TENSILE CAPACITY OF STRESSED CFRP STRAND EXPOSED TO EXTREME AGGRESSIVE GROUNDWATER ENVIRONMENTS

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1 INTRODUCTION

Advancements of fibre reinforced polymer (FRP) products for applications in civil construction have allowed new products such as glass fibre (GFRP), aramid fibre (AFRP) and carbon fibre (CFRP) to pave the way for research into further improvements to the currently favoured steel tendon ground anchor system [1, 2].

Compared to corrosive nature of steel [3], FRP's are characterised by their superior resistance to aggressive environments [4-6]. Where steel strand ground anchors have been restricted in its use due to aggressive ground conditions, researches are hopeful that the technological advancements and research into stressed FRP materials can successfully provide a sustainable construction alternative [7, 8].

This paper looks into current research works, being conducted at Monash University in conjunction with Geotechnical Engineering, investigating the tensile performance of CFRP strands exposed to extreme conditions in a stressed condition.

2 TENSILE ANALYSIS OF STRESSED CFRP STRAND

2.1 Experiment overview

A series of experiments investigating the tensile performance in extreme conditions, cured in an unstressed state at elevated temperature, with increased salinity and exposed to extreme aggressive ground environments were conducted on various CFRP type strands over a 6 month period at Monash University [9]. The paper looks at the next stage of understanding the performance of CFRP strand for use in permanent ground anchor applications – CFRP strand performance exposed to extreme ground environments while stressed.

2.2 Materials

CFCC (Tokyo Rope) material was selected for this phase of research (Table 1). Three types of solutions were used in this experiment in line with previous works carried out on this topic by the authors [9]. A neutral solution, an extreme alkaline and extreme acidic groundwater solution were selected. The aggressive groundwater solutions included increased concentrations of salt, to assist in accelerating any aging process that may occur during the experiment.

2.3 Experimental Procedure

Samples were prepared to provide a 300mm exposed section of stressed CFRP strand to the various aggressive environments then placed into a stressing frame (Figure 1a). Strain gauges were secured to each specimen to record real time monitoring of sample movement during its stressed curing process (Figure 1b). The system was designed to enable sample re-stressing should the strain movement significantly vary overtime by greater than 10% of the lock-off load.

Samples were initially loaded to 50% of the manufactures breaking load (Figure 1c), then each sample was exposed to the various aggressive environments and placed into a curing tank for 1, 3 and 6 months at an elevated temperature of $60^{O}C$. Once cured, samples were tensile tested (Figure 1c) to establish its ultimate capacity.

This paper will present the interim results for the 1 month samples cured in a neutral solution at $60^{O}C$ and compared to published results [9] in an unstressed state.

Table 1: Technical Properties for CFCC (Tokyo Rope, Japan).

Property	CFCC (Tokyo Rope)
Dimensions	
Width (mm)	-
Diameter (mm)	15.2
Nominal Thickness (mm)	-
Effective Cross Sectional Area (mm2)	113.6
Linear Weight (g/m)	226
Carbon Fibre	
Minimum fibre volume ratio	0.62
Density (g/cm3)	1.5
Tensile strength (MPa)	4200
Elastic modulus (GPa)	240
Resin	
Type	modified epoxy
Density (g/cm3)	1.6 - 2.0
Tensile strength (MPa)	80
Product	
Tensile strength (MPa)	2200
Elastic modulus (GPa)	141

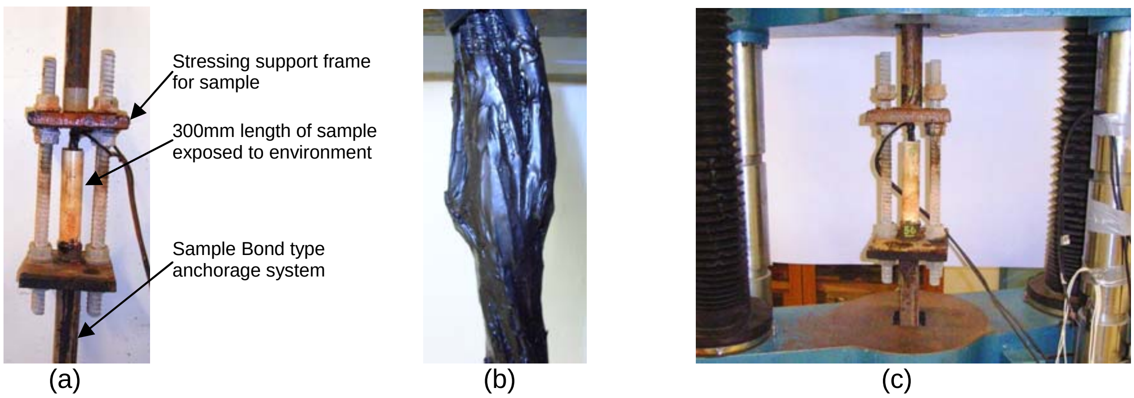

Figure 1: Setup for Stressed CFRP strand analysis; (a) sample setup including stressing frame and environment exposure zone; (b) method of protecting strain measurements on stressed samples exposed to extreme environment; (c) equipment used for initial stressing and ultimate stressing post sample curing.

3 STRESSED TENSILE ANALYSIS RESULTS

3.1 Results

Results comparing the ultimate tensile performance between neutrally cured CFCC samples cured in both an unstressed state and at a constant stressed state (50% breaking load), with reference to control samples can be seen in Table 2, Figure 2 and Figure 3.

Table 2: Tensile performance results comparing stressed cured samples against unstressed and control CFCC strand exposed to neutral solutions.

Solution	Curing Time (months)	Curing Temp (°C)	Curing State	Ultimate Strength (MPa)	Elastic Modulus (GPa)	Failure Strain (%)
Control	0	22	-	2072	170	1.05%
Neutral	1	60	Unstressed	2310	197	1.06%
		60	Stressed	2389	215	1.10%

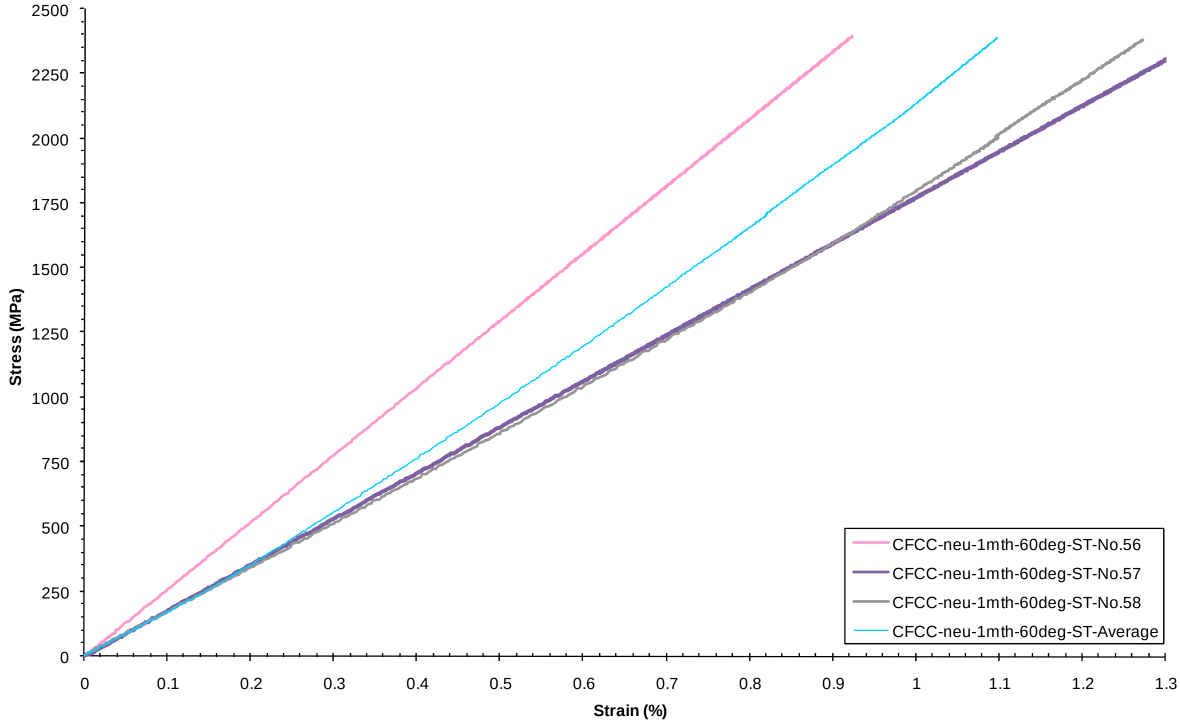

Figure 2: Stressed stress-strain relationship of CFCC strand over 1 month curing in a neutral solution at a curing temperature of 60^{O}C.

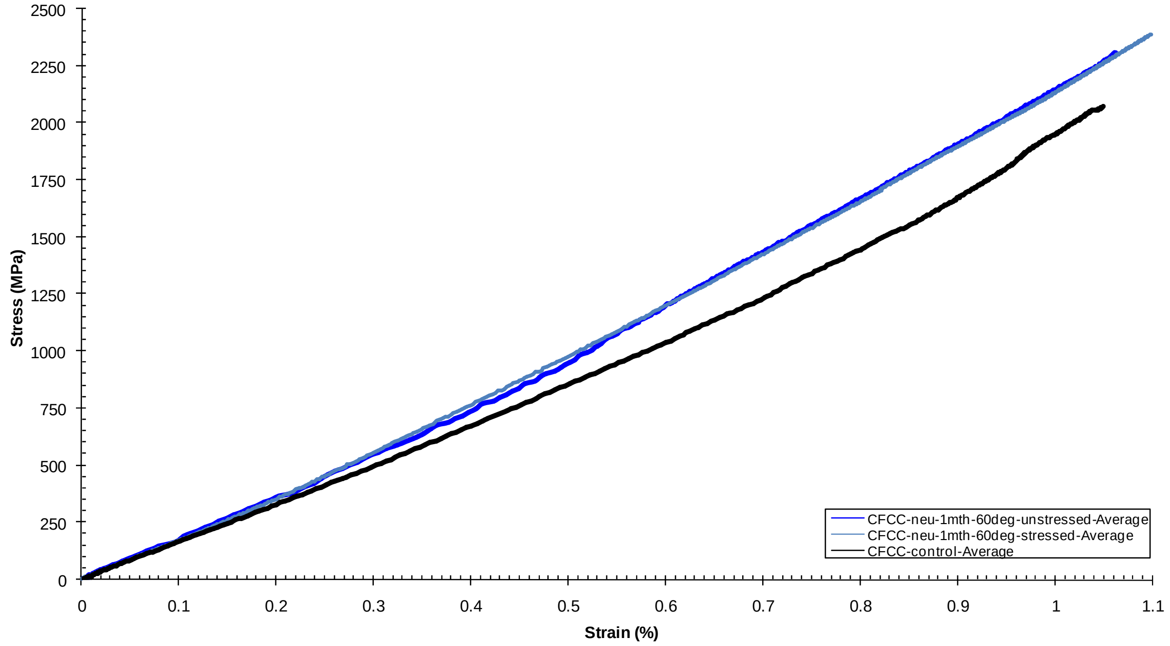

Figure 3: Comparison of average results between CFCC samples exposed to a neutral solution, cured for 1 month at 60^{O}C in an unstressed state, a stressed state and compared to control results

3.2 Discussion

From these indicative results, it can be seen that there is little variation between the ultimate strength for each sample tested under the stressed conditions. There were some variations between each specimen's ultimate strain, ranging from 0.9% to 1.3%. This variation between results did not fall outside two standard deviations from the mean results and as such the average of the three samples was established (Figure 2).

The average result for the stress cured samples were compared against the average results obtained from the unstressed cured samples and control samples [9]. These comparisons between unstressed, stressed and control indicate minimal performance change over this curing time period.

As reported by Sentry et al. [9], the rise in materials ultimate strength and strain after curing at 60^{O}C was a result of post manufacture sample hardening due to additional curing at elevated temperatures.

The stress cured analysis results show promise when compared to previous published results for unstressed cured samples [9]. Specimen failure was brittle, explosive and location of failure was inconsistent, all similar characteristics of control and unstressed cured specimen failure.

4 FURTHER RESEARCH WORKS

As indicated by these interim results, further long term research over 6 months at the elevated temperatures and exposed environments needs to be completed prior to being able to draw sound conclusions on the overall performance of selected CFRP strand when used in a stressed state, exposed to aggressive groundwater environments as possible when used in a permanent ground anchor application. These research works are still be conducted at Monash University in conjunction with industry experts Geotechnical Engineering.

5 CONCLUSIONS

It can be seen from these interim results on the performance of stressed CFRP material exposed to a neutral solution at elevated temperatures over a 1 month period that there is minimal change is the tensile performance when compared to both unstressed CFRP samples exposed to same solutions and control samples [9]. These positive interim results indicate that further research into this area of stressed CFRP performance is critical to the acceptance of new age material into the civil and construction industry as a practical alternative to conventional materials

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