

Experimental Investigation of CFRP Confined Columns Damaged by Alkali Aggregate Reaction

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Abstract: Fiber reinforced polymer is the most effective repair material in use to enhance the strength and ductility of deteriorated reinforced concrete columns. Often, fiber reinforced polymer (FRP) provides passive confinement to columns until the dilation and cracking of concrete occurs. In the case of concrete suspected of Alkali Aggregate Reaction (AAR) where concrete undergoes expansion, FRP wrap provides active confinement to the expanded concrete. In this study, the performance of carbon fiber reinforced polymer (CFRP) wrapped columns damaged by AAR is evaluated based on the number of FRP layers and the time of the polymer application which provides two types of confinement: active or passive. The columns were tested under axial compression to evaluate the residual strength of the columns in comparison with unwrapped columns. The results reveal that the strength of the wrapped columns is enhanced with an increase in the number of CFRP layers. The strength of the columns under passive confinement is higher than the columns under active confinement. Under active confinement, early CFRP wrapping leads to improvement in the strength of the columns.

Keywords: Fiber Reinforced Polymer, Alkali Aggregate Reaction, Confinement

1. Introduction

Alkali Aggregate Reaction (AAR) in concrete was first discovered in the 1940s by Stanton who found distress in the concrete due to the reaction between reactive aggregate and high alkali content in the concrete. The reaction caused concrete to expand and eventually crack. As reported in the literature and confirmed in a preliminary study, AAR reduces the mechanical properties of concrete [1, 2].

AAR is a time-dependent phenomenon where the time the reaction starts and ceases is unknown. It depends on the amount of reactive aggregate and alkali content in the concrete. Most importantly, the surrounding temperature and relative humidity greatly affect the reaction process [3]. Often, the AAR is manifested 20 to 30 years after the construction of structures. Due to uncertainty about the damage by AAR, the repair of concrete structures has to be carried out. Expansion causes the crack to progress and may lead to secondary damage to the concrete such as steel fracture and stability risks during earthquake [4, 5].

Unlike ordinary repair concrete columns where fiber reinforced polymer (FRP) just acts as a protection layer (passive confinement), the time of FRP application on the columns damaged by AAR provides confinement effect on the expanded columns, whether active or passive. In previous study, the authors have presented the effect of FRP wrap on columns that had stopped expanding (passive confinement) and tested under uniaxial

compression. It was found that FRP wrap significantly improved the load carrying capacity of the columns compared with unrepaired columns [6]. In this paper, further investigation by varying the types of confinement according to the time of FRP application is presented.

2. Experimental Program

Concrete mix and test specimen

Only one concrete mix was made in accordance with ASTM C1293 (Standard Test Method for Determination of Length Change due to Alkali Silica Reaction) with fused silica as the reactive aggregate to replace the fine aggregate by 7.5% by mass of the total aggregate content. The cement used was general purpose cement having an alkali content of 0.43% Na₂O equivalent. Sodium hydroxide was added into the mixing water to increase the alkali level by 0.25% Na₂O equivalent.

Two shapes of reinforced concrete (RC) columns were prepared for this experiment. The circular columns had a 215mm diameter and reinforcement ratio of 1.55% whereas the square columns had a 200mm cross section and a corner radius of 40mm. Both types of columns had a 550mm height.

Environmental condition

According to ASTM C1293, the condition required to accelerate expansion in the concrete; is by exposing the concrete at 38°C and 100% RH. With this type of

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concrete, the maximum expansion occurs in the concrete was approximately 11,000 microstrain achieved in 3 months [6].

CFRP confinement

The material used for wrapping the columns was normal modulus carbon fiber reinforced polymer (CFRP). According to the manufacturer (BASF Construction Chemical Australia Pty Ltd), the material characteristics of CFRP are as follows:

Modulus of elasticity:	240GPa
Tensile strength :	3800Mpa
Thickness:	0.176mm
Ultimate tensile strain:	1.55%

The columns which had been removed from the tank were sandblasted and cleaned to ensure better adhesion for CFRP wrapping. A special rotating machine was built to easily wrap the columns as seen in Figure 1. The CFRP wrapping covered only 450mm height of the column. Since the fiber came with 300mm width, additional 150mm was cut to complete the wrapping. A 150mm extra length was used in the hoop direction to provide overlapping. The epoxy was prepared by mixing 3 volumetric of part A (the resin) and 1 part B (the hardener). The compound was applied liberally on the concrete surface with a paintbrush. Any irregularities and air pockets were smoothed out using a roller. On top of the fabric, another layer of resin was applied. The procedure was repeated to apply another layer. The wrapped columns were cured for 7 days before being re-exposed into the environmental tanks.

Two types of confinement were introduced to the damaged columns:

1. Active confinement – Application of CFRP wraps after the columns had been subjected to environmental exposure for 1 and 2 months and still had the potential for further expansion.
2. Passive confinement – Application of CFRP wraps after the columns had been subjected to environmental exposure for 6 months and had developed their maximum expansion.

Uniaxial compression test

All columns were tested using the Amsler Testing machine with a capacity of 5000kN in the NM Murray Strong Floor of Monash University, Australia. Strain gauges were fixed on the column at the middle height of the column. Four strain gauges were installed at the vertical and horizontal direction. The strain gauges were connected to the data taker for collecting the data during the testing.

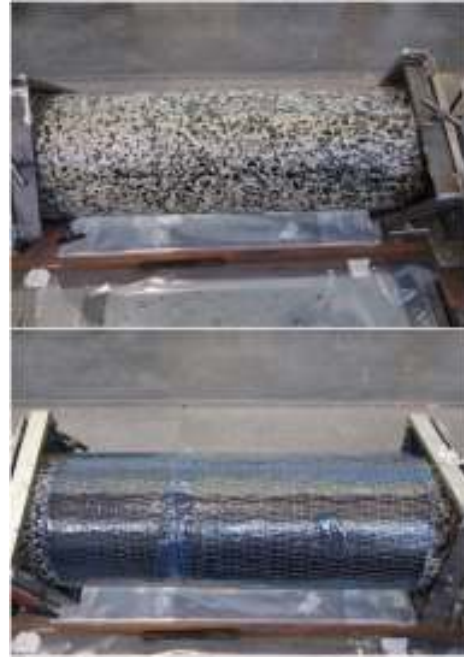


Fig.1 A special rotating machine to wrap the column

3. Results and Discussion

Typical failure mode

Severe cracking was observed on the column surface as result of significant expansion occurs on the columns. Thus, during the test, the failure of the unwrapped columns fractures gradually either from the top or bottom of the columns. On the other hand, the failure of the wrapped columns was a fiber rupture accompanied by concrete crushing. The ruptures started from the top end of the fiber until 150mm height of the column. As mentioned above regarding the FRP wrapping method, the columns were wrapped for only 450mm height; however, due to the limited fiber length of 300mm, an additional 150mm was applied on the top of the columns. Due to discontinuity, the fiber ruptures occurred until 150mm from the top. In some columns, the fiber rupture occurred until at the middle height of the columns, where the strain gauges were located. The failure of the columns is shown in Figure 2.



(a)



(b)

Fig 2 Typical failure of (a) unconfined and (b) confined columns

Ultimate load

Active Confinement

Table 1 presents the ultimate load of columns wrapped after 1 and 2 months of exposure. For the circular columns wrapped after 1 month, the ultimate load of the columns was increased by 66% and 119% with 1 and 2 layers of CFRP, respectively, in comparison with the unwrapped columns. The ultimate load enhancement of the square columns was increased by 34% and 56% with 1 and 2 layers of CFRP, respectively. Results indicate that a significant ultimate load improvement was found with the circular columns wrapped with CFRP compared to the square columns wrapped with CFRP. A possible explanation for this might be that the confining pressure exerted by CFRP wrap on square column concentrates on the corners of the column rather than the circumferential area, as for circular columns.

Table 1 Summary of average ultimate load of CFRP confined columns (active confinement)

Specimen	Shape	Time of CFRP wrapping (month)	No. of CFRP layers	Ultimate load (kN)	Percentage increase (%)
C-0	Circular	-	-	1075	-
C01-1L		1	1	1784	66
C01-2L		1	2	2349	119
C02-1L		2	1	1847	72
C02-2L		2	2	2081	94
S-0	Square	-	-	1216	-
S01-1L		1	1	1631	34
S01-2L		1	2	1898	56
S02-1L		2	1	1603	32
S02-2L		2	2	1777	46

Passive Confinement

Table 2 presents the ultimate load of the circular and square columns wrapped with 1 and 2 layers of CFRP wrapped after 6 months. The ultimate load of the wrapped columns was increased when the number of CFRP layers increased. Ultimate load enhancement was more significant for the circular columns than for the square columns.

Table 2 Summary of average ultimate load of CFRP confined columns (passive confinement)

Specimen	Shape	Time of CFRP wrapping (month)	No. of CFRP layers	Ultimate load (kN)	Percentage increase (%)
C-0	Circular	-	-	1075	-
C06-1L		6	1	1612	50
C06-2L		6	2	2248	109
S-0	Square	-	-	1216	-
S06-1L		6	1	1474	21
S06-2L		6	2	1854	52

Effect of wrapping time on the strength enhancement

The main reason for varying the time of CFRP wrapping is to determine whether the time of wrapping affects the ultimate load of the columns. In order to evaluate the effect of wrapping time on the ultimate load enhancement, the ratio of ultimate load of wrapped column and unwrapped columns (P/P_0) at the same age were compared. As shown in Table 3 and graphically presented in Figure 3, two observations can be made:

- (1) With 1 layer of CFRP, the columns that were wrapped after 6 months had higher P/P_0 in comparison with the columns wrapped after 1 and 2 months.
- (2) With 2 layers of CFRP, the columns that were wrapped after 1 and 6 months had higher P/P_0 in comparison with the columns wrapped after 2 months.

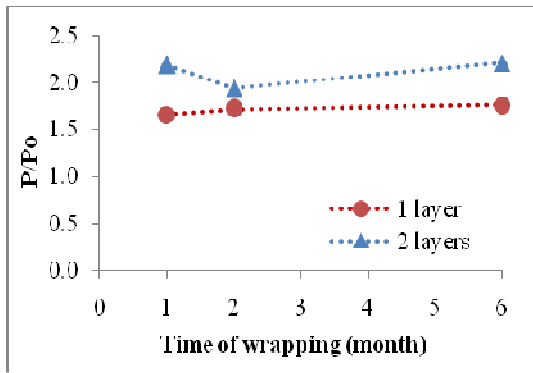
In addition, the time of CFRP wrapping is related to the expansion that occurred in the concrete before the damaged columns were repaired. According to the concrete prism test to determine the reactivity of the aggregate, the value of expansion for the concrete at 1 month and 2 months was 0.3% and 0.63%, respectively, from a total expansion of 1.1% [6]. Initially, without any expansion, the capacity of the CFRP material is about 0.12%. For the columns under active confinement, the samples were returned to the tanks and the occurrence of AAR expansion continued. Cumulative strain in the fiber due to AAR expansion reduced the tensile strain capacity of the columns and hence affected the ultimate load of the columns. For the columns under passive confinement, the cumulative AAR expansion did not occur. The complete tensile strain capacity of the fiber is used for the compression test. Therefore, in this analysis, we found that the P/P_0 of the columns under passive confinement is higher than the P/P_0 for columns under active confinement. The ultimate load enhancement not only depends upon the expansion history of the columns before repair with CFRP but also relies on the duration of the further expansion after the repair [7].

Table 3 Summary of average ultimate load of CFRP confined columns

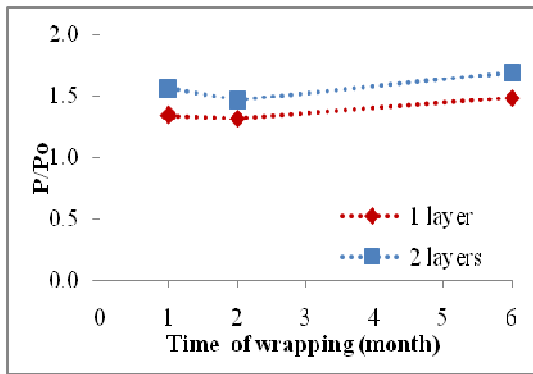
Time of CFRP wrapping (month)	1	2	6
Circular columns			
1 layer	1.66	1.72	1.76
2 layers	2.19	1.94	2.21
Square columns			
1 layer	1.34	1.32	1.48
2 layers	1.56	1.46	1.69

found that that higher P/P_o is achieved when the column is wrapped after the expansion has ceased.

- For the columns under active confinement, the earlier CFRP wrapping enhances the strength of the columns. The strength of the columns under passive confinement is higher than the strength of the columns under active confinement. Time of testing affects the result for the columns under active confinement.



(a)



(b)

Fig. 3 Plot of P/P_o over time for the CFRP confined (a) circular and (b) square columns

4. Summary

The findings of this study indicate that:

- The ultimate load of the columns increases in direct proportion to the number of CFRP layers. The percentage increase in the ultimate load of the columns is more obvious for the CFRP confined circular columns rather than for the CFRP confined square columns.
- The time of CFRP application and the number of CFRP layers affect the ultimate load enhancement of the columns. Two layers of CFRP provide a better improvement in the value of P/P_o with the wrapping carried out as early as possible or after the expansion has ceased. With one layer of CFRP, it is

References

- R. N. Swamy, and M. M Al-Asali. "Engineering properties of concrete affected by alkali silica reaction." *ACI Material Journal* 85, 1988,pp. 367-374
- G., R. Giaccio, Zerbino, J. M. Ponce, and O. R. Batic. "Mechanical behavior of concrete damaged by alkali silica reaction." *Cement and Concrete Research* 38, 2008,pp. 993-100.
- C Larive, A. Laplaud, and O. Coussy. "The role of water in alkali silica reaction." *Proc. of 11th International Conference on Alkali Aggregate Reaction*. Quebec City, Canada, 2000,pp.61-69.
- K.Okada, M. Fujii, Y. Yamaguchi, and K. Imada. "Maintenance system for highway structures damaged by ASR." *Pro. of the 10th International Conference on Alkali-Aggregate Reaction in Concrete*. Melbourne, 1992,pp 995-1002.
- T. Miyagawa, K.Seto, K.Sasaki, , Y. Mikata, K.Kuzume, and T.Minami "Fracture of reinforcing steel in concrete structures damaged by Alkali-Silica Reaction – Field survey, Mechanism and Maintenance." *Journal of Advanced Concrete Technology*,2006. pp. 339-355.
- S. Abdullah, R. Al-Mahaidi, A. Shayan, "CFRP confinement of RC columns damaged by alkali aggregate reaction." *Proceedings of 'Innovative Community Building', the 5th Civil Engineering Conference in the Asian Region and Australasian Structural Engineering Conference 2010 (CECAR 5 and ASEC 2010)*, Sydney, New South Wales, Australia, 09-12 August 2010.
- C. Lacasse, P. Labossiere, and K.W. Neale, (2003). "On Fiber Reinforced Polymer rehabilitation of Alkali-Aggregate Reaction-damaged beams." *ACI Structural Journal*, 2003, pp.66-74.