Author:	Gamage, J. C. P. H.; Al-Mahaidi, Riadh; Wong, Bill; Ariyachandra, M. R. E. F.
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BOND CHARACTERISTICS OF CFRP-STRENGTHENED CONCRETE MEMBERS SUBJECTED TO CYCLIC TEMPERATURE AND MECHANICAL STRESS AT LOW HUMIDITY

J.C.P.H Gamage[1], Riadh Al-Mahaidi[2], Bill Wong[2], M.R.E.F. Ariyachandra[1]

[1]Department of Civil Engineering, University of Moratuwa, Sri Lanka

[2]Department of Civil Engineering, Monash University, Clayton, Victoria 3800, Australia

Abstract

A total of fifty two CFRP strengthened concrete specimens were tested. In preliminary investigation, ten specimens were tested at ambient conditions with varying bond length. This indicated the effective bond length is in the range between 100 mm and 150 mm. The bond length of 150 mm was considered and fourty two specimens were prepared for detailed investigation. Thirty of them were conditioned under a range (0% - 50%) of sustained loading. All specimens were subjected to the temperature cycles of 20^{o}C–50^{o}C and constant relative humidity (30%) during conditioning. These specimens were tested using the single-lap shear test method at ambient conditions after 1800 hrs and 2250 hrs exposure for accelerated aging. The conditioned specimens showed the maximum strength reduction of 24%. The test results indicate that the concrete/epoxy interface as the weakest part of the composite in service life. Reduction in peak bond stress was noted from conditioned specimens with exposed level of sustained loading.

Keywords: CFRP/concrete, Cyclic temperature, Low humidity, sustained loading, Durability, Bond-slip, Effective bond length

1. Introduction

The significant issue of Carbon Fibre Reinforced polymer (CFRP)/concrete composites is the lack of data available on durability, especially related to their bond performance under harsh and changing environmental conditions with sustained loading [1]. The composite must withstand the mechanical forces acting on it while exposes to the operating environment to ensure service performance. Under the changing environmental conditions, there are a number of consequences that can occur within the interfaces of adhesive/CFRP, adhesive/substrate and also in the material level. In aggressive environments, the composites can be subjected to physical and chemical ageing mechanisms [2]. Physical ageing is a reversible process primarily associated with temperature fluctuations whereas chemical ageing is the permanent molecular level degradation of fibres, resin or interface due to long term exposure to the environment [2]. In previous research studies thermal degradation at material level such as pure epoxy and CFRP has been investigated [3,4]. However the thermal degradation of CFRP/epoxy/concrete composite is one of the important areas that should be further researched because the composite behavior is completely different from the behavior at material level.

The aim of the present research is to elaborate the behavior of CFRP/epoxy/concrete bond subjected to temperature cycles under different level of sustained loading percentages that the strengthened structures expose during their service life. In this regards, a constant low humidity of 30% was maintained throughout the test series to identify the temperature effects. Mechanical properties of epoxy bond degrade heavily around its glass transition temperature (T_g) [5]. Since epoxy polymers used in the construction industry having low T_g, the daily temperature fluctuations can also adversely affect on the bond between CFRP and concrete. Edward noted that the mobility of polymer particles increases around T_g [3]. Epoxy resins have low glass transition temperature which is attributed to their higher molecular mobility resulting in incomplete curing [6]. This condition facilitates the penetration of moisture or any form of liquids between polymer particles.

Epoxy adhesive exposed to humid environment attracts water because it possesses polar groups that can attract water molecules. Water may alter the properties of polymer both in reversible or irreversible manner [7,8]. The water ingress into polymeric adhesive led to the plasticization of the adhesive by reactivation of cross-linking reactions. The consequence of water exposure is equivalent to the effects of thermal exposure at temperature around the Tg. Fib suggested that the T_g should be 20^oC above the maximum air temperature, but not less than 45^oC [9]. The T_g of epoxy also decreases with exposure to high humidity. Lowering of T_g due to water ingress may adversely affect on the service performance [7,8]. In this research, the humidity level was kept as a constant and very low as 30%. This may helps to evaluate the effects of cyclic temperature and sustained loading on bond performance. In general, the interfaces of the bond line are weaker than the adhesive. The nature of interfacial phenomena is strongly affected by the residual stresses [4]. Depending on the loading condition, compressive or tensile stresses could be developed at interfaces resulting in a high stress gradient [10,11]. These tensile stresses create micro cracking and those can be localized around voids in the resin [12]. These micro cracks consequently spread towards the interfaces resulting in delamination of CFRP sheet. The presence of water with this condition increases the mobility of polymer resin through weak interaction [9] and degrades the bond performance. This research is focused on the bond characteristics of composite after prolong exposure to the accelerated daily temperature profile under different level of sustained loading.

2. Experimental Programme

2.1. Overview

This test programme was conducted in two series; preliminary investigation and detailed investigation. The main focus of preliminary investigation was to determine the effective bond length. The detailed experimental programme was devised to examine the durability performance of CFRP strengthened concrete composites subjected to accelerated ageing mechanisms which typically characterizes the actual exposure conditions. These ageing mechanisms comprised a cyclic temperature, constant humidity and four different sustained loading intensities. The residual strength of bond was determined at ambient conditions after exposure to the accelerated environmental conditioning of 1850 hrs and 2250 hrs. A total of 52 specimens were tested and the details of conditioning are listed in Table 1.

2.2. Specimen preparation

A total of fifty two concrete blocks with dimensions of 75 mm×75 mm×250 mm were prepared using Grade 30 (weight proportion of cement: sand: aggregate is 1:1:2) concrete. These blocks were kept to cure for more than 28 days immersed in water. The compressive strength of concrete was determined in accordance with ASTM C39 [12]. The water/cement ratio selected for the concrete mix in this investigation was about 0.6. A combination of coarse aggregate (10 mm -14 mm) and fine aggregate was used. The target slump and 28 days compressive strength were 100 mm and 30 MPa, respectively. The measured average compressive strength (28 days) of six concrete cubes was 33.8 MPa and the standard deviation was 0.2. The surface to be bonded was sand blasted to remove the concrete paste and to be able to expose coarse aggregates. Before bonding application, the surface was cleaned using a brush (Fig.1). A primer layer (1 mm-2 mm thick) was applied on prepared surface. These specimens were cured at room temperature between 30 and 60 minutes, resulting in a dry, non-sticky surface that can be protected from contamination until the substrate is ready to be bonded with an adhesive. As there have always been some discrepancies between given material properties (provided by manufacturer [13, 14]) and actually material properties, a series of tensile coupon tests had been conducted by Fawzia to determine the material properties [15]. The measured average material properties using tensile coupon tests by Fawzia are listed in Table 2 because the same materials were used for this test programme. The wet lay-up method was used to bond the CFRP sheet to the concrete. Finally, two aluminum sheets were fixed to the CFRP sheet (Fig.1) for the application of loading in detailed investigation while two steel plates were used to apply load in preliminary investigation. The purpose of this change is to have a light weight gripping. After preparation, these specimens were kept to cure more than 7 days under ambient conditions.

2.3 Preliminary Investigation and Results

The main outcome of this test series was the ultimate bond strength for different CFRP bond lengths. Ten specimens were tested at ambient temperature under uniformly increased loading. Loading was applied using the INSTRON loading machine with a displacement rate of 1mm/min until failure. All specimens were tested by single shear test method. Two steel plates, fixed at the time of bonding, were used to apply load to the specimen. The failure load for each of the bond lengths was noted.

The combination of peeling off of the adhesive layer with concrete substrate was noted for the specimen with a short CFRP bond length (= 75 mm), under ambient temperature (Fig. 2(a)). Concrete rupture was the observed typical failure pattern for the specimen with the CFRP bond length (≥ 100 mm), at ambient temperature as shown in Fig. 2(b). In these tests a correlation between the failure load and the bond length under ambient temperature could be clearly observed.

Table 3 shows the variation of the failure load with bond length of the CFRP sheets. As can be seen from Table 3, the failure load is increasing with increasing bond length for the specimen strengthened with CFRP (1-layer) under ambient temperature up to 100 mm. Then the failure load is almost similar for the considered bond lengths which are up to 175 mm. This implies that the ultimate capacity of CFRP-Concrete joint cannot be increased with extending the bond length more than 100 mm. This indicates the effective bond length is closer to 100 mm for the considered materials and specimen configuration. The similar results were noted for the specimen strengthened with different CFRP layers (2 and 6-layers) under shear tests conducted by Pham and Mahaidi [17,18].

2.4 Accelerated ageing mechanisms

The environmental chamber was programmed to cycle the temperature from 20°C to 50°C within 4.25-hr duration, with 1.25-hrs soaking time at minimum and maximum temperatures. Fig. 3 (a) illustrates the oven programmed temperature and measured temperatures using thermocouples. Even though this was planned to soak at minimum temperature (20^{o}C) for 1.25 hrs, the measured temperature indicates the latter soaking time is about 0.5 hrs. This may not affect on bond performance because the epoxy bond is not sensitive to environmental changes at this temperature [5]. After fully cured, six specimens were kept in the environmental chamber without applying a mechanical stress (0% sustained loading). The tensile load equivalent to 25%, 35% and 50% of ultimate failure load was applied on CFRP sheet in remaining test specimens using the loading frames as shown in Fig. 3(b). Moreover, humidity was kept at the constant rate of 30%. At the end of the exposure period, those were kept at ambient conditions for at least 4 hrs before shear testing. The aim of this is to provide equivalent ambient conditions for the bond line of all specimens during testing.

2.5 Bond Performance

Failure loads of the control specimens and residual strengths of conditioned test specimens were measured using single lap shear test method. Tensile load on CFRP sheet was applied at the displacement rate of 0.5 mm/min. An optical measuring technique was used to measure the strain variation along the CFRP sheet. In this regard, 3D image correlation photogrammetry (ARAMIS) was chosen to measure the strains along the bond length of CFRP sheet. The purpose of using optical measurements is to collect the strain readings at 5 mm spacing along the CFRP bond length to develop the bond stress – slip relationships for different exposure conditions. The set-up used is shown in Fig.4(a) and a schematic diagram of test specimens is illustrated in Fig. 4(b). The strain measurements collected from conventional strain gauges those fixed along the CFRP sheet with 20 mm spacing in randomly selected few specimens as shown in Fig.4(c) were also used to verify the accuracy of optical measuring system. Since the use of conventional strain gauges is expensive and there are practical difficulties in collecting strain at closer spacing. Selection of optical measuring system for strain data collection facilitated well to collect all the required data.

2.6 Substrate condition

2.6.1 Compressive strength

Properties of the substrate are important for the strength and service performance of the composite. The average twenty-eight day compressive strength of concrete before conditioning was 33.8 MPa. The compressive strength of substrate was determined in accordance with ASTM C39 [12] at the age of testing. The concrete cubes, 75 mm × 75 mm × 75 mm in size were extracted from the conditioned specimens as shown in Fig. 5. Caps for uniform distribution of stress during testing were attached to the top and bottom faces of the cubes while two strain gauges to monitor strain variation were fixed on to the two opposite vertical sides. Amsler loading machine with an approximate loading rate of 20 MPa/min was used for the application of compressive load on the concrete cubes (Fig.5(c)). The failure loads and strain measurements were recorded. The equivalent cylinder strength was calculated. These cubes were extracted from conditioned specimens subjected to 1800 hrs conditioning and non conditioned specimens at room temperature. These specimens were tested 665 days after casting, including the conditioning period. This shows the average substrate strength of conditioned and non conditioned specimens at this age as 45.5 MPa and 45.7 MPa, respectively. The respective standard deviations were 1.2 and 2.3. This indicates the evidence of similar substrate properties of conditioned and non conditioned specimens.

The equivalent cylinder strength was calculated using the following equation:

$$f_c = \alpha f_{cu};$$ where $\alpha = 0.85$. This was computed using the equation

$$\alpha = 0.2\log_{10}\left(\frac{f_{cu}}{2840}\right) + 0.76$$ where f_c and f_{cu} are the respective cylinder strength and cube strength of concrete.

2.6.2 Tensile strength

The split cylinder test for modulus of rupture was conducted in accordance with ASTM C 496[16]. This test measures the tensile strength of concrete by compressing a concrete cylinder through a line load applied along its length. The applied load creates a lateral tensile stress, given in the following equation, in the cylinder across the vertical plane of loading:

$f_t = \frac{2p}{\pi l d}$, where f_t the tensile strength of concrete is, p is applied load, l and d are the respective length and diameter of the cylinder.

The concrete cylinders with average diameter of 41 mm and length of 76 mm were cored from the substrate of tested CFRP strengthened concrete specimens as shown in Figure 6 (a). The cylinders were split using the Baldwin testing machine which is capable of applying a loading with the rate of 1.5 MPa/min (Fig. 6 (b)). In split cylinder tests the material at the median plane is subjected to approximately uniform ultimate stress. The peak load during the split testing was noted. The average tensile strength noted from the samples extracted from conditioned and non conditioned specimens were 3.6 MPa and 4.4 MPa, respectively. The non conditioned specimens showed a comparatively higher value. This may due to low humidity exposure of conditioned specimens and relatively higher environmental humidity exposure of non conditioned specimens which facilitate for better curing.

2.6.3 Elastic Modulus

The elastic modulus of the concrete substrate of conditioned specimens was determined using strain readings monitored during the cube test. The computed average elastic moduli of substrate of conditioned and non conditioned specimens were 26650 MPa and 24800 MPa, respectively. This difference is about 7%.

3 Detailed experimental programme

3.1 Failure of control test specimens – short term performance

Consistent with previous research [17-20], the most common failure pattern observed from non conditioned specimens in shear testing was interface failure with major concrete rupture as shown in Fig. 7(a). A total of 12 control specimens (non-conditioned) were tested. The average failure loads of 16.9 kN, 17.7 kN, 19.2kN and 20.4 kN were reported for batch no. 1, 2, 3 and 4, respectively. The failure line was occurred in concrete a few millimeters beneath the concrete-adhesive interface as shown in Fig. 7(a). A concrete prism was pulled out near the loaded end. This concrete wedge spread about 30% - 40% of the bond length from the loaded edge. The average strain distribution of control specimens are shown in Fig.7(b). As indicated in Fig. 7(b), the load at 5 kN level is carried mainly by the initial 35% of the bond length where significant strain exists. When the load level increases to 15 kN, the load carrying bond length is increased to about 70% of the total length with a relatively high strain of approximately 5000 micro strain at 16 mm from the loaded edge. This level of strain was kept fairly constant along a bond length up to about 60 mm from the loaded edge, after which the strain decreases quite rapidly. The fact that strain in the CFRP sheet increases along a limited length of the bond line as the load increases was demonstrated by the concrete prism pull-out failure during some of the tests at this high load level. This is about 80 mm from the loaded edge.

The strain readings collected at 12 kN load level were used to develop the bond stress – slip relationships described in this paper as shown in Fig.8. Failure loads of all specimens in conditioned and non conditioned series were exceeded this load level. Hence, 12 kN load level was selected for the purpose of comparison. The graphs indicate approximate non linear behavior with ascending and descending parts. The bond slip curves were developed using the average strain values on CFRP sheet at 17 mm, 43 mm, 63 mm and 103 mm from the loaded edge. The maximum shear stress of 4.6 MPa was noted at 17 mm from the loaded edge. The average maximum shear stress was less than 0.5 MPa at 103 mm from the loaded edge. This provides further evidence on effective bond length of CFRP strengthened concrete specimens considered in this investigation is in the range between 100 mm and 150 mm and also that closer to 100 mm.

3.2 Failure of conditioned test specimens

A total of thirty specimens were examined. Specimens were subjected to conditioning for 1800 hrs and 2250 hrs. Nine specimens failed in the environmental chamber during conditioning. These failed specimens were conditioned under 50 % sustained loading. Failure occurred at the interface between concrete and adhesive. The remaining specimens were tested at ambient condition using single lap shear test. The observed failure loads are shown in Table 4.

The average maximum strength reduction resulting from 2250 hrs conditioning was 24%, observed in unstressed specimens. The specimens subjected to 25% and 35 % sustained loading showed optimum and similar performance under these conditions and showed the average strength reduction of 8%. Then, trend of strength reduction increases with increased sustained loading level. About 15% of strength reduction was observed for the specimens subjected to 50% sustained loading. This can be explained by the fact that the accelerated bond degradation resulted from increased micro-cracks in the polymer matrix, which was subjected to relatively high stress [6]. Fig. 9 shows typical failure mechanisms observed under different conditioning regimes. Concrete rupture followed by bond failure was noted for both unstressed specimens and those subjected to lower stress levels. The failure pattern observed in unstressed specimens was very similar to that in control (unconditioned) specimens where concrete failure occurred. This shows the importance of concrete properties for the performance of unstressed specimens. The measured properties of concrete extracted from conditioned and non conditioned specimens with similar age describe in section 2.6. This shows similar compressive strength in conditioned and non conditioned specimens. Tensile strength and Elastic modulus of conditioned specimens are lower than the non conditioned specimens. Interface failure appeared with minor concrete failure in the specimens subjected to higher stress level (50% of sustained loading) while conditioning. This implies that the weakest part of the system is the interface between concrete and primer, indicating that the high mechanical stresses have adversely affected the interface strength between concrete and primer. There was no significant difference noted in failure mechanisms of the specimens (under the same sustained loading level) tested after 1800 hrs and 2250 hrs exposure. This may indicate that either the maximum performance degradation of this system has been completed during the initial 1800 hours exposure to the accelerated environmental cycling under these conditions, or the rate of degradation has decreased considerably after 1800 hrs. Some degradation might appear if the system were exposed to exposure periods of more than 2250 hrs.

The average bond length between 30 mm and 50 mm from the loaded edge was effective for initial load transfer as shown in Fig.10. However, there is a trend that strain near the start of the loaded edge increases slightly as the sustained loading level increases. Fig. 10 also shows a relatively high strain level near the loaded edge for unstressed specimens. About 70% of the bond line is subjected to high strain near failure in specimens conditioned under 25% and 35% sustained loading. The failure surface observed for these specimens was 2 – 6 mm beneath the concrete/epoxy interface including pull-out of concrete wedge near the loaded edge. The maximum effective bond length of control and conditioned specimens that showed concrete failure was 100 mm. This is consistent with Pham and Mahaidi reported bond behaviour for specimens with similar failure patterns under ambient conditions [17]. Only

30% of bond length showed a high strain in specimens conditioned under 50% sustained loading. The strain in CFRP sheet increases with loading without spreading along the full bond length until failure. This indicates the reduced force transfer ability of bond due to degradation. A negligible strain variation was observed beyond 100 mm from loaded edge till failure. Therefore it can be concluded that the selected bond length of 150 mm is higher than the effective bond length.

Fig.11 shows the average bond stress variation at 17 mm from the loaded edge when the specimens at 12 kN load level during single lap shear testing. All these curves indicate non linear behavior with approximate ascending and descending parts. The peak stresses of bond decline with the level of sustained loading that the specimens exposed during conditioning. This can be considered as an indication of bond degradation with level of sustained loading.

4.0 Effects of sustained loading

The strength variation with level of sustained loading shown by the specimens during conditioning is presented in Fig.12. The graph shows very similar behaviours for exposure periods of 1800 hrs and 2250 hrs. The maximum strength reduction of approximately 22% was observed in unstressed specimens after 1800 hrs conditioning. Specimens subjected to a range of sustained loading from 25% to 35% shows minimum reduction in strength. Further reduction was noted when the specimens were subjected to high levels of sustained loading (≥ 50%). Therefore, no high level of mechanical stress should be imposed on the system in order to maximise service performance.

5.0 Effects of exposure period

The results obtained from the test program demonstrated that the bond performance in terms of bond strength, strain and failure mechanism is significantly influenced by the temperature cycles up to 1800 hours. This is evident from the residual strength values shown in Fig.13. These plots show a trend of strength deterioration at up to 445 temperature cycles (1800 hours). The maximum strength reduction observed for these specimens was 24 % from the unstressed specimens. These specimens failed during shear testing because of concrete failure. This is due to the weak tensile properties of concrete resulting from dry exposure conditions as described in section 2.6. The exposed elevated temperature under dry conditions can cause evaporation of moisture in concrete. This will induce micro-cracks in concrete resulting in weaker mechanical properties. The specimens subjected to 50% sustained loading showed a maximum strength reduction of approximately 15%. However, three specimens subjected to 50% sustained loading failed during conditioning. This indicates the evidence of negative impact on bond performance when the composite subjected to high level of stresses. Further strength reduction was negligible (less than 1%) for the exposure periods from 1800 hours (445 cycles) to 2250 hours (565 cycles). In other words, strength deterioration has bottomed out after a certain period of temperature cycle exposure and no further strength deterioration is expected beyond this period or this period may not sufficient to observe a considerable bond strength degradation.

6. Conclusions

The following conclusions can be drawn from this study:

- The maximum strength reductions noted for this system after 1800 hours and 2250 hours exposure for conditioning were 22% and 24%, respectively.
- A negligible strength reduction was noted for the exposure period from 1800 hours to 2250 hours. This may be due to the fact that either the maximum degradation of bond performance of this system occurred within the initial 1800 hours exposure to the accelerated environmental condition, or the rate of degradation decreased considerably after 1800 hrs exposure. Degradation of bond properties is related to both exposure period and level of sustained loading.
- When conditioned at lower sustained stress levels ($\leq 35\%$), mixed failure of concrete and bond was observed. The properties of the interface and concrete are governing factors under this condition. Failure was observed at the interface between concrete and primer in the specimens subjected to the combined effects of cyclic temperatures and high sustained stress levels ($\geq 50\%$ of failure load of control specimens). This indicates the adverse effects of high stress on interface characteristics between primer and concrete when the system expose to cyclic temperatures.
- The study shows the importance of low levels of sustained loading for optimum service performance. This can be achieved by applying a suitable range of pre-loading conditions during installation.

- Two types of shear stress distributions along the bond length were noted, depending mainly on the failure pattern. For specimens that failed by concrete rupture, the initial shear stress distribution along the bond length showed that the stress dropped very quickly from the loaded edge. As the load increased, the stress started to shift from the loaded edge. Three stages of stress distribution were observed up to failure within the 150 mm bond length from the loaded edge.
- All bond-slip curves from conditioned specimens showed non-linear ascending and descending variation in a way very similar to that of the control specimens. The level of sustained loading influences peak stress of bond-slip curves.

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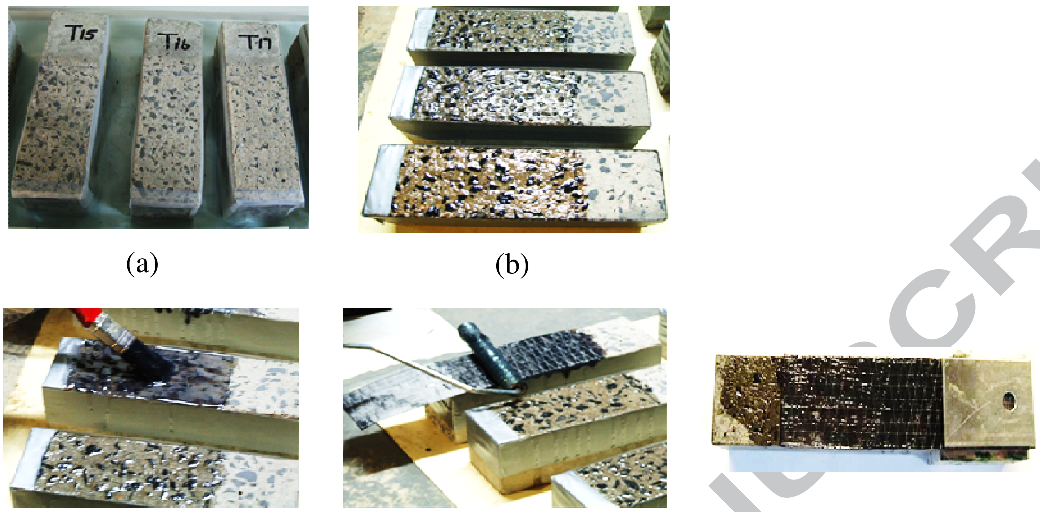


(a) (b)

(c) (d) (e)

Fig. 1(a)Sand blasted surface (b) Primed concrete substrates (c) Applying adhesive on primed surface (d) Removing entrapped air bubbles and pressing (e) Prepared test specimens with gripping

(a) (b)

Fig.2 Typical failure mode under ambient temperature; (a) bond length = 75 mm, (b) bond length ≥ 100 mm

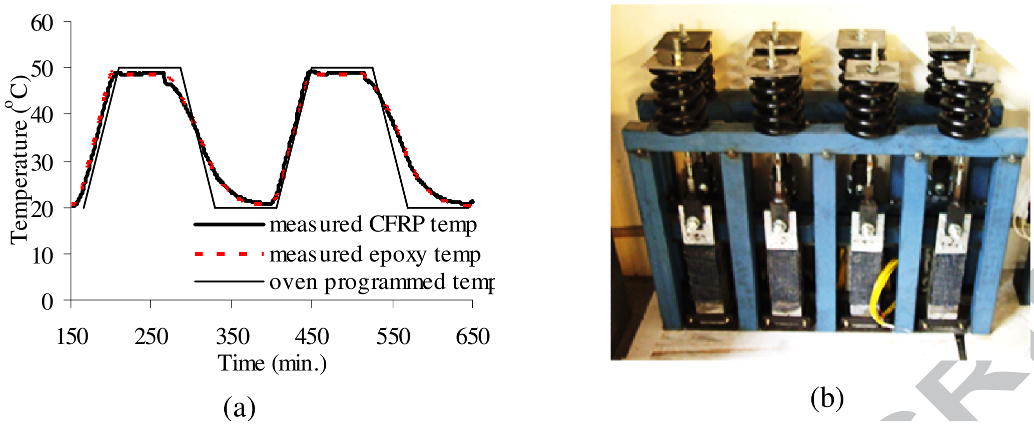
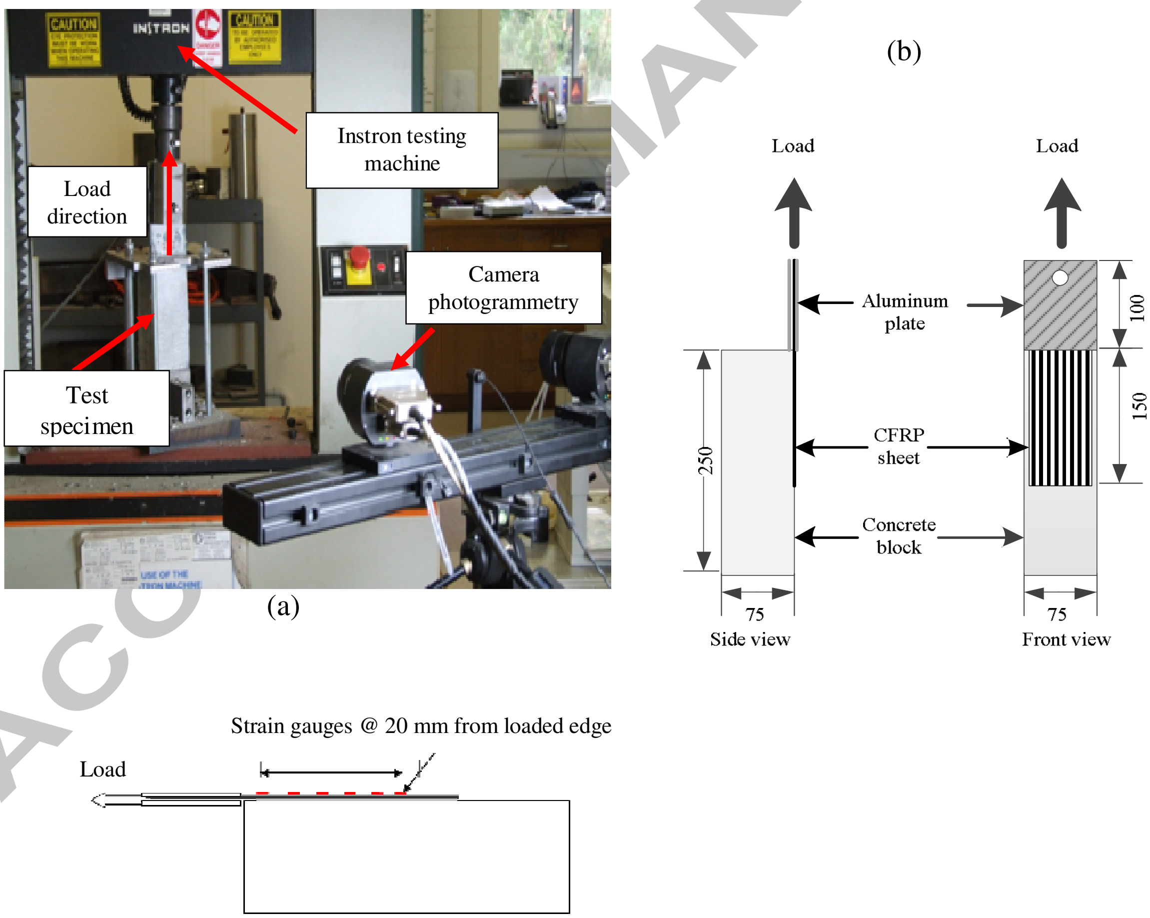


Fig. 3 (a) Variation of temperature in environmental chamber (b) Loading frames to apply mechanical stress



(c)

Fig. 4 (a)Testing set-up (b) Schematic diagram of single lap shear test, (c) strain gauges

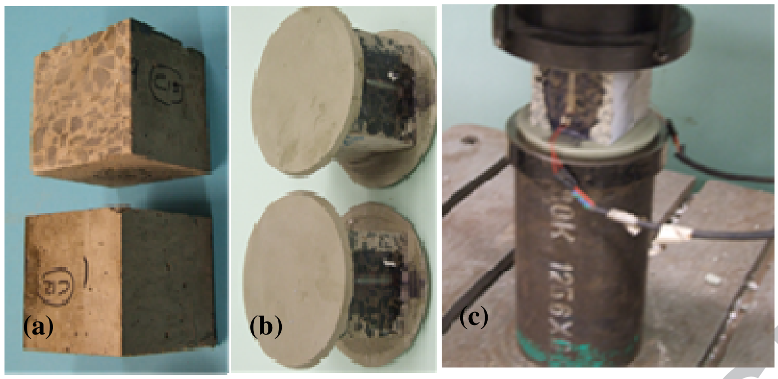


Fig.5: (a) concrete cubes, (b) prepared specimens for testing, (c) test set-up

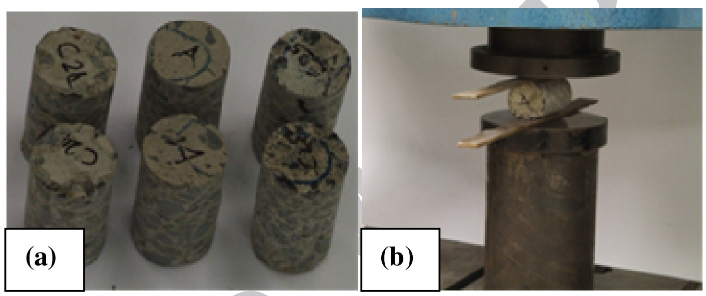


Fig.6: (a) Test samples, (b) Split-cylinder test set-up

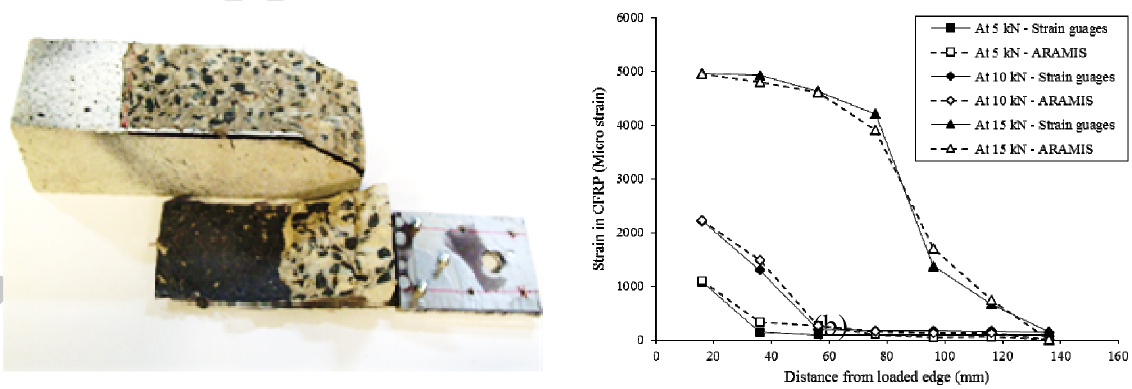


Fig. 7 (a) Failure pattern of control test specimens (b) Average strain distribution measured with strain gauges and ARAMIS photogrammetry technique

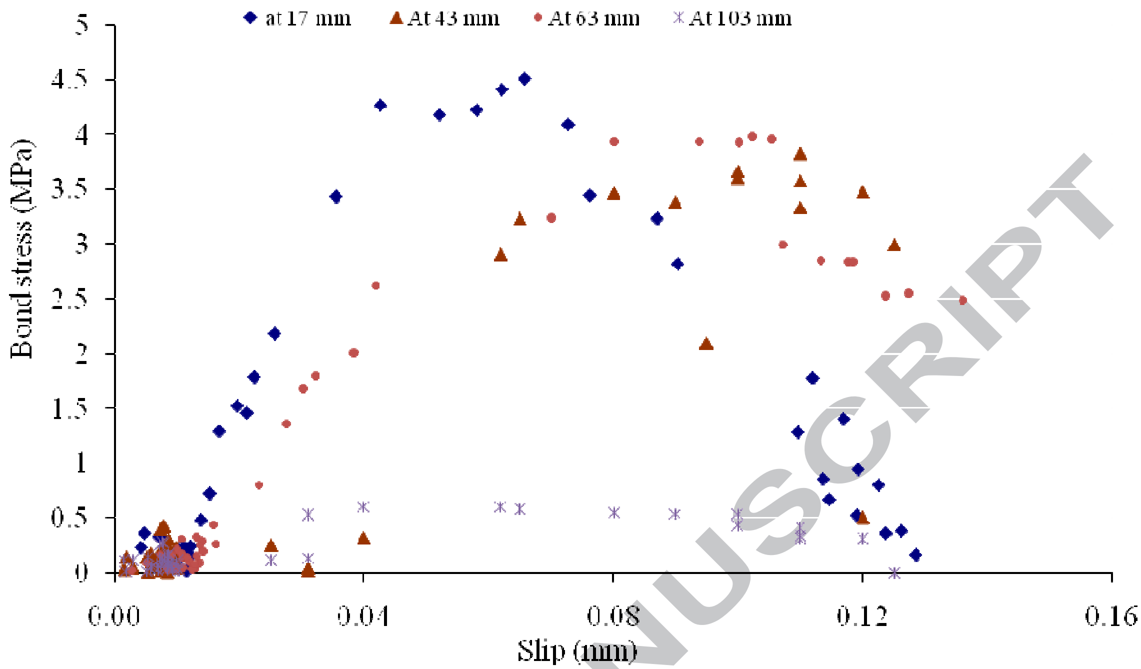


Fig.8 Average bond stress Vs. CFRP slip for specimens tested at ambient conditions

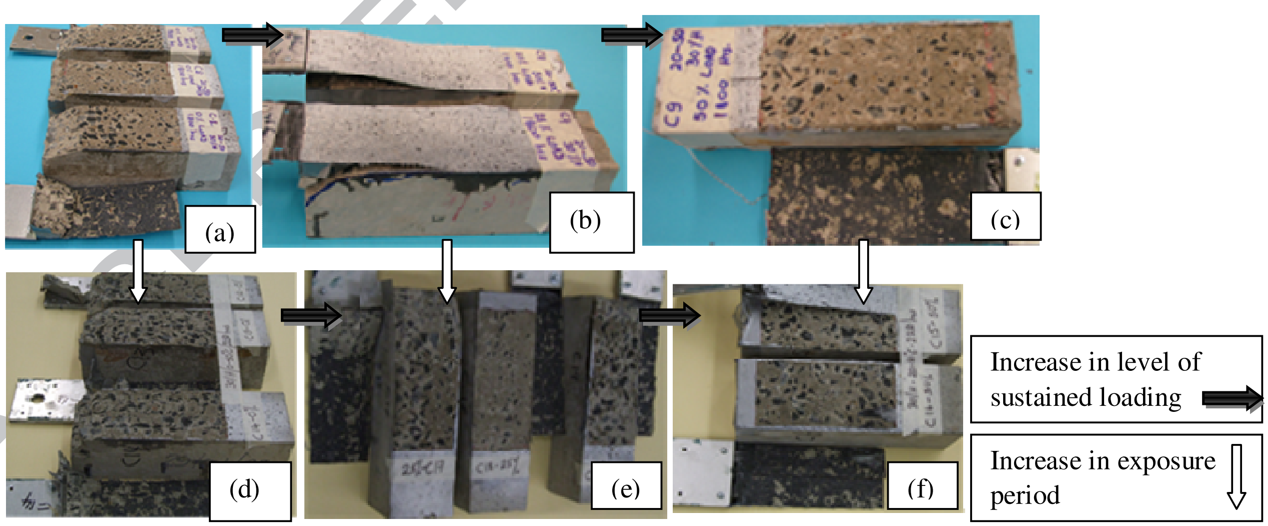


Fig.9: Failure mechanism,(a) 0% load, 1800 hrs, (b) 25%, 1800 hrs, (c) 50%, 1800 hrs, (d) 0%, 2250 hrs, (e) 25%, 2250 hrs, (f) 50%, 2250 hrs

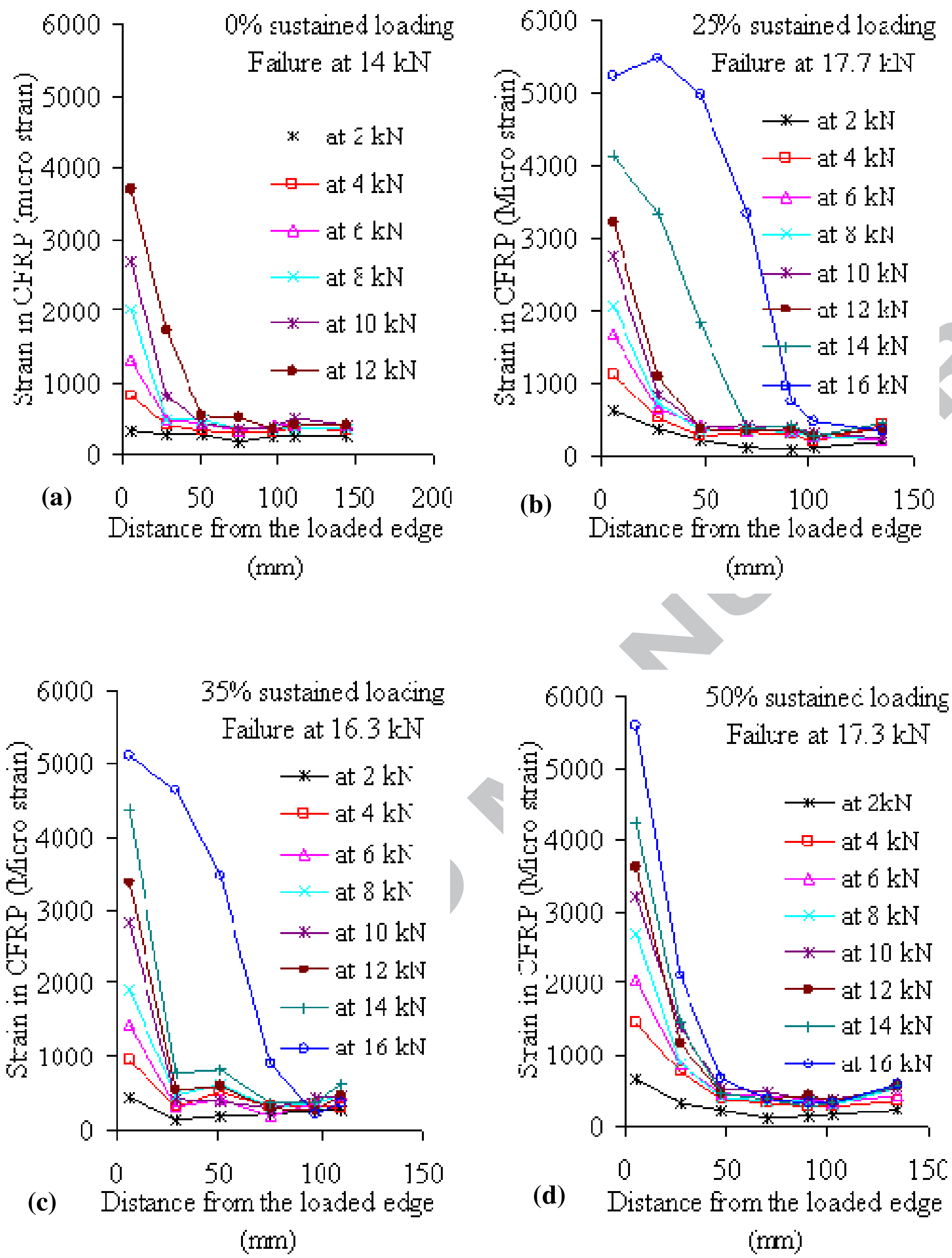


Fig.10 Strain variation in CFRP sheet after 2250 hrs conditioning under (a) 0%, (b) 25%, (c) 35%, (d) 50% sustained loading

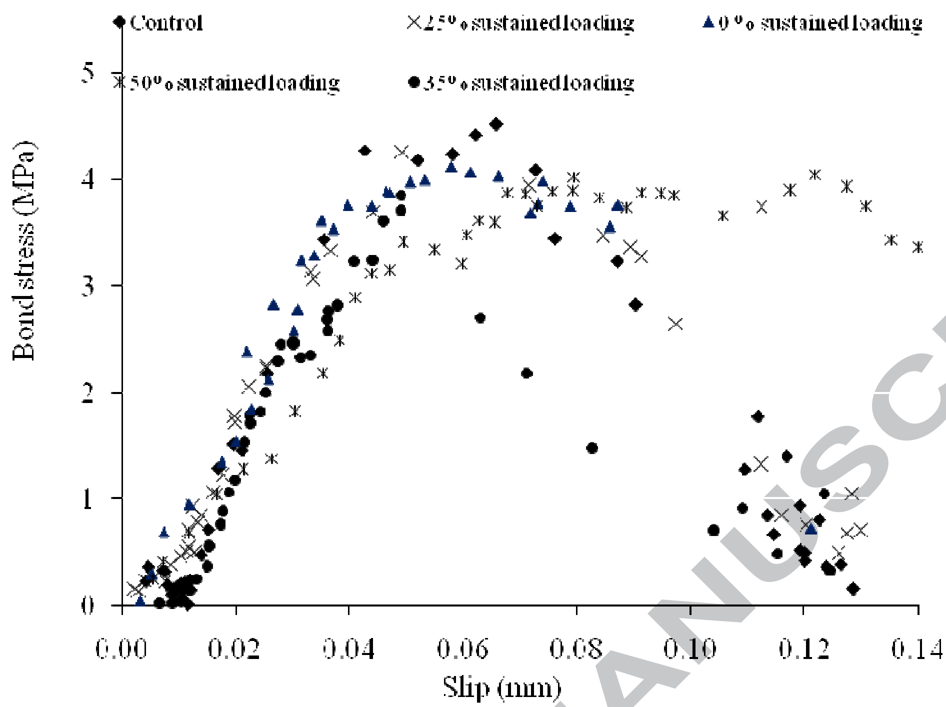


Fig.11 Bond stress vs slip @ 17 mm from the loaded edge for conditioned (2250 hrs) specimens under different level of sustained loading

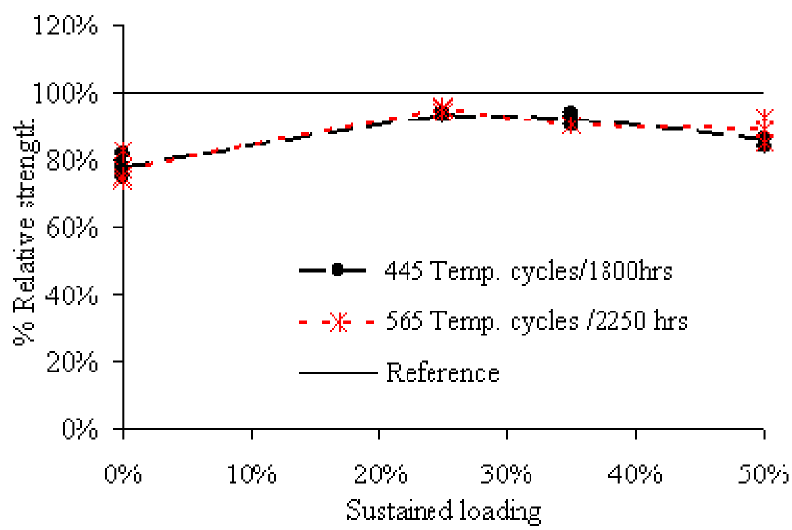


Fig.12 Variation of relative strength with level of sustained loading

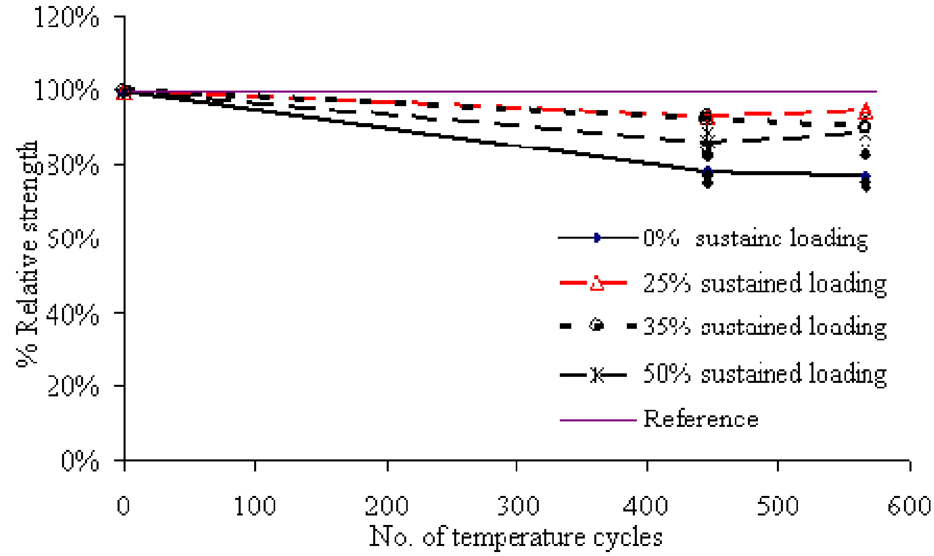


Fig.13 Strength variation with exposure period

Table 1 Summary of the test programme

Preliminary Investigation		Detailed Investigation		
Bond length (mm)	**Number of specimens**	**Exposure period**	**2250 hrs**	**1850 hrs**
		Sustained loading	**Number of specimens**	
75	2	0%	3	3
100	2	25%	2	3
125	2	35%	2	2
150	2	50% *	3	3
175	2	Control (non-conditioned)		12

* 9 specimens subjected to 50% sustained loading. Three of them failed during conditioning.

Table 2 Material properties of CFRP sheet and two-part epoxy adhesive

Material property	CFRP sheet		Two-part epoxy adhesive (saturant)	
	Manufacturer 's data[13]	Measured data [15]	Manufacturer 's data [14]	Measured data [15]
Elastic Modulus (MPa)	240000	230000	3034	2028
Tensile strength (MPa)	3800	2675	55	24.8
Fibre density (g/cm^3)	1.7	-	N/A	N/A
Thickness (mm)	0.176	0.176	N/A	N/A
Ultimate tensile elongation	1.55 %	1.2%	2.5%	1.46%
Fibre weight (g/m^2)	300	300	N/A	N/A
Poisson's ratio	N/A	N/A	-	0.32

Table 3: Failure loads of non conditioned specimens in preliminary testing

Bond length (mm)	75	100	125	150	175
Average failure load (kN)	16.42	20.70	20.72	20.45	20.54

Table 4: Residual strength of conditioned specimens

Sustained loading	After 1800 hrs exposure			After 2250 hrs exposure		
	Failure loads (kN)	**Average Load (kN)**	**strength reduction**	**Failure loads (kN)**	**Average Load (kN)**	**% strength reduction**
0%	12.7, 13.9, 13.1;	13.2	22% ***(16.9)****	14, 14.3, 15.7	14.6	24% ***(19.2)****
25%	18.8, 18.6	18.7	8% ***(20.4)****	17.2,16.9, 14.9	17.1	8% ***(17.7)****
35%	17.6, 17.7	17.7	8% ***(19.2)****	16.3, 16.4	16.4	8% ***(17.7)****
50%	17.7, 16.8, 17.4	17.3	15% ***(20.4)****	18.5, 17.3, 16.9	17.6	14% ***(20.4)****

* Figures in parenthesis are strength values of control specimens.