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Behaviour of FRP Confined Concrete Cylinders under Different Temperature Exposure

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ABSTRACT: Bridge structures are exposed to the elements with a high variation in temperature. The purpose of this study is to investigate the effect of different high temperatures on the behaviour of concrete cylinders wrapped with Fibre Reinforced Polymer (FRP). Twelve concrete cylinders made of 60 MPa having 100 mm diameter and 200 mm height were cast and tested. The cylinders were divided into four groups: cylinders wrapped with a single CFRP layer, cylinders wrapped with two CFRP layers, cylinders wrapped with a single GFRP layer, and cylinders wrapped with two GFRP layers. Each group was exposed to temperatures of 20°C, 20°C to 70°C, and 70 °C for 30 days. All cylinders were then tested to failure by the application of an axial concentric compression loading. The study indicated that the ultimate strength of concrete cylinders wrapped with one and two layers of CFRP and GFRP did not significantly change after being exposed to 20°C to 70°C, and 70 °C. The exception was observed on the cylinder wrapped with one layer of GFRP where its ultimate strength decreased. However, the results had shown a good performance (increased) of their ductility. The exception was observed on cylinders wrapped with one and two layers of GFRP where their ductility did not significantly change.

1 INTRODUCTION

Fibre Reinforced Polymer (FRP) is known as an excellent material for retrofitting, repairing and strengthening structural members. It is characterised by the following features: light weight material, corrosion resistant; available in various forms for field application, such as bar, sheet, strip and plate, and also available in long length thus eliminating the need for joints and splices; and can be cured within 24 hours when applied in the field.

Moreover, application of FRP to confine concrete members is widely used all over the world, due its high strength to weight ratio and ease of installation. When FRP is applied, it will lead to improving the strength of concrete members and it will increase their ductility dramatically, and reduce their maintenance cost compared to other methods such as attachment of steel jacketing.

However the behaviour of FRP confined concrete members has not been explored extensively especially at different temperature environment where solar gain could lead to a high concrete surface temperature. The maximum reported environment temperature applied to FRP confined concrete member is +45°C. It is also noticed that the global temperature tends to increase as a result of climate changes.

Therefore if the behaviour of FRP confined concrete members under different temperatures is known, the application of FRP confined concrete members can be used more confidentially in a wide range of temperature. This study investigates the effect of different temperatures on the behaviour of FRP confined concrete cylinders under axial compression loading.

2 REVIEW OF LITERATURE

Green et al. (2006) investigated the effect of extreme conditions on the behaviour of FRP wrapped concrete columns where cold region, corrosion, and fire were the extreme conditions. Furthermore the cold region was divided into low temperature and freeze thaw regions. For low temperature region test, six cylinders (two plain and four wrapped with single and two layers of CFRP-A) were kept at -18°C for 200 days and then tested at room temperature, nine cylinders (three plain and six wrapped) were kept at room temperature as control specimens, and 16 cylinders (wrapped with a single layer of CFRP-B and two layers of GFRP-A) were kept at -40°C and room temperature for 16 days and then tested immediately after removing from frozen place for cylinder under -40°C. Each cylinder had 152 mm diameter and 305 mm height while notation A and B represented the manufacturer that produced the CFRP and GFRP material. It is found that at low temperature cylinder with CFRP-A wrapping did not experience reduction in its strength even observed increasing 14% at temperature of -40°C. For freeze thaw test, sixty three cylinders having 152 mm diameter and 305 mm height wrapped with CFRP-A and GFRP-B were exposed to 250 freeze thaw cycles where the cycle consisted of 16 h of freezing at -18°C and 8 h of thawing at +15°C in a water tank. The air entrainment of CFRP and GFRP wrapped cylinders was equal to 5% and 6%. It was found that CFRP and GFRP wrapped cylinders had a reduction less than 10% and 5% of its strength while unwrapped cylinder had reduction more than 50% of its strength.

El-hacha et al. (2010) investigated the behaviour of plain concrete cylinders wrapped with FRP sheets subjected to a harsh environment such as high temperature, heating and cooling cycles, and prolonged heat temperature. The high temperature was represented by a temperature of +45°C for 70 days, heating and cooling cycle was represented by a temperature of +23°C to +45°C for 33 cycles, and prolonged temperature was represented by a temperature of +45°C for 70 days. Thirty six plain cylinders having 150 mm diameter and 300 mm height were cast and tested under axial compression loading until failure. Nine cylinders were unwrapped and used as control specimens and 24 cylinders were wrapped with 2 layers of CFRP sheets. Half of the cylinders under heating and cooling cycle temperature were then subjected to freezing and thawing cycle (-18°C to +23°C) for 33 cycles and the others were submerged in fresh water at +23°C for 33 days or salt water at +23°C for 33 days. The study found that no significant difference of strength was observed for both wrapped and unwrapped specimens subject to heating and cooling cycle compared to the room temperature specimen. Slightly negative effect was monitored on the compressive strength of both wrapped and unwrapped specimens under freezing and thawing cycles as well as fresh and salt water immersion. The strength of wrapped concrete cylinders was observed not to decrease as a result of high temperature exposure.

Kabhari et al. (2000) investigated the effect of extended freeze-thaw (dry) cycles on the response of both CFRP and GFRP reinforced FRP composite wrapped concrete. Cylinders made of 50 MPa having 152.4 mm diameter and 304.4. 8 mm height were cast and tested. After 28 days in a water tank, the cylinders were removed and wrapped with two types of FRP (CFRP and GFRP) and were placed in room temperature for one month before testing. Next the specimens were divided into two groups; the first group was stored at 22.5°C and the others were subjected to 201 freeze-thaw cycles between 22.5°C to -20°C C. All specimens were tested until failure by axial compression loading. It was found that there was no significant change of ultimate strength of the wrapped cylinder after being exposed to freeze and thaw cycles and its stiffness was observed increasing compared to room temperature cylinders.

Homan and Sheikh (2000) tested FRP tensile coupons and FRP single lap bonded specimen to investigate the durability of FRP composite and FRP reinforced concrete under various environmental conditions. The environmental condition was freeze-thaw cycles (between -18°C to + 4°C) and submerged into water, UV radiation, temperature variation (4 cycles/day between -20°C to + 40°C in dry chamber), alkaline solution, moisture (water submersion at 22°C room temperature). It was concluded that all environmental condition had a minimal effect on the mechanical properties of FRP composites. Freeze-thaw cycles and moisture exposure were observed as noticeable effects on the bond properties of single lap bonded specimen.

Karbhari and Eckel (1994) tested eight cylinders made of 51.88 MPa concrete having 152.4 mm diameter and 304.8 mm height to investigate the effect of temperature on three different composite jackets subjected to temperature of 22.8°C and -17.8°C. After a curing period of 28 days, six specimens were wrapped with two layers of CFRP, GFRP, and AFRP using epoxy and were placed in a vacuum bag and cured at room temperature for 36 hours. Next, the specimens were divided into two groups where each group consisted of one unwrapped specimen and three cylinders wrapped with two layers of CFRP, GFRP, and AFRP. All the specimens of the first group were exposed to a temperature of 22.8°C for 60 days and the specimens of the second group were exposed to a temperature of -18.8°C for 60 days. After being exposed to the temperature, all specimens were tested using axial compression load until failure. The research found that the compressive failure load of confined cylinder increases after being exposed to a temperature of -17.8°C.

Karbhari (2002) performed an experimental test on confined concrete exposed to extended freeze (both before and after moisture absorption) and freeze-thaw regimes in order to evaluate the effect caused by exposure, both neat resin (unreinforced resin matrix) specimens, and FRP composite when exposed to same environments as the confined concrete cylinders. Plain cylinders made of 41.4 MPa concrete having a size of 152.4 mm diameter and 304.8 mm height were cast and tested. After curing for 28 days, all cylinder moulds were removed and wrapped with 3 layers of CFR and then put into a chamber with temperature of 23°C and 50% room humidity. Sample of neat resin and composite were fabricated and treated as confined cylinder specimens. Before being exposed to a number of cycles, a set of unconfined cylinders and confined cylinders and also unreinforced resin matrix and composite were tested under axial compression loading. Next, the specimens were divided into three groups where one group was exposed to freeze environment, one was exposed to saturated freeze environment, and the other one was exposed to freeze-thaw environment. Specimens were exposed to freeze environment by placing them at a temperature of -18°C. Specimens were exposed to saturated freeze environment by immersing them in deionised water at 23°C temperature for 25 days and then placing them at -18°C temperature. Specimens were exposed to saturated freeze-thaw environment by immersing them in deionised water at 23°C temperature for 25 days and then exposing them to daily cycles between 20°C to -18 °C. Next all specimens were tested under axial compression loading. It was found that after being exposed to a prolonged temperature of -18°C and freeze-thaw cycles (20°C to -18°C) after moisture, degradation of matrix and bonding between matrix and FRP were observed, resulting in a reduction of FRP composite confined concrete cylinders' strength. From previous studies, it seems that the temperature range above 45° C needs to be investigated and also solar gain can lead to concrete temperatures being much higher than ambient. Some regions such Australia have experienced very extreme temperatures where 50.7° C was observed in 1950 (Australian Bureau of Meteorology 2010). Therefore there is a need to investigate the behaviour of FRP wrapped reinforced concrete members at higher temperatures above 45° C. This study is a step in this direction.

Teng et al. (2003) investigated the performance of new bridge columns wrapped with FRP subjected to aggressive environmental conditions such as corrosion and freeze-thaw cycle. The research was conducted by field monitoring and laboratory test. The laboratory test was undertaken to investigate the effect of temperature cycle on the mechanical performance of FRP wrapped bridge column and study how FRP wraps save concrete columns from corrosion and freeze-thaw. In field monitoring, temperature data was collected from various locations of bridge columns and visual inspection was conducted periodically of two bridges during two years. In laboratory test, 17 small plain concrete specimens of 76 mm X 102 mm X 381 mm, 60 plain concrete cylinder specimens of 152 mm X 305 mm, and 5 plain rectangular specimens of 254 mm X 254 mm X 508 mm made of 41.370 kPa of concrete compressive strength at 28 days were cast and tested. Wrapping was conducted by using epoxy and single layer and two layers of GFRP. The research found that no evidence of deterioration on the GFRP wrap was observed under the aggressive environments during field monitoring. From the laboratory test, the overall behaviour of GFRP wrapped specimens showed insignificant effect after being exposed to freeze-thaw. However, there was a loss of both axial and hoop strain capacities of GFRP wrapped specimens after being exposed to freeze-thaw cycles.

3 EXPERIMENTAL PROGRAMME

Twelve cylinders having 100 mm diameter and 200 mm height made of 60 MPa concrete were cast and tested. One day after pouring, all cylinders were removed and submerged into a water tank for 28 days for hydration. After that the cylinders were dried and cleaned. Wrapping was done by mixing epoxy resin and hardener with a ratio of 1:5. The mixture dried up in room temperature after one day of application. For cylinders that were wrapped with 2 layers, the second layer was applied after 30 minutes of the application of the first layer. This length of time can protect the first layer from movement when the second layer was applied. The mechanism of wrapping can be seen in Figure 1.

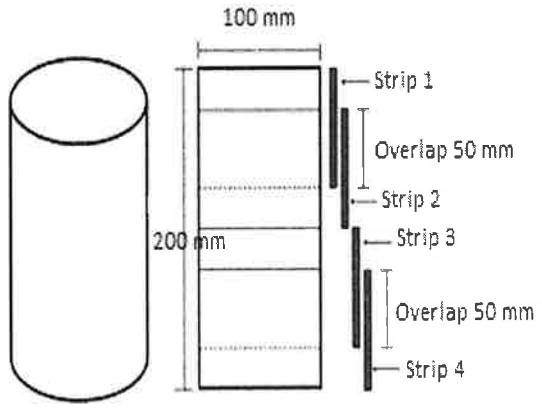

Figure 1. Mechanism of Wrapping

All cylinders were then divided in four groups; cylinders wrapped with one CFRP layer, cylinders wrapped with two CFRP layers, cylinders wrapped with one GFRP layer, and cylinders wrapped with two GFRP layers. Each group was exposed to different temperatures of approximately 20°C, 20°C – 70°C, and 70°C for 30 days. Cylinders exposed to 20°C were placed inside a room. Cylinders exposed to 20°C – 70°C were placed in an oven with a 70°C temperature for 1 day and then removed out of the oven and kept at room temperature for 1 day. This process was repeated for 30 days. Cylinders exposed to 70° C were placed in an oven with 70° C temperature. Details of the cylinders can be seen in Table 1.

Table 1. Details of tested cylinder

Temp °C	Number of cylinders				Treat
	1 CFRP	2 CFRP	1 GFRP	2 GFRP	
20	1	1	1	1	Room
20 to 70	1	1	1	1	1 day in oven and 1 day room
70	1	1	1	1	Inside oven

After temperature exposure, the cylinders were tested in room temperature by the application of an axial concentric loading until failure. The strain-controlled loading was applied on the cylinder using a compression machine with a capacity of 5000 kN at a rate of 0.2 mm/s. Data obtained was load and axial deflection and was recorded every 2 seconds. All the tests were conducted at the Engineering Laboratories at the University of Wollongong, Australia.

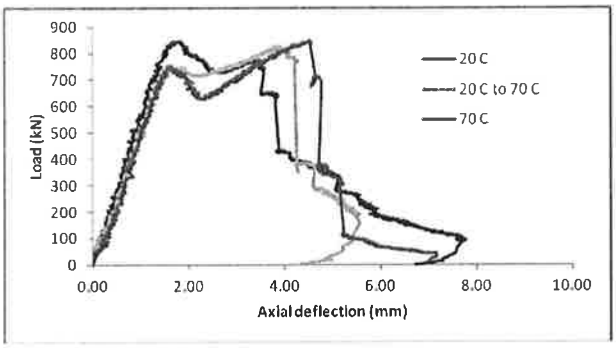

Figure 2. Load-axial deflection of cylinders wrapped with a single CFRP layer

4 EXPERIMENTAL RESULTS

4.1 *Cylinders wrapped with a single CFRP layer*

The load-axial deflection curve of the cylinders wrapped with a single CFRP layer and exposed to 20°C, 20° C – 70° C, and 70° C are presented in Figure 2.

4.2 *Cylinders wrapped with 2 CFRP layers*

The load-axial deflection curve of the cylinders wrapped with two CFRP layers exposed to 20°C, 20°C – 70°C, and 70°C are presented in Figure 3.

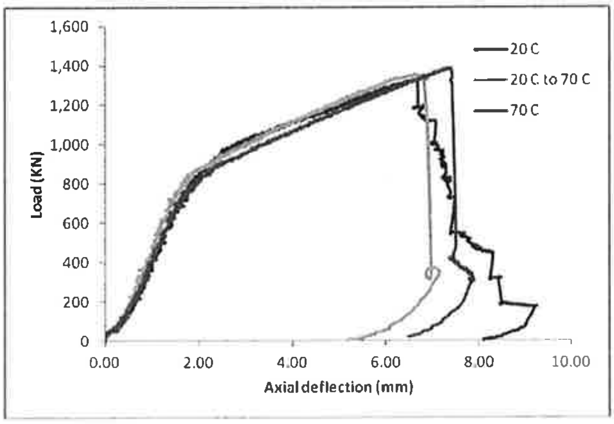

Figure 3. Load-axial deflection of cylinders wrapped with two CFRP layers

4.3 *Cylinders wrapped with a single GFRP layer*

The load-axial deflection curve of the cylinders wrapped with a single GFRP layer and exposed to 20°C, 20°C – 70°C, and 70°C are presented in Figure 4.

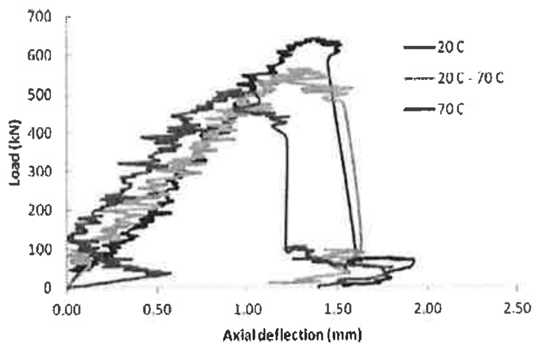

Figure 4. Load-axial deflection of cylinders wrapped with a single GFRP layer

4.4 *Cylinders wrapped with 2 GRRP layers*

The load-axial deflection curve of the cylinders wrapped with two GFRP layers and exposed to

20°C, 20°C – 70°C, and 70°C are presented in Figure 5.

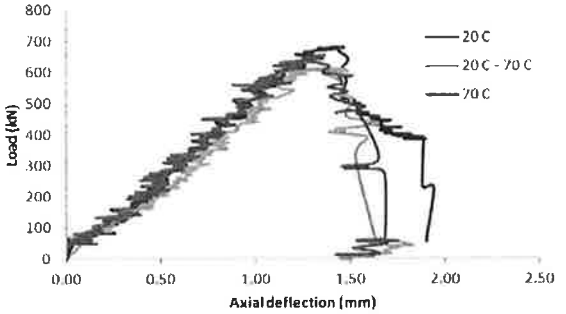

Figure 5. Load-axial deflection of cylinders wrapped with two GFRP layers

5 ANALYSIS OF RESULTS

5.1 *Ultimate strength and displacement ductility characteristics*

5.1.1 *Cylinders wrapped with a single CFRP layer*

Table 2 shows the ultimate strength and ductility of the cylinders wrapped with a single CFRP layer. It can be seen that after being exposed to different temperature; 20°C to 70°C and to 70°C, the ultimate strength of the cylinders wrapped with a single CFRP layer did not significantly change (less than 10%). On the other hand their ductility increased with the maximum increase being observed on the cylinder after being exposed to 70°C.

Table 2. Ultimate strength and displacement ductility of cylinders wrapped with a single CFRP layer

Behav.	Temp. Exposure °C			Diff.	
	20	20 to 70	70	20 to 70 by 20	70 by 20
Ult. Load kN	846.22	825.89	848.88	-2.4	0.31
Disp. Duct. mm/mm	1.49	2.95	3.27	97.99	119.46

5.1.2 *Cylinders wrapped with 2 CFRP layers*

Table 3 presents the ultimate strength and ductility of the cylinders wrapped with two CFRP layers. It can be seen that after being exposed to different temperature; 20°C to 70°C and to 70°C, the ultimate strength of the cylinders wrapped with two CFRP layers did not significantly change. Moreover, their ductility increased with the maximum increase being observed on the cylinder after being exposed to 70°C.

Table 3. Ultimate strength and displacement ductility of cylinders wrapped with two layers of CFRP

Behav.	Temp. Exposure °C			Diff.	
	20	20 to 70	70	20 to 70 by 20	70 by 20
Ult. Load kN	1324.99	1353.65	1385.94	2.16	4.6
Disp. Duct. mm/mm	3.62	436	4.65	20.44	28.45

5.1.3 *Cylinders wrapped with a single GFRP layer*

As shown in Table 4, the ultimate strength and ductility of the cylinders wrapped with a single GFRP layer. It can be seen that after being exposed to different temperature: 20°C to 70°C and to 70°C, the ultimate strength of the cylinders wrapped with a single GFRP layer decreased. The maximum decrease was observed on the cylinder after being exposed to 70°C. Meanwhile, the ductility did not significantly change (less than 10%) after being exposed to 20°C to 70°C and increased after being exposed to 70°C.

Table 4. Ultimate strength and displacement ductility of cylinders wrapped with a single GFRP layer

Behav.	Temp. Exposure °C			Diff.	
	20	20-70	70	20 to 70 by 20	70 by 20
Ult. Load kN	643.81	562.61	509.56	-12.61	-20.85
Disp. Duct. mm/mm	1.33	1.22	1.87	-8.27	40.60

5.1.4 *Cylinders wrapped with 2 GFRP layers*

Table 5 shows the ultimate strength and ductility of the cylinders wrapped with two GFRP layers. It can be seen that after being exposed to different temperature; 20°C to 70°C and to 70°C, the ultimate strength of the cylinders wrapped with two GFRP layers decreased but they did not significantly change. On the other hand their ductility increased especially the cylinder after being exposed to 70°C.

Table 5. Ultimate strength and displacement ductility of cylinders wrapped with two GFRP layers

Behav.	Temp. Exposure °C			Diff.	
	20	20 to 70	70	20 to 70 by 20	70 by 20
Ult. Load kN	679.86	612.13	653.82	-9.96	-3.83
Disp. Duct. mm/mm	1.21	1.27	1.63	4.96	34.71

6 CONCLUSIONS

Based on findings of this study, the following conclusions are drawn.

The ultimate strength of cylinders wrapped with one and two layers of CFRP did not significantly change after being exposed to 20°C to 70°C and 70°C. Meanwhile, their ductility increased with the maximum increase being observed on the cylinder after being exposed to 70°C.

The ultimate strength of cylinders wrapped with a single GFRP layer decreased after being exposed to 20°C to 70°C and 70°C. The maximum decrease was observed on the cylinder after being exposed to 70°C. Meanwhile, the ductility did not significantly change after being exposed to 20°C to 70°C but increased after being exposed to 70°C.

The ultimate strength of cylinders wrapped with two CFRP layers decreased but it did not significantly change. On the other hand their ductility increased especially the cylinder after being exposed to 70°C.

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