Mansoura Engineering Journal

Volume 30 | Issue 4 Article 4

12-23-2020

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Recommended Citation
Fahmy, W. and Heniegal, A. (2020) "Response of FRP Jacket under Sustained Load and Low Temperature.," *Mansoura Engineering Journal*: Vol. 30 : Iss. 4 , Article 4.
Available at: https://doi.org/10.21608/bfemu.2020.131821

Mansoura Engineering Journal, (MEJ), Vol. 30, No. 4, December 2005.

RESPONSE OF FRP JACKET UNDER SUSTAINED LOAD AND LOW TEMPRATURE

أداء القميص البولمرى للخرسانة تحت تاثير الأحمال والحرارة المنخفضة

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خلاصة

دراسة تدعيم العناصرالإنشائية بإستخدام المواد البولمرية أصبحت من أكثر التطبيقات انتشاراً سواء بإستخدام مواد الألياف الكربونية أو الزجاجية. وهذة الدراسة تستعرض مدى تحمل العناصر الإنشائية الخاضعة للأحمال والمدعمة بإستخدام الألياف الكربونية أو الزجاجية للتأثير المزدوج من الحمل والحرارة المنخفضة لتماثل حالة العناصر الانشائية الموجودة فى الطبيعة. وقد تم من خلال هذة الدراسة المعملية إختبار العديد من الإسطوانات الخرسانية المدعمة بإستخدام نوعين من المواد البولمرية (الكربونية أوالزجاجية)حتى الانهيار وقد تم عمل عدة مقارنات لنتائج العينات المدعمة من حيث الإنفعالات والإجهادات والحمل الكلى وكذلك طراز الإنهيار سواء تحت التأثير المزدوج للحمل والحرارة المنخفضة أوالتأثير الفردى لكلا منهم وقد أظهرت الدراسة بشكل عام تطور كبير فى الأداء الإنشائى للعينلت المدعمة من حيث الزيادة الكبيرة فى حمل الإنهيار مقارنة مع العينات الغير مدعمة وكذلك كان لدرجات الحرارة المنخفضة تأثيركبير على تدهور العينات الخرسانية الغير مدعمة وتأثير طفيف على الأداء الإنشانى للعناصر المدعمة بالمواد البولمرية تحت التأثير الفردى للحرارة المنخفضة . وقد أوضحت النتائج المعملية للمواد البولمرية كفاءة عالية فى الأداء الإنشائى للعينات المدعمة فى حالة التأثير المزدوج للحرارة المنخفضة مع الحمل.

ABSTRACT

FRP materials are now increasingly being used in the construction industry. Confinement of circular concrete members using FRP is a popular application. As such, studying the performance of concrete members confined by FRP jackets, under severe weather conditions is quite important for both rehabilitated and new structures in cold climatic conditions. However, no sufficient data on FRP-wrapped cylinders subjected to the two conditions combined, as in actual structures, which may have a synergetic effect. Stress level and temperature are two factors that influence creep-strain in composites. Orientation of the fibres is another factor that needs to be considered when analyzing creep in FRPs.

This research is intended to examine the combined effects of freeze-thaw cycles and sustained loads, simultaneously applied on FRP-confined concrete cylinders, including cylinders with GFRP wraps and CFRP wraps. Test results of specimens subjected to the combined effects have been compared to those of other specimens subjected to sustained loading only at room temperature and to those of specimens subjected to freeze-thaw only without sustained loading. It should be noted that columns in actual structure are not free to expand axially as they are restrained by the floors above or below. As such, it is believed that the sustained loading setup used in this study has represented the end constraints and has provided boundary conditions similar to actual conditions.

In general, the study showed that freeze-thaw cycling had minimal effect on FRP-wrapped concrete cylinders without sustained loads, and almost no effect on FRP-wrapped concrete cylinders with sustained loads. On the other hand, plain concrete cylinders under the same freeze-thaw conditions were completely disintegrated after only 100 cycles. It was also noticed that the sustained loading changes the stress-strain curve of FRP-confined concrete, where the transition in the bi-linear curve occurs at higher load.

Key words: concrete confinement, retrofitted, composites, sustained load, low temperature.

Accepted December 31, 2005.

INTRODUCTION

There has been an ever-increasing need for structural repairs of existing infrastructure due to rapid deterioration. In recent years, engineers and material scientists have made great strides by incorporating Fibre Reinforced Polymer (FRP) composite materials into design and construction to meet this need. These materials have been successfully used in many structural applications, but little information is available on their behaviour in cold regions. Freeze-thaw cycles contribute to the reduction in strength and ductility of the confined concrete due to the change in mechanical properties of the confining material and the concrete. In most cases, it was found that GFRP was more susceptible to freeze-thaw damage than CFRP (Karbhari, 2001). In most cases a reduction in strength can be attributed to the exposed concrete and the degradation in the FRP composite sheets. During freezing and thawing these composites absorb moisture which causes changes in their material properties, that in turn increases the level of microcracking and further degradation of the composite (Karbhari et al. 2002). It must be noted that freeze-thaw does not just affect the confining material but also the bond between the confining material and the confined concrete (Lord and Dutta, 1988). Karbhari (2002) found that CFRP wrapped cylinders after 300 freeze-thaw cycles had reductions in strength from 18 to 20 %. Soudki and Green (1997), tested 13 concrete cylinders (150 mm x 300 mm) of which nine was subjected to 50 freeze-thaw cycles and the remaining four left at room temperature. Seven of the nine cylinders subjected to freeze-thaw had CFRP sheets for confinement. The freeze-thaw cycle consisted of 16 hours of freezing at -18°C and 8 hours of thawing at 18°C. They found that CFRP wraps contributed significantly the performance of the wrapped cylinders after freeze-thaw compared to the unconfined specimens.

The performance of CFRP retrofitted concrete cylinders at low temperature was studied by Soudki and Green (1996). They tested a total of 42 reinforced and plain 150 mm x 300 mm cylinders at temperature ranges of -18°C for freezing and +20°C for thawing. Of the cylinders tested 15 were subjected to freeze-thaw cycling, six to low temperature for 200 days, six at room temperature in water bath for 200 days and the additional 15 kept at room temperature. The one layer CFRP wrapped cylinders subjected to freeze-thaw experienced a 15 % decrease in strength compared to CFRP wrapped cylinders at room temperature, while the CFRP wrapped cylinders that had two layers only experienced a 5 % decrease in strength .Callery and Green (2000) tested 200 concrete cylinders (CFRP & GFRP), 150 mm x 300 mm, exposing them to freeze-thaw, wet-dry, fresh water, salt water, and no water for 50 to 250 cycles. They found that CFRP-wrapped cylinders subjected to freeze-thaw did not show any form of ductility and failure is a sudden manner, noisy and explosive. GFRP confined cylinders tend to have a longer cracking and warning period. Toutanji and Balaguru (1999) tested 16 concrete cylinders (152 mm x 304 mm) with 2 layers (C1 and C5) of carbon, 2 layers of glass (GE) and 2 unconfined at room temperature then in freeze-thaw cycles. Both carbon and glass showed strength degradation due to freeze-thaw cycles. The carbon fibre was significantly more damaged than the glass FRP. Literature has shown that FRP composites exposed to freezing temperatures and alkaline solutions may suffer matrix micro cracking, degradation in the fibre-matrix bond, and even damage to the fibres themselves. Numerous researchers have examined FRP-confined concrete cylinders exposed to freeze-thaw without sustained loading and it was found that wrapped cylinders at low temperature (-18°C) may suffer brittleness of FRP fibres (7, 8, 9, 10). This research is intended to examine the combined effects of freeze-thaw cycles and sustained loads, simultaneously applied on FRP-confined concrete cylinders, including cylinders with GFRP wraps and CFRP wraps. Test results of specimens subjected to the combined effects have been compared to those of other specimens subjected to sustained loading only at room temperature and to those of specimens subjected to freeze-thaw only without sustained loading.

EXPERIMENTAL PROCEDURES

The experimental program is intended to prepare and test concrete cylinders confined by FRP jackets after being exposed to freeze-thaw cycles with and without sustained axial compression loads. For each concrete specimen, three or four types of FRP confining jackets were examined, namely GFRP wraps and CFRP wraps, details of test specimens are shown in Table 1. For each type of jacket, two groups of identical specimens were kept at room temperature, with and without sustained axial compression load. Also, two similar groups of specimens were kept inside the environmental chamber and subjected to 150 cycles of freeze-thaw, one group was subjected to the sustained axial compression load and one was not. The sustained axial load was equivalent to 50 % of the confined concrete strength. Environmental chamber was used in this study to fulfill the requirements of ASTM standard C 666 – 97, "Standard Test Method for Resistance of Concrete to Rapid Freezing and Thawing." This standard provides guidelines for subjecting the concrete specimens core to a temperature range of + 5 °C to – 18 °C and back to + 5°C within a period of 5 hours, which is considered as one freeze-thaw cycle. At the end of the exposure period, all specimens were tested to failure to obtain their axial compressive

Concrete Mix.

Concrete was mixed and cast in the laboratory, using ordinary Portland cement (350 kg/m3), sand (661 kg/m3), gravel (1072 kg/m3) and water (200 kg/m3), the concrete had maximum aggregate size of 20 mm. The moulds used to form the concrete cylinders were filled in three layers, each layer was tapped 25 times with a tapping rod to ensure adequate compaction and to reduce or eliminate any trapped air in the concrete. A total of 43 cylinders were cast. The concrete cylinders were removed from the plastic moulds one week after casting and left to cure at room temperature.

Wrapping of Concrete Cylinders with FRP Sheets

A total of 32 cylinders were externally wrapped with both CFRP and GFRP sheets. The thicknesses of the cured CFRP and GFRP sheets were 0.8 mm and 1.3 mm, respectively. The effective mechanical properties of the prefabricated GFRP and CFRP sheets used in this study are summarized in Table 2. Both the carbon and glass fibre fabrics were cut such that the concrete cylinder wrap circumferentially, and have an overlap length of 100 mm. The same epoxy was used for impregnating the carbon and glass fabric. The cylinder surfaces had to be carefully cleaned before the epoxy could be applied. The wet lay-up method was employed for applying the sheets to the cylinders. Using a paint brush, the epoxy was applied to the fabric and care was taken to ensure complete saturation of the sheets with epoxy. The concrete cylinders were then lightly coated with epoxy to fill any surface voids and to ensure adequate bonding. The cylinders were carefully placed on the FRP sheets. During the rolling process, the FRP sheet was continuously pressed and gently stretched to release any trapped air between the FRP sheet and the concrete. After completely wrapping the cylinders with the FRP sheets, they were left to cure in the same spot for 24 hours.

Sustained Loading of Test Specimens

Cylinders were stacked together in each of the steel frames in a series parallel to the floor. After all the cylinders were placed in the frame; the fourth threaded bar was put in place. The nuts were then carefully tightened, resulting in the two end plates gripping the cylinders in place. In order to apply the required load 50% of the concrete confined strength, a load cell was placed in the frame, behind one of the end plates, followed by a hydraulic ram, as shown in Figure 1. An additional 50 mm thick metal plate was then placed at the end of the frame, behind the ram, in order to jack against.

TEST RESULTS AND DISCUSSION

.After the completion of the 150 freeze-thaw cycles, each specimen was instrumented with three 100 mm displacement-type strain gauge transducers (PI Gauge) in the axial direction to measure the average axial strain. These gauges were placed 180° apart, avoiding the FRP overlap as best as possible. The three PI gauges were placed at equal spacing around the perimeter of the cylinder, at mid-height, avoiding the overlap region as best as possible. In addition to the three PI gauges, two 5 mm electric-resistance strain gauges were also placed circumferentially on two opposite sides of the cylinder for measuring the average hoop strain (Figure 2). Prior to testing, all the FRP-wrapped cylinders as well as the plain concrete cylinders were capped with sulphur mortar at both ends. The specimens were then tested under axial compression, using a 1000 kN testing machine. The cylinders were loaded in stroke control at a rate of 0.3 mm per minute.

Unconfined Concrete Cylinders

The average compressive strength of the cylinders tested after 28 days was 25 MPa. URC specimens were left in dry conditions, whereas UCWD specimens were submerged in water for 10 days, which is equivalent to the total thawing time of the other specimens that were subjected to freeze-thaw. The increase in compressive strength due to the water curing effect was very small, about 4 %. The average ultimate axial and hoop strains for the URC cylinders were 0.16 % and 0.06 % respectively. For the UCWD cylinders, the average ultimate axial and hoop strains were 0.18 % and 0.05 % respectively. All the plain concrete cylinders that were placed in the environmental chamber during freeze-thaw cycling were completely disintegrated after 100 cycles, as shown in Figure 8, due to the lack of air-entrainment. Ideally much better performance would be expected for plain concrete after freeze-thaw exposure if they were air entrained.

CFRP-Wrapped Cylinders

A total of 16 CFRP-wrapped cylinders were tested as shown in Table 1. Two of these cylinders were tested to failure, initially, to determine the suitable level of sustained loading. The other 12 cylinders were subjected to the various conditions described in Table 1. Wrapping the concrete cylinders with CFRP sheets has increased the strength by about 87 %. The average strength of three out of four CFRP-wrapped cylinders that survived after being subjected to freeze-thaw and sustained load (CFS) was 41.4 MPa. In comparison, the CFRP-wrapped cylinders that were kept at room temperature under sustained loading (CRS) had an average strength of 42.7 MPa, based on the four cylinders tested. The average ultimate axial and hoop strains for cylinders subjected to freeze-thaw and room temperature, under sustained load, were (0.9 % and 1.36 %) and (0.76 % and 0.61 %), respectively. The freeze-thaw cycles had a minimal effect on the strength of the CFRP-wrapped cylinders under sustained load, when compared to specimens at room temperature. Only a 3 % strength reduction was noted.

Two of the three CFRP-wrapped control cylinders (without sustained loading) were completely damaged during freeze-thaw cycling, as shown in Figure 8, and were not tested. This was attributed to expansion of the concrete core in the longitudinal direction, which was not uniform and resulted in bending of the cylinders. As all the fibres in the CFRP sheet were oriented in the hoop direction, expansion was not restricted longitudinally, except at the overlap location, where less expansion occurred due to the double CFRP layers and excess epoxy. Only one CFRP-wrapped control cylinder could be tested after the completion of the 150 freeze-thaw cycles, which gave a strength of 34.6 MPa. The control CFRP-wrapped cylinders at room temperature had an average strength of 39.6 MPa. This indicates a 13 % reduction in strength due to freeze-thaw cycling in the absence of sustained loading. The average axial and hoop strains were (1.33 % and 0.47 %) and (1.66 % and 0.72 %) for the CFRP-wrapped control cylinder under freeze-thaw (CFC) and CFRP-wrapped control cylinder at room temperature (CRC), respectively. It should be noted that columns in actual structure are not free to expand axially as they are restrained by the floors above or below. As such, it is believed that the sustained loading setup used in this study has represented the end constraints and has provided boundary conditions similar to actual conditions.

Figure 3 shows the stress-strain curves for both the control and sustained-loaded CFRP-wrapped cylinders subjected to freeze-thaw cycling. Also, Figure 4 shows the stress-strain curves for both the control and sustained-loaded CFRP-wrapped cylinders at room temperature. Generally, these curves depict a bilinear behaviour with the room temperature cylinders having a more pronounced strain hardening branch. It can be clearly seen in Figure 4 that the sustained-loaded cylinders (CRS) at room temperature had their bilinear transition point occur at higher stress values than those of the control specimens (CRC). This is attributed to the creep effect, where axial strains increase under the constant sustained stress, and consequently the radial and hoop strains also increase due to Poisson's ratio (dilation) effect. This mechanism seems to activate the confinement imposed by the FRP jacket, further.

During compression testing of the FRP-wrapped cylinders, and as the stress exceeded 50 % of the ultimate strength, a popping sound could be heard and at failure, an explosive sound could be heard. Careful observation shows fibre rupture approximately at mid-height of the cylinder, Figure 8, for cylinders subjected to sustained loads at room temperature. For the control specimens subjected to freeze-thaw, failure occurred closer to the upper end of the cylinder.

GFRP-Wrapped Cylinders

In total, 16 GFRP-wrapped cylinders were tested, of which, two specimens were tested initially to confirm the required sustained-loading level, while the other 14 specimens were tested under the various conditions outlined in Table 1. GFRP-wrapped cylinders subjected to freeze-thaw and sustained loading (GFS), and the three cylinders at room temperature (GRS) had average strengths of 36.6 and 37 MPa, respectively. The GFRP wrapping has increased the compressive strength by about 79 %. This is comparable to the effect of CFRP-wrapping, despite the typically lower tensile strength of GFRP, compared to CFRP. The axial and hoop strains were 1.45 % and 1.20 % for the (GFS) specimens, and were 1.63 % and 1.43 % for the GRS specimens. The reduction in strength of GFS specimens, due to freeze-thaw effects was 3.3 %, when subjected to sustained loads.

The average strengths of the control GFRP-wrapped cylinders subjected to freeze-thaw (GFC) and the control GFRP-wrapped cylinders at room temperature (GRC) were 35.7 MPa and 38.0 MPa, respectively. Thus the reduction in strength due to freeze-thaw was 6 % in the absence of sustained loads. The average axial and hoop strains for GFC were 1.83 % and 1.64 %, respectively, while for GRC cylinders were 1.72 % and 1.68 %, respectively.

Figures 5 &6 show the stress-strain curves for GFRP-wrapped cylinders subjected to freeze-thaw, and those at room temperature, respectively. These cylinders show similar trends as the CFRP-wrapped cylinders, except for the cylinders subjected to freeze-thaw condition, where the performance was more consistently bi-linear, compared to the CFRP-wrapped cylinders. This could be attributed to the structure of the GFRP laminate, which included individual longitudinal roving. The longitudinal fibres may have controlled expansion in the longitudinal direction, but most importantly eliminated the uneven expansion problem, which resulted in bending of the cylinders in case of CFRP wraps. All control GFRP-wrapped specimens were in excellent condition after freeze-thaw exposure with no signs of distortion. Figure 7 shows a comparison between stresses and strains of both CFRP & GFRP specimens.

The typical failure modes for GFRP-wrapped cylinders at room temperature can be seen in Figure 8, the explosive effect that was observed in the CFRP-wrapped cylinders wasn't evident in this case. This may be attributed to the lower GFRP strength and stiffness compared to CFRP.

CONCLUSIONS

The experimental study clearly demonstrates that FRP composite wrapping can significantly enhance the structural performance of concrete columns, durability, ductility and compressive strength.

1-Freeze-thaw cycling had little effect on concrete cylinders confined with prefabricated CFRP sheets and GFRP sheets, compared to the unconfined concrete that was totally disintegrated after 100 to 150 freeze-thaw cycles.

2-Sustained loading caused a stiffening effect on the confined concrete cylinders, where the transition point in the bilinear stress-strain curve occurred at higher loads in comparison to FRP-confined concrete cylinders without sustained loads.

3-Sustained load was very effective in reducing damage to the wrapped specimens subjected to freeze-thaw exposure, compared to non-sustained specimens and unconfined specimens. This is attributed to the end restraints, which presented longitudinal expansion.

4. Sustained loads tend to affect the performance of the confined cylinders during the freeze-thaw period. There are two ways in which this occurs, first, the end plates of the frames serve as protection for the cylinders faces, and secondly, the sustained frames help in preventing longitudinal expansion of the specimens.

5-The failure modes of CFRP-wrapped cylinders subjected to freeze-thaw were more catastrophic than CFRP-wrapped cylinders at room temperature and GFRP-wrapped cylinders.

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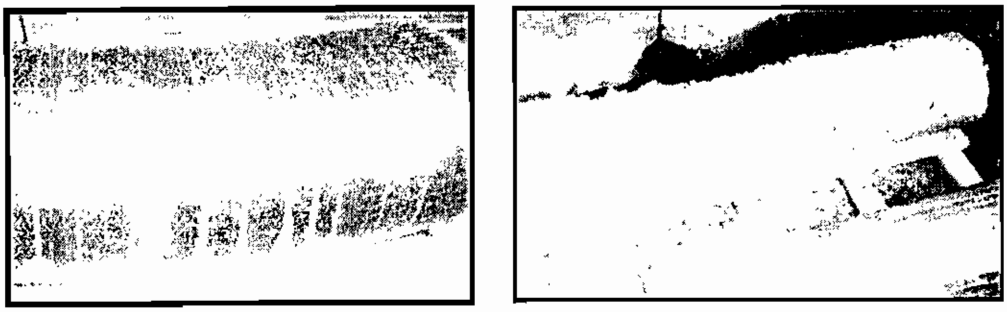
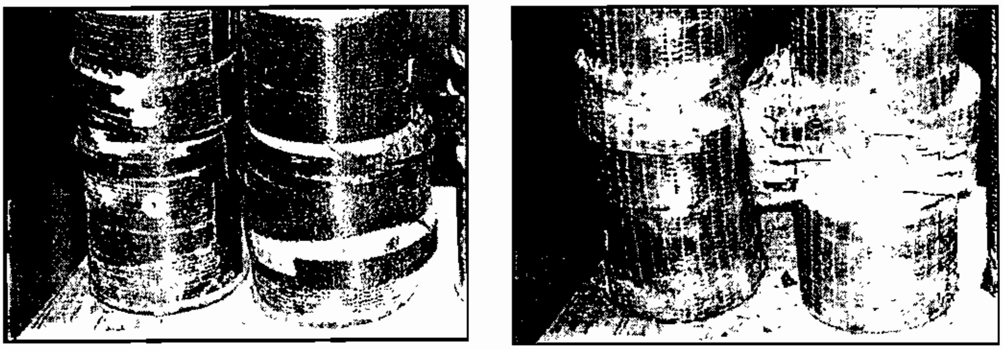
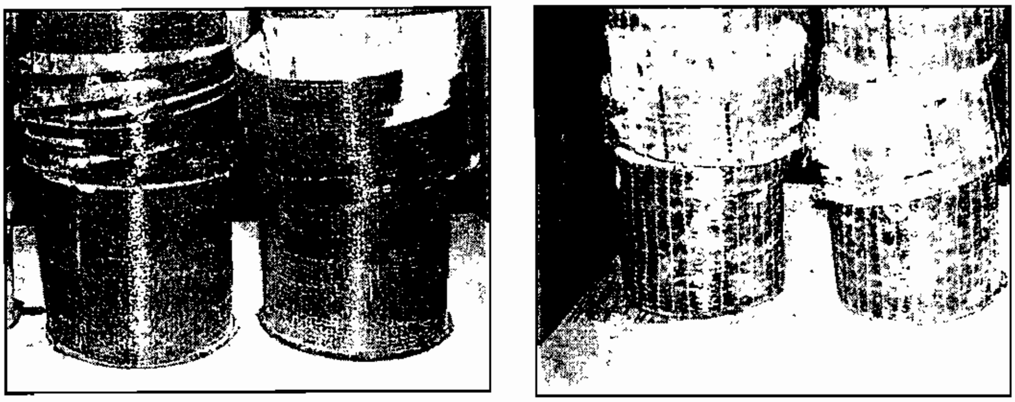


CFRP **URC & GFRP**



CRS **GRS**



CFS GFS

FIG. 8 Samples of failure mode for tested Specimens