.52	44%	11.0%	27.7%
11		5.8310	686.35						
12		5.5350	678.84						
13		5.8300	723.01						
14	Carbon 2 Layers	4.1910	885.33	921.34	6.20	864.94	77%	6.1%	56.7%
15		6.2730	865.37						
16		8.2750	845.25						
17		7.6130	859.54						
18		4.6500	869.22						

increase 45.8, 27.7 and 56.7 percent in their ultimate strength with respect of unsalted control specimen. Although chloride ion penetration cause to decrease in control specimens strength by 11.6 percent but CFRP fibers show an excellent performance in chloride ions prevention therefore in schemes 3 and 4 strength decreased only by 11 and 6.1 percent due to unsalted specimens. These results show that effect of carbon fibers confinement to prevent chloride ions penetration was better than the deterioration effect of chloride ions on fibers corrosion. However, glass fibers behave weaker and lose their strength by 16.8, 7.2 percent with respect to unsalted specimens. Thus effect of GFRP confinement in chloride ions prevention is weaker than chloride ions effect on GFRP strength.

3.2.3. Group III

The compressive strength test results in the site specimens of group III are summarized in Table 5. Each data represents two to three results. After

Table 5. ultimate load and deflection of group III specimens

No.	Description	Ultimate			Average		Increase percent	Decrease percent to unsalted	Increase percent to unsalted control
		salted		unsalted					
		Displacement mm	Force (KN)	Force (KN)	Displacement mm	Force (KN)			
1	Control	1.5976	314.67	355.02	1.54	319.69		10.0%	
2		1.4312	307.06						
3		1.5890	337.33						
4	Glass 1 Layer	2.7290	553.58	612.34	2.74	532.94	67%	14.9%	50.1%
5		2.7510	512.29						
6	Glass 2 Layers	3.2560	644.08	719.54	3.42	649.51	103%	10.8%	83.0%
7		3.5810	654.93						
8	Carbon 1 Layer	3.1700	589.49	618.43	3.52	563.70	76%	9.7%	58.8%
9		3.8700	537.9						
10	Carbon 2 Layers	3.5680	692.1	722.54	3.49	683.99	114%	5.6%	92.7%
11		3.4125	675.87						

Table 6. Comparison between group II results and Micelli et. Al. results

No.		Description	Ultimate salted Stress (MPa)	Ultimate unsalted Stress (MPa)	Average Stress (MPa)	Increase percent	Decrease percent to unsalted	Increase percent to unsalted control
1	Group II	Control	24.68	31.24	27.61		11.6%	
2			28.74					
3			29.41					
4		Glass, 1 layer	36.89	40.64	33.81	22%	16.8%	8.2%
5			31.56					
6			32.97					
7		Carbon, 1 Layer	41.33	44.80	39.89	44%	11.0%	27.7%
8			38.86					
9			38.43					
10			40.93					
1	Micelli et. al.	Glass, control	28.00	32.00	28.00		12.5%	
2		Carbon, control	33.00	37.00	33.00		10.8%	
3		Glass, 1 layer	43.00	52.00	43.00	54%	17.3%	34.4%
4		Carbon, 1 Layer	56.00	60.00	56.00	70%	6.7%	51.4%

3 years exposure in severe condition of Persian Golf region, significant degradation was observed in this group, especially for control and one layer GFRP specimens. In case of control cylinder, about 10 percent reduction was observed for compressive strength. Similarly, the GFRP specimens also exhibited a compressive strength reduction of about 14.9 and 10.8 percent for one and two layers, respectively. In addition, degradation was observed for CFRP specimens but results show that these specimens' strength decreased only 9.7 and 5.6 percent for schemes 3 and 4. These results indicate that generally CFRP strengthened specimens, after exposure to three years of tidal condition, behave better than control specimens. Degradation effects of chloride ions on FRP fibers were less than the confinement effect of fibers on penetration of chloride ions. Inversely GFRP fibers were influenced more by chloride ions and specimen's strength reduced 4.9 and 0.8 percent more of strength of control specimens for one and two layers, respectively.

Group II specimens approximately simulate site conditions of group III. Therefore, the results of these groups show good agreements. The ultimate load obtained by wetting and drying cycles is lower than that of real site specimens by 0.5% to 1.9%. This is probably due to using continuous high temperature in group II library specimens (38 ^{o}C). However, both group II and III specimens show significant change on ultimate strength with group I specimens and their strength decreased by 13.3 and 9.7 percent for GFRP and CFRP strengthened specimens, respectively.

The results of all three groups indicate that laboratory specimens increased 22-33, 65-65, 44-50 and 77-75 percent for schemes 1 to 4 in respect of to salted control specimens but site specimens with lower compressive strength increased 67, 103, 76 and 114 percent due to salted control specimens for schemes 1 to 4, respectively. These data specifies that the lower concrete compressive strength of the specimens leads to better strengthening results.

Table 6 presents the ultimate load for group II and a comparison with micelli et al10 data. In that paper CFRP and GFRP fibers have been used for strengthening columns and encountered with dense NaCl solution. Group II results indicate that the rate of decrease of strength due to chloride ions was 16.8 and 11 percent for GFRP and CFRP, respectively, while micelli results show that corrosion decreased the strength of GFRP and CFRP strengthened specimens by 17.3 and 6.7 percent. These results confirm that there is a good agreement for the effect of chloride ions on strength decrease between group II and micelli results. However, micelli results show higher increase percent due to unsalted control specimens by 26.2 and 23.7 percent for glass and carbon specimens. Using especial fiber with higher thickness (0.16 mm and 0.35 mm instead of 0.12 and 0.2 for GFRP and CFRP) explain higher rate of strengthening in micelle results.

4. Conclusions

This study concentrated on the durability evaluation of the concrete cylinder specimens strengthened with GFRP and CFRP laminates. The experimental results indicate that adequate performance against chloride ions can be obtained for concrete cylindrical columns by bonding layers of FRP sheets. Based on the results from experimental tests the following conclusions can be drawn:

1. Addition of CFRP laminates especially in full wrapping schemes reduces chloride ions penetration significantly. Test results showed that chloride ions penetration decreased in cylinders specimens wrapped with FRP laminates around 70 percent for group II and III specimens.
2. Although chloride penetration reduces the strength of concrete specimens up to 11.6 percent but not only FRP strengthened salted specimens achieved their initial strength but also increased up to 92.7 percent in respect to unsalted control specimens for group III two layers of CFRP.
3. CFRP fibers behave better than GFRP fibers against chloride ions as the confinement effect of CFRP fibers in all cases overcomes the corrosive effect of chloride ions on FRP fibers.
4. Wetting and drying simulating system can predict the results in real site exposed specimens with acceptable accuracy.
5. Addition of CFRP laminates increases ultimate strength of the specimens. The maximum increase in load carrying capacity due to strengthening was 114% with respect to the control specimens. Generally, specimens with lower concrete strength carried higher load at ultimate failure.
6. Wetting and drying system, especially when came out at high temperature, intensified chloride ion corrosion as the strength of one layer GFRP strengthened specimen reduced by 14 percent due to wetting and drying cycles.

References

[1] Khaloo A. R. and Gharachorlou A.: 2005, Finite element analysis of RC beams strengthened in flexure CFRP laminates, International Journal of civil Eng., 3, pp. 1-9.

[2] Esfahani M. R.: 2008, Effect of cyclic loading on punching shear strength of slabs strengthened with carbon fiber polymer sheets, International Journal of civil Eng., 6, pp. 208-215.

[3] Esfahani M. R.: 2008, Effect of cyclic loading on punching shear strength of slabs strengthened with carbon fiber polymer sheets, International Journal of civil Eng., 6, pp. 208-215.

[4] Teng. F., Chen J. F. and Smith S. T.: 1988, FRP-strengthened RC structures. Wiley, New York.

[5] Beaudoin Y., Labossiere P. AND Neale K. W.: 1998, Wet-dry action on the bond between composite materials and reinforced concrete beams, Proceedings of CDCC, Sherbrooke, CDCC, pp. 537-546, Canada.

[6] Lacasse C., Labossiere P. and Neale K.: 2001, FRP for the Rehabilitation of concrete beams exhibiting alkali-aggregate reactions. University of Sherbrooke, Canada.

[7] Homan S. and Sheikh S.: 2005, Fiber reinforcement polymers and FRP concrete composites subjected to various loads and environmental exposures, Research in Department of Civil Eng., University of Toronto, p. 475, Canada

[8] Micelli F., Myers J. and Murthy SH.: 2002, Performance of FRP confined concrete subjected to accelerated environmental

conditioning. Proceedings of the Second International Conference (CDCC 02), pp. 87-98, Canada.

[9] Sangeeta G., Mukherjee A. and Malhotra S. N.: 2009, Corrosion of steel reinforcements embedded in FRP wrapped concrete, Construction and Building Materials, 23, p. 153-161.

[10] Manuel A.G., Silva A and Hugo B.: 2008, Degradation of bond between FRP and RC beams, Composite Structure, 85, p.164-174.

[11] American society for testing and materials: 2004. Standard test method for Acid-Soluble Chloride in Mortar and Concrete, ASTM C1152.