

# Laboratory Experiments conducted on Carbon Laminate Interfacial Shear Stress

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**ABSTRACT:** Tests were conducted on one beam and four coupons to determine the interfacial shear strengths of carbon fabrics and laminates bonded on steel surfaces. The tension flange of the beam was intentionally cut at midspan and retrofitted with carbon laminates, in an effort to regain the beams original moment capacity. The four coupons consisted each of a rectangular steel plate, cut at mid-height to reduce the steel cross-section by 90% , and three layers of carbon fabric on each side of the plate. The experiment was conducted to study the transfer of axial forces from the steel plate into the carbon fabric through interfacial shear stress.

## 1.1 Beam Specimen Details

One center-point load test was applied on a W10x33 beam, composed of A572 Grade 50 ( $F_y = 50\text{ksi}$ ) steel. The beam was 9'-8" long, with a six inch overhang on one end and a thirty-eight inch overhang on the other (Fig. 1). The clear span of the beam was six feet. In the center of the six foot span, the tension flange was cut

across its entire width (Fig. 2). The beam was then retrofitted by laminating two layers of 0.050 inch thick carbon plate over the full flange width (Fig 3). The laminates were five feet in length, which covered eighty percent of the six-foot tension flange, and were centered about the saw-cut at midspan.



Figure 1. Beam shown after experiment



Figure 2. Tension flange cut on both sides of web.

## 1.2 Test Setup

The beam test was conducted in the vertical load frame shown in Figure 1. This particular test frame is equipped with a 110 kip MTS actuator, which is supplied by a 30 gpm hydraulic pump. Load was applied at midspan and lateral bracing was provided six inches away from the load point. Rollers were used at all load and reaction locations (Fig. 4).



Figure 3. Carbon laminates on tension flange.



Figure 4. Rollers used during testing. Top roller is not shown in actual location used for testing.

### 1.3 Testing Procedure

Using a center-point load test setup, the retrofitted beam specimen was subjected to a continuous displacement by the 110 kip MTS actuator. Displacement control, as opposed to load control, was used because it is safer in a post-yield situation. The displacement rate for this test was 0.05 inch/minute, and was determined based on the desired 10-20 minute test duration. During the test, load and displacement were recorded from the actuator's

load cell and Linear Voltage Displacement Transducer (LVDT), respectively. This data can easily be plotted in Microsoft Excel or the like.

### 1.4 Test Results

It was predetermined that the plastic moment capacity of a fully intact W10x33 beam is 1940 k", which would require a 108 kip load at midspan. After considering the cut through the tension flange, the plastic moment capacity at that section was approximated to be 850 k". To reach this moment, a 47.2 kip load would be required.

At the onset of testing, the slip in the system was gradually removed. This continued up to about a 0.06" deflection. At that point, the slope of the load-displacement curve increased dramatically. That slope was maintained up to a deflection of 0.30". At that point the curve began to soften as the beam began to yield (Fig. 5).

As load increased, the compression flange began to buckle near the point of applied load (Fig. 6). More importantly, the carbon plates did not de-laminate and no other deformations or failures were observed. The bond at the interface of carbon and steel remained intact throughout the entire range of loading; up to the failure of the beam.

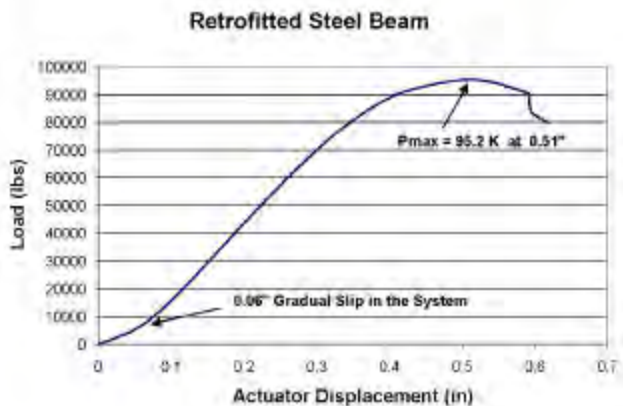


Figure 5. Load vs. Displacement Curve

The beam reached a maximum load of 95.2 kips at a deflection of 0.51". Shortly thereafter, the load began to decrease with increasing deflection. The test was terminated at a deflection of 0.61" under 80 kips of load. A maximum moment of 1714.6 k" was observed. This is less than the plastic moment for a W10x33 beam, due to the local buckling caused by the non-compact section.



Figure 6. Local deformation of compression flange under point of applied load.

## 2 COUPONS

### 2.1 Coupon Specimen Details

Tests were conducted on four coupon specimens. These specimens consisted of 6 layers of 25 oz. carbon fabric and rectangular steel plate. The steel plate was 2" wide, 5/8" thick and 24" long. It was intentionally cut at mid-height, leaving only ten percent of the original area at that cross-section (Fig. 7). A circular grinder was used to prepare the steel plate's entire surface (Fig. 8). After all of the rust and carbon scale had been removed from the steel plate, three layers of the carbon fabric were laminated along 18" of the 24" length on both sides, and were centered at the saw-cut (Fig. 9). The remaining three inches of bare steel on either end were used as the gripping surface in the MTS testing machine.



Figure 7. Post-test close-up of the cut made in the steel plate.



Figure 9. Specimen in pre-test form.

### 2.2 Test Setup

All three coupons tests were conducted in an MTS vertical testing machine, equipped with a 220 kip actuator and hydraulic grips (Fig. 10). The grips were calibrated to apply 10,000 psi to the ends of the specimen during testing to eliminate any vertical slip. The grip marks can be seen in Figure 8 above. After the specimens were centered and plumbed in the testing machine, axial tension was applied until failure occurred.

### 2.3 Testing Procedure

Once the specimens were plumbed and the gripping pressure was applied, the specimens were strained at a constant rate of 0.05 inch/minute. This rate was suggested by ASTM for carbon polymer matrix materials under axial tension. During the test, load and displacement were recorded similar to that of the beam test.



Figure 10. Specimen shown in MTS testing machine with gripping pressure applied.

### 2.4 Test Results

The test results from the four coupon tests are shown in Table 1. Load vs. displacement curves throughout the

entire range of loading for three of the specimens can be seen in Figures 11-13.

Table 1. Coupon specimen test results

Specimen	Load	Interfacial Shear Stress
	lbs	psi
1	32739.0	909.4
2	17329.6	481.4
3	22877.3	635.5
4	36667.2	1018.5
Average	27403.3	761.2
Std. Dev.	8874.2	246.5

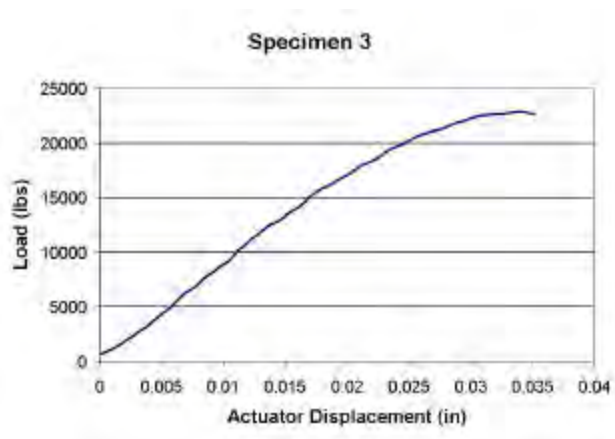


Figure 13. Load vs. Displacement for specimen 3.

### 3 CONCLUSIONS

Test results on the beam with the tension flange cut out clearly demonstrate that the strength of such damaged beams can be fully restored by epoxy bonding carbon laminate to the damaged area. No delamination or bond failure were observed throughout the entire range of loading up to the failure of the beam which was occurred due to the compression flange buckling.

The results from the coupon tests, while indicating significant variation, show that a good interfacial shear strength can be expected from carbon fabrics bonded to steel plates. The variation in the bond strength was primarily due to different surface conditions of the steel. Nevertheless, the results indicate that by selecting a safe, lower bond shear strength for the carbon/steel interface, such composite construction can properly be designed. Also, proper surface preparation of the steel using abrasive blasting or other means will improve the surface condition and thus increase the bond strength.

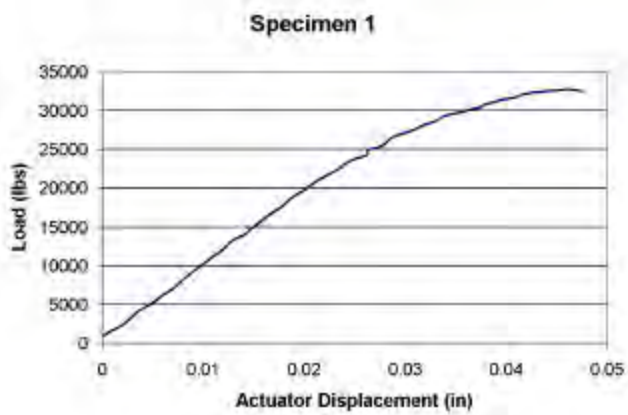


Figure 11. Load vs. Displacement for specimen 1.

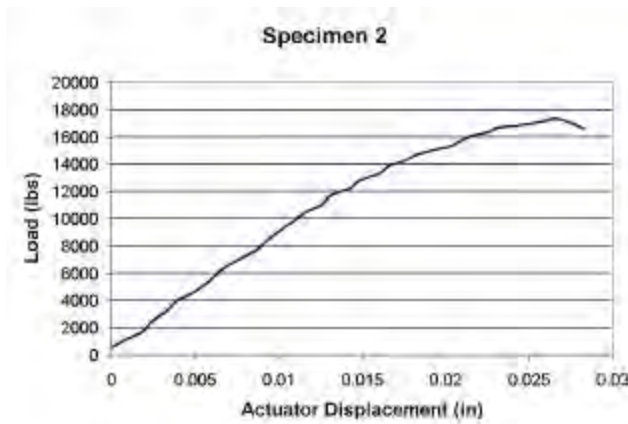


Figure 12. Load vs. Displacement for specimen 2.