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SHEAR AND BENDING BEHAVIOUR OF SHORT-SPAN STEEL-REINFORCED CONCRETE-FILLED FRP TUBES WITH ±55° FIBER ORIENTATION

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Abstract: In this study, steel-reinforced concrete-filled ±55° glass-fiber-reinforced-polymer (GFRP) tubes (CFFT) are examined under monotonic loading to understand their shear behaviour. A total of three test specimens with three different nominal pressure ratings (50, 100 and 150 Psi) were tested under three-point bending. The pressure ratings are associated with the tube wall thickness. The shear span to depth ratio (a/D) was adopted as 1 for this study. The applied load for each test was measured using a 1.5MN load cell. The deflection at mid-span and the bond-slip measured with the help of a string potentiometer and linear potentiometers. The strains at the compression and tension regions were measured using strain gauges with a gauge length of 6mm. The test results show that the increase in the ultimate strength of the concrete-filled GFRP tubes was due to the increase in the wall thickness. All specimens failed in flexure: initial stretching of the tensile fibers with minor compression fracture development at the top and ultimately failed due to fracture at the tension fibers at mid-span. No significant amount of slip between concrete core-GFRP tube and steel reinforcement were recorded, which shows that the superior compositeness between the components of the test specimens. The importance of this study is to improve the understanding of shear and flexural behaviour of the CFFTs with ±55° fiber orientation.

1 INTRODUCTION

Efficient infrastructure systems such as highways, bridges, buildings, pipelines, flood control systems (waterways) and utilities are all necessary for a healthy economy and comfortable standard of living. The long-term structural durability of reinforced concrete structures has been a long-term issue for the infrastructure industry. Corrosion of steel reinforcement causes major degradation problems to the structures worldwide. In the last decade, a hybrid system such as concrete-filled fiber-reinforced-polymer (FRP) tubes (CFFTs) are promising for various structural applications such as structural columns, piles, poles, pipes, signalling post, bridge components, etc. Their fascinating features include durability, concrete confinement, resistance towards chemical attacks, etc. grabbed the attention of researchers and the infrastructure industry.

Due to their resistance to corrosion, internal pressure and axial loads, ±55° filament wound GFRP tubes are readily available and popular among the oil and gas and municipal sector (Betts et al. 2019). Although the behaviour of CFFTs (Mirmiran and Shahawy 1997; Fam and Rizkalla 2002) have been studied substantially under various loading conditions (Fam et al. 2003; Fam and Cole 2006; Burgueño and Bhide 2006; Fam et al. 2007; Mirmiran et al. 2008), very few studies have been executed to understand the shear behaviour of CFFTs, especially with ±55° fiber orientation. From those studies, it has been noticed that depending on the fiber orientations of FRP tube, longitudinal reinforcement ratio and composite action between the components of CFFTs, the deep CFFTs are more susceptible to shear failure. Due to the limited and specific nature of previous studies, it doesn't give a conclusive idea of the shear behaviour of the CFFTs.

To incorporate CFFTs in the structural systems, it is essential to understand and characterize the behaviour of CFFTs and their components, which will allow accurate analysis and design of members. Previous studies by Betts et al. (2019) and (2021) discussed the nonlinear behaviour of hollow ±55° filament wound GFRP tubes. In this study, the shear behaviour of steel-reinforced concrete-filled ±55° fiber-orientated GFRP tubes is experimentally investigated by testing under three-point bending with varying wall thickness.

2 EXPERIMENTAL PROGRAM

2.1 MATERIALS AND FABRICATION

In this study, each GFRP tube was internally reinforced with six 15M longitudinal steel rebars, whose nominal diameter was 16mm. 30 mm was selected as a clear cover for all the test specimens. No additional shear reinforcement in terms of stirrups was used in internal reinforcement. For the final casting, the test specimens were filled up with concrete. The concrete had a compressive strength of 36 MPa at the time of testing.

2.2 TEST MATRIX

For this study, a total of 3 CFFTs were tested under three-point bending. The main test parameter was tube wall thickness. The test matrix is presented in the following table 1. The following specimens were named PX-Y-ADZ, Where X is the nominal pressure rating in psi (i.e., 50, 100 and 150), Y is internal reinforcement (15M steel rebars referred to as b), and Z is the shear span-to-depth ratio.

Table 1: Test Matrix

Test Specimen	Nominal Pressure Rating (Psi)	Inner Diameter (mm)	Wall Thickness (mm)	Shear Span-to-Depth Ratio	Internal Reinforcement Ratio (%)
P50-b-AD1	50	203.2	2.7	1	3.7
P100-b-AD1	100	203.2	4.7		
P150-b-AD1	150	203.2	6.7		

2.3 TEST SETUP

The test setup for this experimental study is provided in figure 1. The total length of the specimens was 1219.2 mm. The load was applied in the mid-span of the test specimens. For each specimen, the supports were roller at each end. To restrict the shear span to depth ratio to 1, the supports were placed at the distance of 330.2 mm and 886.2 mm respectively. A string potentiometer and two linear potentiometers were used to measure the deflection at the mid-span. Three strain gauges were attached at the mid-span to measure the strain at the extreme top and bottom fiber and the strain in the bottom steel reinforcement zone. Three more strain gauges were also used in the middle of the shear span to measure the principal tensile strain. Four linear potentiometers, two at each end of the specimens were used to detect any bond-slip occurrence between concrete core, steel rebar and GFRP tubes. All of the three tests were performed at a rate of approximately 2mm/min.

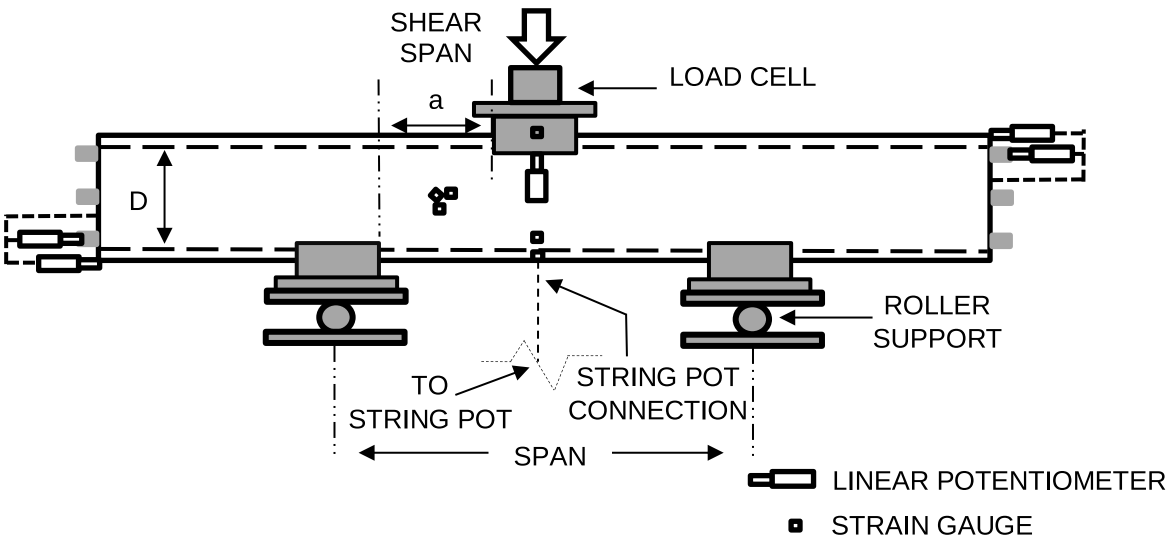


Figure 1: Test set-up

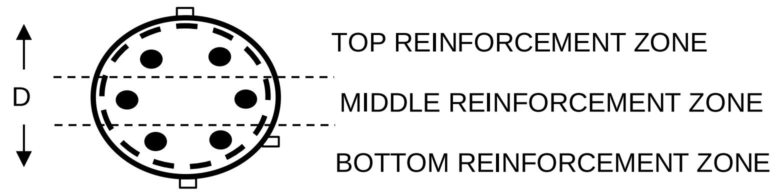
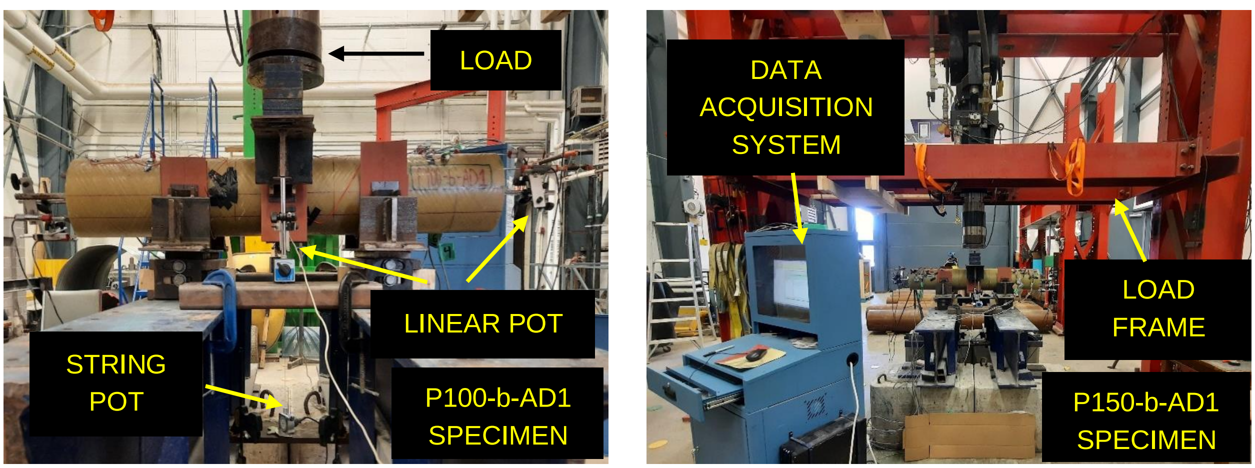


Figure 2: Cross-section at mid-span and strain gauge locations



(a) (b)

Figure 3: (a) Instrumentation of P100-b-AD1, and (b) Test arrangement of P150-b-AD1

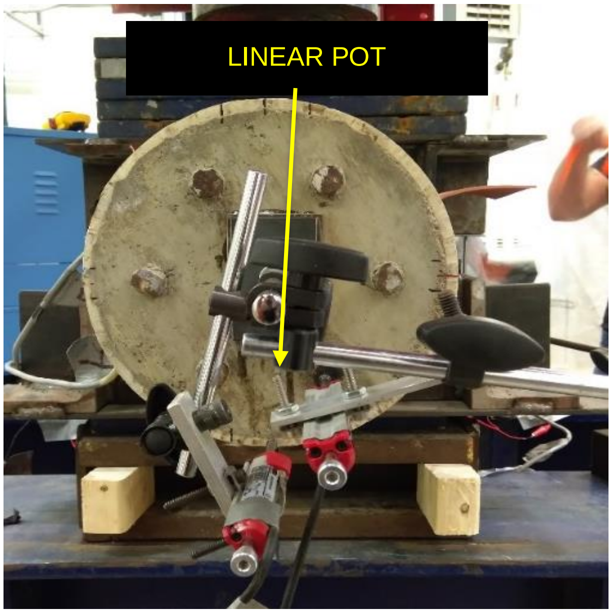


Figure 4: Slip measurement between concrete-steel reinforcement-GFRP tube

3 RESULTS AND DISCUSSIONS

This section will be comprised of the test results and the discussion of the behaviour of the test specimens under three-point bending. All the test data was processed and modified using MATLAB, a numeric computing and programming language by MathWorks.

3.1 FAILURE MODE

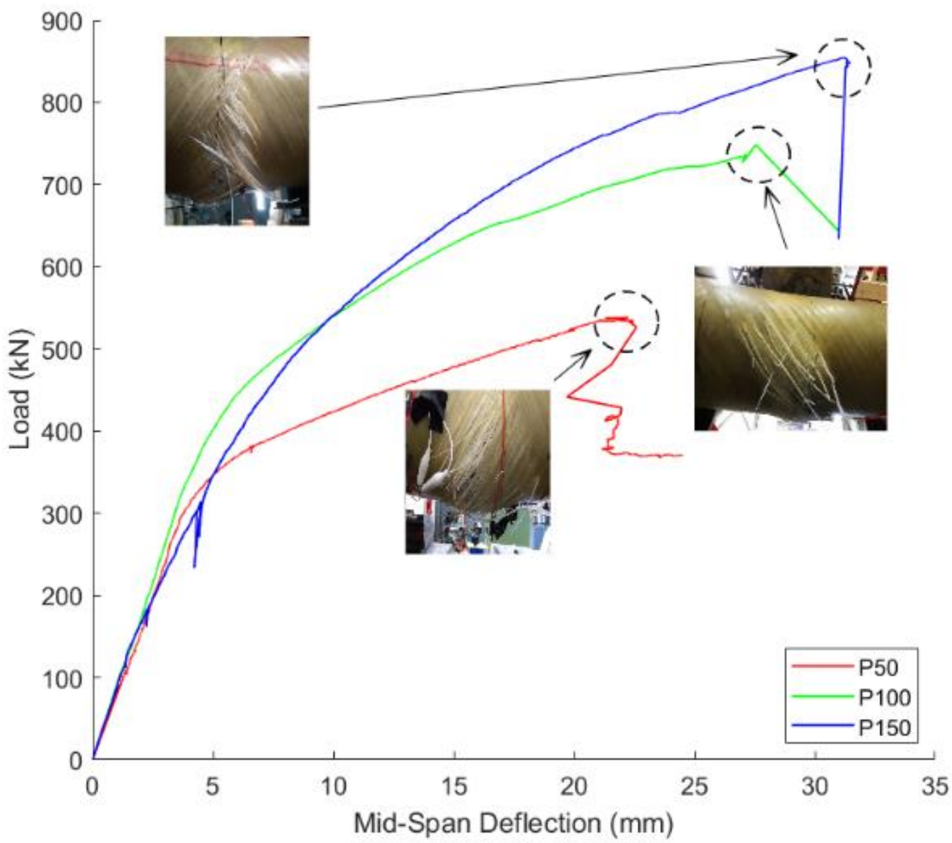
In all three tests, a similar failure pattern was noticed, initial stretching of fiber in the tension region of the CFFTs, and successive crack generation in the compression zone under the top support. The specimens then ultimately failed due to fiber rupture/ fracture in the tension region. Figure 5 exhibits the ultimate failure pattern of the three different test specimens.

(a) (b) (c)

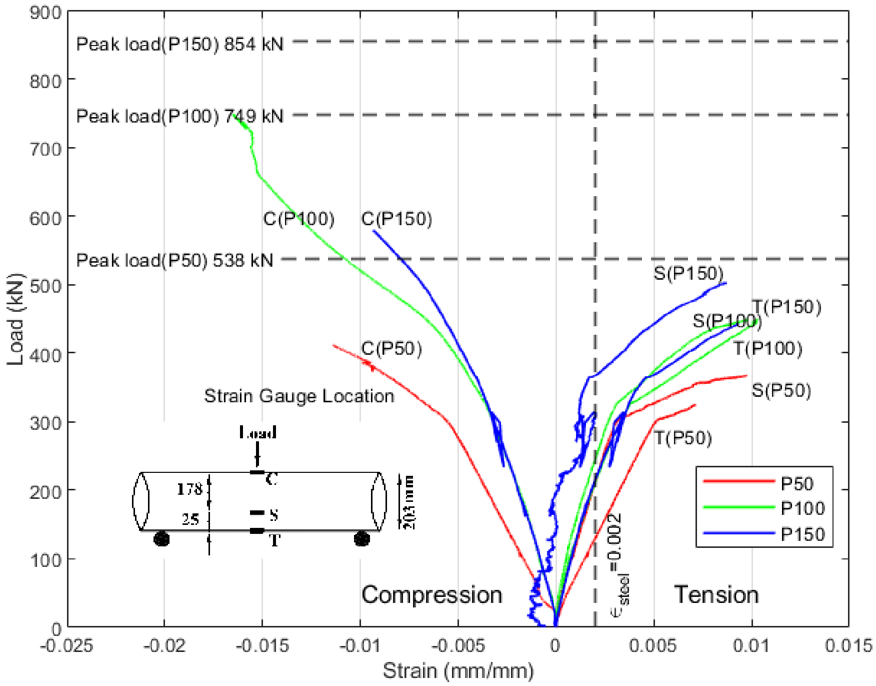
Figure 5: Failure mode- Tension rupture (a) P50 specimen (b) P100 specimen (c) P150 specimen

3.2 BEHAVIOUR

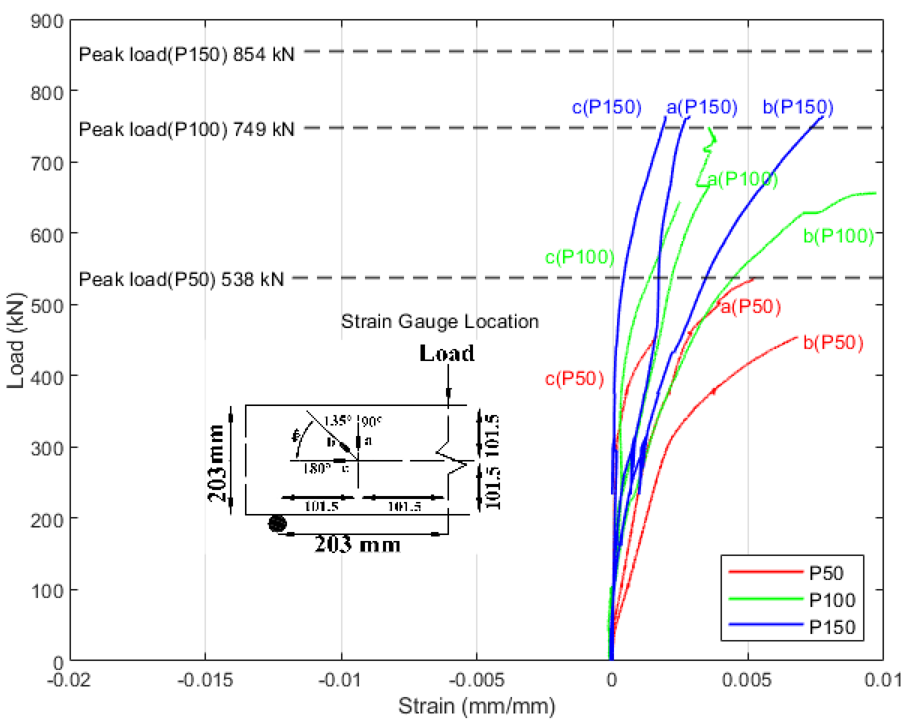
Figure 6 shows the load vs mid-span deflection, load vs various strains, and load vs bond-slip between the concrete-GFRP tube and longitudinal steel reinforcement. It has been observed that the pressure rating, which is correlated to the wall thickness, has a significant effect on the ultimate capacity of the CFFTs. With the increase in the tube wall thickness, the ultimate strength of the CFFTs increases. The recorded ultimate capacity was approximately 60% higher for the P150 CFFT specimen compared to the P50 CFFT specimen. The load vs mid-span deflection shows the nonlinear behaviour of the CFFTs. This nonlinear behaviour could be related to the fiber elongation, crack development and propagation in the test specimens' tension region. Additionally, out of all the three test specimens, a maximum slip of 0.4 mm between concrete core and longitudinal steel rebar has been observed for the P150 test specimen at its peak load. This further signifies the enhanced composite behaviour between concrete core, internal steel rebars, and GFRP tubes.



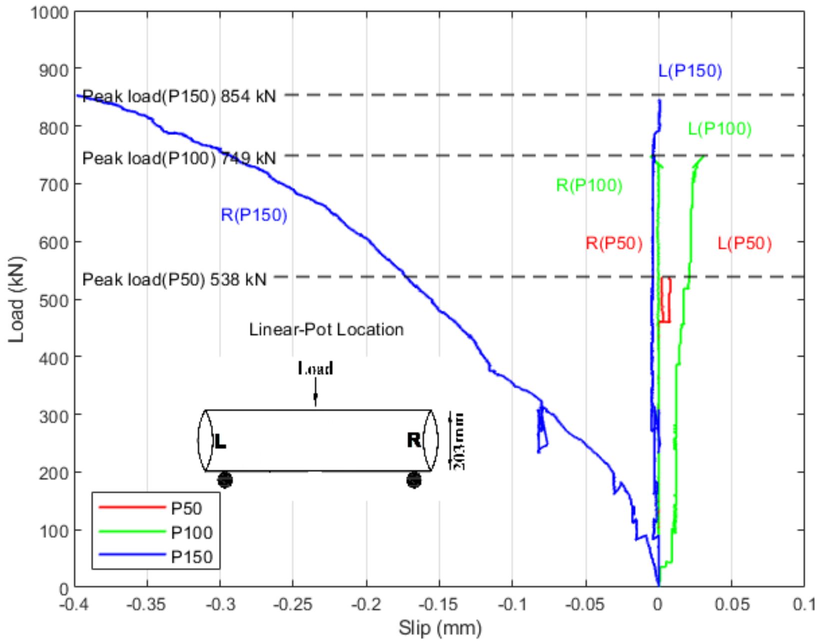
(a)


Peak load(P150) 854 kN
Peak load(P100) 749 kN
Peak load(P50) 538 kN
C(P100)
C(P150)
C(P50)
S(P150)
S(P100)
T(P150)
T(P100)
S(P50)
T(P50)
Strain Gauge Location
Load
178
25
C
S
T
203mm
Compression
Tension
ϵ_{steel}=0.002
P50
P100
P150
Load (kN)
Strain (mm/mm)

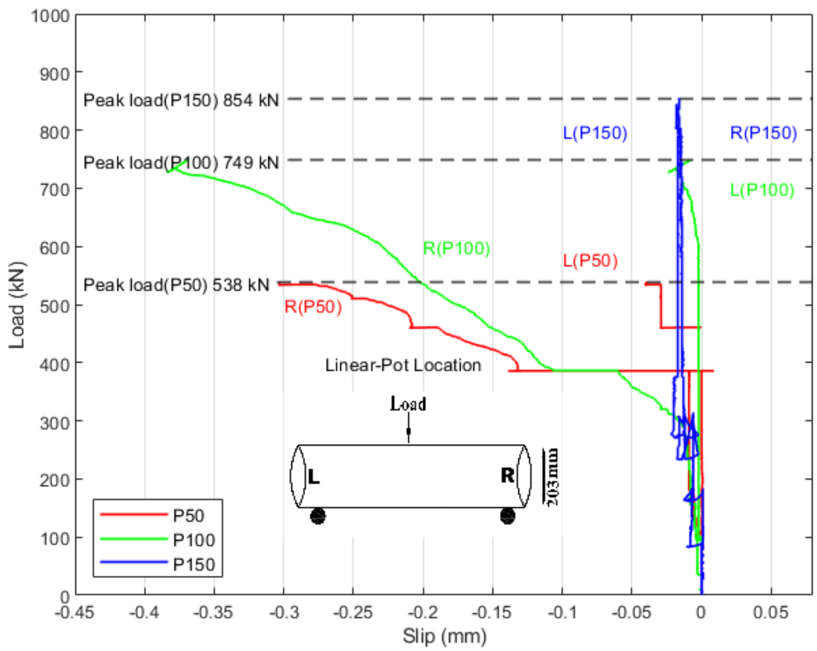
(b)


Peak load(P150) 854 kN
Peak load(P100) 749 kN
Peak load(P50) 538 kN
c(P150)
a(P150)
b(P150)
a(P100)
b(P100)
c(P100)
a(P50)
b(P50)
c(P50)
Strain Gauge Location
Load
203mm
203 mm
101.5
P50
P100
P150
Load (kN)
Strain (mm/mm)

(c)



(d)



(e)

Figure 6: Test results- (a) Load vs Deflection (b) Load vs Mid-span Strain (c) Load vs Strain Rosette at Mid-shear span (d) Load vs Slip between concrete-steel (e) Load vs Slip between concrete-GFRP tube

4 CONCLUSIONS

This paper demonstrates the results of three-point bending tests on CFFTs with varying wall thickness. Based on this study, it has been observed that all of the specimens failed similarly, initial fiber elongation in the tension region of CFFT and minor crack development in the compression region followed by an ultimate failure due to tension rupture/flexure in the bottom fiber. The ultimate capacity of the test specimens significantly depends on the wall thickness of the GFRP tubes. Furthermore, no significant amount of bond-slip between the concrete core and internal longitudinal steel reinforcement, and between concrete core and GFRP tube has been observed. Besides, to understand this unique behaviour of CFFTs with ±55° fiber orientation more extensively, a study of these CFFTs by changing the shear span to depth ratio and longitudinal reinforcement ratio is currently in progress. Moreover, a robust finite element model is in development to analyze and predict the behaviour of CFFTs with ±55° fiber orientation.

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