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EVALUATION OF FRP CONCRETE COMPRESSION MEMBER UNDER REPEATED LOAD AND HARSH ENVIRONMENT

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ABSTRACT: Strengthening and rehabilitation have been increasingly applied in many structures to improve their capacity and serviceability. Fiber Reinforced Polymer (FRP) materials are universally known for their ability to improve the load capacity of damaged structural elements because of their high linear-elastic behavior. However, enhancing the capacity of structural elements that are exposed to repeated load coupled with harsh environment is an area that requires further investigation. This research focused on experimental analysis of the behavior and response of confined and unconfined concrete compression members (300mm x 150mm) under repeated load while exposed to 1440 cycles of seawater splash zone in United Arab Emirates (UAE). Confining concrete compression members with Carbon Fiber Reinforced Polymer (CFRP) and Glass Fiber Reinforced Polymer (GFRP) sheets have increased the load capacity compared to the control sample at room temperature by 110% and 84%, respectively. Results showed that the average value of compressive strength for the confined concrete exposed to sea water splash zone conditions for CFRP and GFRP specimens has decreased by 33% and 23%, respectively, compared to the confined concrete in the room temperature. However, GFRP specimens showed higher performance in compressive strength under sea water splash zone than those of the CFRP specimens. Different mode of failures such as delamination, de-bonding and combination of such modes were observed and related to various exposure factors and mechanical properties.

Keywords: Concrete compression member, CFRP, GFRP, Repeated load, Sea water splash zone.

1. INTRODUCTION

Concrete is one of the most commonly used materials in building construction projects. Many scientists and professionals continue to find new ways to improve the strength of concrete material and reduce its weight/volume ratio to preserve natural materials and reduce energy consumption. Another area explored in concrete structures is the stability of the structure against external forces such as earthquakes, wind loads, repeated loads, etc. FRP sheets are usually bonded externally to the concrete surfaces to enhance the performance of the concrete compression members. They are also used to strengthen structures that suffer from problems imposed by harsh surrounding environments as well as severe operation that may ultimately lead to catastrophic failure of the deteriorating structure.

Environmental conditions have a significant effect on concrete's durability and structural integrity, such as corrosion of the concrete, column failure and a decrease in life expectancy. To reduce or eliminate these effects, FRP sheets are used in the design of concrete compressive to increase its strength and durability. The technique of concrete compression member by FRP on a concrete is used due the numerous advantages that the fibers materials possess such as high strength, low conductivity, low weight and corrosion resistance. One of the first applications of FRP wrapping on concrete was started in Japan to enhance the loading capacity of structural elements [1]. This was followed by several applications and modeling of CFRP [2]. However, the sustainability of externally confined fiber with the concrete compression members is not fully investigated and requires further analyses and studies.

Deterioration of the bond between the FRP sheet and the material surface is the main concern of composite member when it is exposed to an extreme condition. This bond can get affected by different environmental factors such as high temperature and humidity.

Silva, [3] conducted an experiment to study the effects of the temperatures cycles at fixed humidity. The main goal was to know if there is any change in tensile stress in concrete columns strengthened with GFRP warps exposed to temperature cycles at the fixed humidity of 80%. It showed decrease of about 11% at 3000 hours to 5000 hours. There was a negligible decrease after 5000 hours. Since the loss of strength after 10,000 hour was less than 5%, the ratio of the ultimate strength by the tensile strain did not vary too much.

Leone and Aiello, [4] presented a paper investigates the effects of elevated service temperature on the bond between FRP systems and concrete by applying tests at FRP reinforcements such as sheets and laminates. The concrete specimens were (150 mm x 150 mm x 800 mm) with three FRP reinforcements: GFRP sheets, CFRP sheets, and CFRP laminates. The tests were conducted at 50ºC, 65ºC and 80ºC. These temperatures were chosen with respect to the glass transition temperature (T_g). The results showed that in all three cases the maximum bond stress decreased beyond (T_g). However the numbers were different for each category of the reinforcement. For example, for CFRP sheets case, the maximum stress decreases about 13% at 65ºC degree and 54% at 80ºC degree. For GFRP sheets and CFRP laminates, however, the stress decrease was 72% and 25%, respectively. The authors concluded, thus, that the different surface textures of the utilized products potentially affect the bond function, in terms of FRP alignment, uniform resin distribution and thickness.

Frigione et al., [5] studied the effects of water on the bond strength between concrete and the adhesive specimens were immersed in water for one month and then tested according to ASTM C 882-91. The results show that when the resin matrix allows water adsorption which in turn leads to change in the mechanisms that cause deterioration of the polymer materials. This affects the performance of the FRP materials. Due to that, the effect of water on the adhesion of the joints was found to be significant, especially at longer immersion periods. It was found that the bond strength of concrete–adhesive specimens reduced by 30% after one month of immersion in water.

Another study, [6] that was conducted in University of Alabama that tries to investigate the effect of the wet/dry cycles at the strengthened concrete beams (by FRP) indicates that the improvement in the load capacity happened in both beam groups (the one that is kept in room temperature and the one is under wet/dry cycles). However, the improvement in the beams that are kept in room temperature is more improvement than the beams that are under wet/dry cycles in many aspects such as load capacity. Most of the studies that are dealing with the effects of harsh environment, their experimental specimens were tested under the static loading, without considering other types of loads system such as repeated loading.

Repeated loads decrease the mechanical capacity of any concrete compressive member particularly in bridges. Therefore, it is imperative studying repeated/dynamic loading on concrete compressive member to examine the hysteretic characteristics. Repeated loading is considered a complex loading as it contains tension and compression loadings. There are many experimental studies conducted to investigate the behavior of the plain concrete under the repeated loading either in tension or compressive phase. It was concluded that unloading damages and reloading damages affect the stiffness of the concrete when subjected to the repeated loading. To explain, unloading and reloading cycles cause degradation in stiffness and strength in plain concrete. Therefore, it is a good idea to get the unloading curve and reloading curve for any repeated loading as they are related to the damage accumulation so that the energy dissipation capacity of the material could be determined [7]. Shahawy et al., [2] conducted an experiment includes 24 FRP-confined concrete compression members were tested under cycles of loading and unloading in uniaxial compression. High correlation was observed between the analytical estimates of the model and the experimental results of an independent test series, approving the capability of the model to predict the repeated behavior of FRP-confined concrete specimen. There is no research work that is focused on the effect of FRP in increasing the load capacity of concrete compression member under both repeated load and harsh environment. Hence, the main focus in this study is to evaluate the performance of the compression members that are under the influence of both repeated loading and environmental exposures.

2. EXPERIMENTAL PROGRAM

A total of 15 concrete compression members were cast in one batch using concrete grade 40.The concrete compression members were 150mm in diameter and 300 mm in height, and were all made of the same batch of concrete with a 28-day compressive strength of 40 Mpa. CFRP and GFRP wraps were used. The specifications for CFRP and GFRP sheets are shown in the Table 1.

Table 1 Characteristics of FRP sheets

Property	CFRP	GFRP
Grade	CF 300HS	E-glass 90/10
Fiber weight (g/m2)	300	980
Fiber density (g/m2)	1.80	2.78
Design thickness (mm/ply)	0.168	0.352

Table 1 continue

Property	CFRP	GFRP
Composite thickness (mm/ply)	0.60	-
Tensile strength of fiber (N/mm2)	4800	3400
Tensile/elastic modulus (N/mm2)	236000	>72000
Ultimate elongation (%)	2.1	≥4.5

In this experimental study, the wet layup process method was used. This method consists of applying resin on the concrete surface then applying the fabric layers which was attached and bonded to the surface. This method provided maximum flexibility [8]. However, there are two main problems related to the resin used in this method such as mixing of the resin and absorption of moistures. It could cause serious damage of the whole wrapping process like wrinkling and shearing of fibers.

Therefore it is critical to have compatible resin with the fabric materials used in the wrapping. The importance of the epoxy consists of providing a strong bond between the concrete surface and the fabric materials for prolonged periods against the harsh environment factors. The epoxy must be equally spread in the desired area. Rollers were used with 0.6-1 l/m^2 amount of resin at the primed surface [9]. The side area was equal to 0.28 m^2. However, 1in was added as overlap length where the recommended length for the overlap is 1-2in [2].

Table 2 shows that the control samples include three unconfined concrete compression members tested under room temperature. There were six concrete compression members wrapped with CFRP and six with GFRP. Three samples in each case were exposed to harsh environment as shown in Fig.1.

Table 2 Exposure methods of the specimens

Type and name of the specimen	Exposure condition
Control	
C-RT1	Room temperature
C-RT2	Room temperature
C-RT3	Room temperature

Table 2 continue

Type and name of the specimen	Exposure condition
Strength with CFRP	
CFRP-RT1	Room temperature
CFRP -RT2	Room temperature
CFRP -RT3	Room temperature
CFRP -W1	Wet/dry cycles
CFRP -W2	Wet/dry cycles
CFRP -W3	Wet/dry cycles
Strength with GFRP	
GFRP -RT1	Room temperature
GFRP -RT2	Room temperature
GFRP -RT3	Room temperature
GFRP -W1	Wet/dry cycles
GFRP -W2	Wet/dry cycles
GFRP -W3	Wet/dry cycles

The harsh environment consists of 12 wet/dry cycles per day using sea water representing splash zone for four months during summer time. The average temperature was 45ºC and total time of exposure was 2880 hrs. Prior to apply the repeated loading on the specimens, the program of the loading and unloading should be pre-defined.

Fig. 1 Sustainability Center used for the specimens

The number of cycles, frequency and unloading-reloading values should be determined. Therefore, number of concrete compression members (confined and unconfined) with the same dimensions as the matrix specimens were tested under static load to determine load capacity as shown in Table 3.

Table 3 Trial monotonic loading test for the specimens

Type and Name of the Specimen	Compressive strength (MPa)	Ultimate load (kN)
Control		
(S-C) A	42	742.14
(S-C) B	38	671.46
(S-C) C	40	706.80
Average	40	706.80
Strength with CFRP		
(S-CFRP) A	82.56	1461.36
(S-CFRP) B	77.97	1380.02
(S-CFRP) C	79.59	1408.80
Average	80.04	1416.63
Strength with GFRP		
(S-GFRP) A	68.25	1207.96
(S-GFRP) B	71.59	1267.07
(S-GFRP) C	72.36	1280.70
Average	70.73	1251.85

Various researchers used different loading patterns to apply the compression repeated loading test. For example, the first step of defining the cyclic loading pattern is by knowing the load capacity of the sample. This can be determined by applying the monotonic load until fracture. After getting the fracture capacity of the sample, many options are available to be applied.

For example, Shahawy et al., [2] in his experiment used five cycles until the first peak reached to 80% of the fracture load and then three cycles applied with peaks between 60 % and 80% of the fracture capacity. The last cycle represented peaks between 60% and 100% of the fracture capacity.

The objective of developing this test method is to have a test that applies to all confined and unconfined specimens. For each case there is an average of the ultimate static load which is showed in Table 3. The developed test for each case will be based on this load. Fig. 2 shows three cycles which have been applied where the maximum load is 40% of the ultimate load.

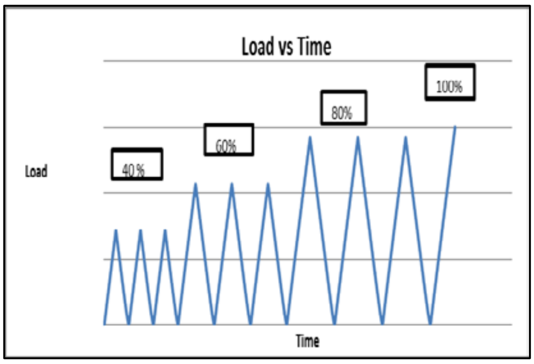

Fig. 2 The developed Repeated Load

Then, the same process will be applied with 60% and 80% of the ultimate load. The maximum load for the last cycle is equal to 100% of the ultimate load.

3. RESULTS AND DISCUSSION

The mechanical performances of the samples under different exposures conditions and repeated load are presented in Table 4.

Table 4 Mechanical response for the specimens

Type and name of the specimen	Compressive strength (MPa)	Ultimate load (kN)
Control		
C-RT1	36.61	647.78
C-RT2	35.34	625.51
C-RT3	37.51	663.71
Average	36.48	645.66
CFRP-under room temperature		
CFRP-RT1	77.21	1366.63
CFRP-RT2	77.15	1365.45
CFRP-RT3	76.25	1349.55
Average	76.87	1360.54
GFRP-under room temperature		
GFRP-RT1	67.54	1195.39
GFRP-RT2	66.23	1172.21
GFRP-RT3	67.91	1201.94
Average	67.22	1189.85

Table 4 continue

Type and name of the specimen	Compressive strength (MPa)	Ultimate load (kN)
CFRP-under wet/dry condition		
CFRP-W1	48.47	857.89
CFRP-W2	50.98	902.45
CFRP-W3	53.44	945.98
Average	50.96	901.94
GFRP-under wet/dry condition		
GFRP-W1	52.14	922.92
GFRP-W2	54.15	958.35
GFRP-W3	47.56	841.76
Average	51.28	907.68

The modes of failures for unconfined and confined concrete compression member are cone, border, delamination, de-bonding and FRP rupture [10, 11]. Cone and border failures were observed for the unconfined specimens as shown in Fig.3 (a,b) and de-bonding and delamination failures for confined specimens shown in Fig.3 (c,d). The mode of failure for the confined concrete compression member is related with its ultimate stress.

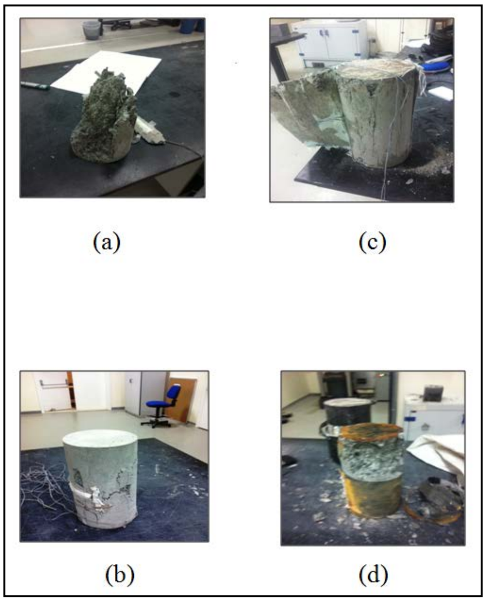

Fig. 3Failure modes: (a) Cone failure, (b) Border failure, (c) De-bounding failure, (d) Delamination failure

The load capacity of confined concrete compression members has been increased compared to the control samples as shown in Fig.4.

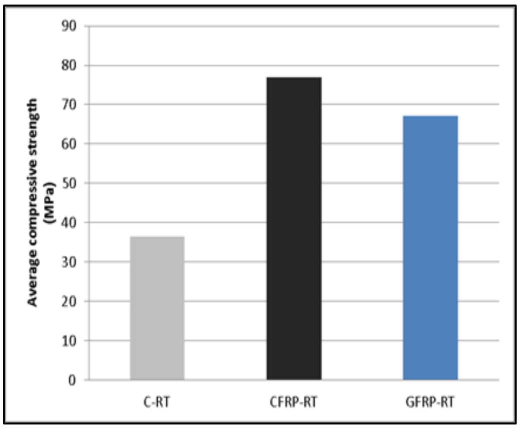

Fig. 4 Average compressive strength for C-RT, CFRP-RT and GFRP-RT specimens

Table 5 shows that the CFRP sheets increased the compressive strength of the concrete compression members more than the GFRP sheets. The percentage of improvement of the CFRP specimens (CFRP-RT) is 110% compared to the control specimens (C-RT) and 84% for the GFRP specimens (GFRP-RT). All the pervious specimens (confined or unconfined) were not exposed to any harsh environment conditions.

Table 5 Average compressive strength for (C-RT), (CFRP-RT), and (GFRP-RT) specimens

Set/Group	Average compressive strength (MPa)	(%) Increase
(C-RT)	36.48	-
(CFRP-RT)	76.87	110.71
(GFRP-RT)	67.22	84.26

Sea water wet/dry cycles exposure has a major effect in the load capacity for the confined concrete compression members. For example, by comparing the confined specimens under wet/dry cycles (CFRP-W) with the one under the room temperature (CFRP-RT), a clear difference in compressive strength values can be noticed as shown in Fig.5.

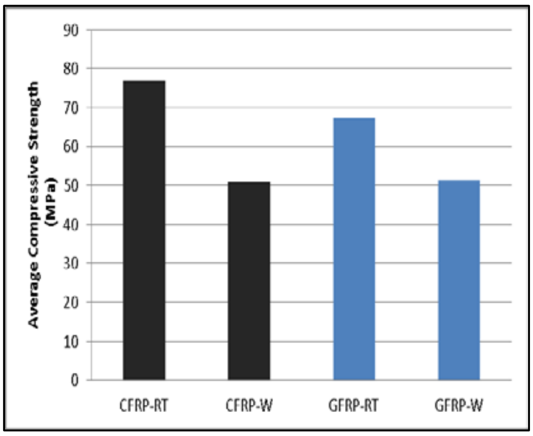

Fig. 5 Average compressive strength for CFRP-RT, CFRP-W, GFRP-RT and GFRP-W specimens

Table 6 shows that the average compressive strength for the (CFRP-W) specimens under repeated load is less than (CFRP-RT) specimens by 33%. The same trend was observed in the GFRP specimens but with less extent. To illustrate, the average compressive strength for the (GFRP-W) specimens is less than (GFRP-RT) specimens by 23%. This indicates that wet/dry cycles has more deteriorating effect in CFRP specimens than the GFRP specimens.

Table 6 Average compressive strength for (CFRP-RT), (GFRP-RT), (CFRP-W), and (GFRP-W) specimens

Set/Group	Average compressive strength (MPa)	(%) Increase	(%) Increase
(CFRP-RT)	76.87	-	-
(GFRP-RT)	67.22	-	-
(CFRP-W)	50.96	-33.70	-
(GFRP-W)	51.28	-	-23.71

4. CONCLUSIONS

This study tested 15 concrete compression members, 12 of which were confined with CFRP and GFRP sheets. The research program covered various parameters and their effects. Generally, samples confined with FRP showed significant mechanical improvement under combined factors of repeated loads and exposures to sea water splash zone.

The following conclusions summarize the results of this research:

1. One layer of CFRP has increased the load capacity concrete compression member by 110% compared to the control specimens.
2. One layer of GFRP has increased the load capacity the concrete compression member by 84% compared to the control specimens.
3. De-bonding failure mode was more frequent in CFRP specimens at wet/dry condition due to the damaged bond between the resin and CFRP sheet.
4. Wet/dry cycles had deteriorating effects on the load capacity GFRP specimens. It has reduced the compressive strength by 33% compared to 1-layer GFRP specimens at room temperature.
5. Wet/dry cycles had deteriorating effects on the load capacity for GFRP specimens. It has reduced the compressive strength by 23% compared to the 1-layer GFRP specimens at room temperature.

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6. NOMENCLATURE

C-RT	Compression member under room temperature
CFRP-RT	Compression member wrapped by one layer of CFRP under room temperature
GFRP-RT	Compression member wrapped by one layer of GFRP under room temperature
CFRP-W	Compression member wrapped by one layer of CFRP under sea water wet/dry cycles
GFRP-W	Compression member wrapped by one layer of GFRP under sea water wet/dry cycles
S-C	Compression member under static load
S-CFRP	Compression member wrapped by one layer of CFRP under static load
S-GFRP	Compression member wrapped by one layer of GFRP under static load

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