



# PRODUCT INFORMATION

Citadel Technologies  
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## Composite Strengths

The strength of the composite was determined from tensile testing performed independently at the University of Tulsa.

HOOP DIRECTION					
Cloth Type	Thickness (inches)	Ult. Load (pounds)	Ultimate Strain	Ultimate Stress	Elastic Modulus
				psi	psi
CxB	0.09	3,690	1.27%	83,646	7,132,620
BxB	0.09	2,208	1.64%	55,424	4,057,470
BxA	0.10	3,228	0.97%	39,412	5,031,504
AxA	0.06	1,584	1.33%	59,838	4,759,843
AXIAL DIRECTION					
Cloth Type	Thickness (inches)	Ult. Load (pounds)	Ultimate Strain	Ultimate Stress	Elastic Modulus
				psi	psi
CxB	0.09	2,850	1.30%	35,930	3,463,741
BxB	0.09	2,208	1.64%	55,424	4,057,470
BxA	0.10	2,720	1.43%	64,434	4,586,913
AxA	0.06	1,584	1.33%	59,838	4,759,843

## Lap Shear Strengths

The lap shear strength of the Diamond Wrap System was determined by testing done independently at the University of Tulsa.

Ultimate Strength (psi)
1250

## Rupture Testing

Rupture testing was performed by the University of Tulsa in conjunction with Citadel Technologies. The results are shown for repairs with a maximum of 6 layers of carbon on the repair, when the pipe was repaired with no internal pressure applied. Both defects were 6 inches long, and the patch defect was 6x6 inches in area.

Defect Type	Wall Loss	Failure Pressure			
		No Repair		Repaired	
		ksi	(Mpa)	ksi	(Mpa)
No Flaw	N/A	6.65	45.85	N/A	N/A
Axi-symmetrical	50%	4.35	29.99	6.35	43.78
	80%	1.88	12.96	5.12	35.3
Square, Patch-shaped	50%	4.4	30.34	6.25	43.09
	80%	1.88	12.96	5.25	36.2

## Fatigue Testing

Fatigue tests were performed by TU, on pressure vessels to determine the effectiveness of repairs made using a carbon/epoxy composite material system. The carbon/epoxy system is intended to repair externally damaged or corroded steel pipe where blunt defects are present. Six-inch nominal diameter by five feet long pressure vessels were constructed from A-106 Grade B steel for test purposes. Defects were machined into the outer surface of each pressure vessel to determine limitations of the carbon/epoxy repair system. The vessels were then cyclically pressurized until a leak in the system was detected. The repaired vessels were compared to un-repaired vessels with equal size defects to determine the effectiveness of the repair. Results indicate there was a substantial increase in the performance of the pipe.

Repair	None	Repaired		
Defect	1.125" x 5.19"	1.25" x 2.75"	1.125" x 5.19"	1.125" x 5.19"
Wall Loss	80%	80%	70%	80%
Cycles	3	Infinite	Infinite	Infinite

## Cathodic Disbondment

Cathodic Disbondment testing was performed independently by the University of Tulsa. Cathodic Disbondment tests were conducted on A-106, Grade B steel pipes on which carbon-fiber-reinforced polymeric wraps were installed. The composite wraps are part of a system used to repair externally damaged or corroded steel pipes. To simulate a corrosive environment, pipes coated with the composite wraps were submerged in an electrolyte consisting of potable water, sodium chloride, sodium sulfate, and sodium carbonate. Holidays or breaks in the composite wrap were produced, exposing bare steel to the electrolyte. Test results indicate the carbon-fiber-reinforced polymeric repair system exhibits no Cathodic Disbondment.

## Galvanic Corrosion

Galvanic corrosion tests were performed by the University of Tulsa using composite panels joined in conjunction with dissimilar metals. The test results showed no corrosion attributed to galvanic corrosion.

## Creep Testing

Preliminary coupon-level, room-temperature creep testing was performed by the University of Tulsa on carbon-fiber-reinforced/epoxy-matrix composite specimens using an in-situ creep-rupture fixture developed by the University of Tulsa. The first test, performed at 65% ultimate tensile strength (UTS), showed little creep and did not result in failure during 1000 hours of testing. The second test was done at 77% UTS, and the results were virtually identical for the 1350-hour test period. This creep testing supports the fact that carbon-fiber composites are resistant to creep and creep rupture under ambient conditions. The level of creep in the tests was small enough to extrapolate that the material would not fail at either the 65% or 77% UTS load during a reasonable lifetime.

## Thermal Expansion Testing

Testing of the linear coefficient of thermal expansion of a carbon-fiber-reinforced/epoxy-matrix composite specimen was performed by the University of Tulsa using a strain-gage measurement method. The specimen tested was of plain-weave architecture. The results of the testing show coefficient of thermal expansion (CTE) values ranging from 3.47 ppm/°C to 18.09 ppm/°C for temperatures well below the glass-transition temperature, T<sub>g</sub>, of the material.