

Crush Test for 950.0 kcmil ACCS/TW/C7™ Overhead Conductor

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Crush Test for 995.0 kcmil ACCS/TW/C7 Overhead Conductor

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1.0 BACKGROUND

CIGRE Technical Bulletin 426 describes a test to evaluate the crush resistance of composite-core conductors. A crush test was performed to evaluate the crush resistance of 995.0 kcmil Aluminum Conductor Composite Supported (ACCS) conductor provided by the Lower Colorado River Authority (LCRA).

A test was designed to identify the damage threshold for the conductor. Crush loads of 75 lb/in, 100 lb/in, 125 lb/in, and 150 lb/in were applied to samples cut from the shipping reel. The test matrix provided for three (3) replicates at each crush load. One (1) identical fourth (4th) sample was cut for reference (no crush load) values.

The compressive force was applied by a four (4) inch long compression platen. For the crush loads listed above, the total force was 300 lb, 400 lb, 500 lb, and 600 lb, respectively, applied to a four-inch length of the conductor.

Crush load damage was assessed by a post-test dissection of each sample. Tensile testing proved impractical because the relatively soft thermoplastic composite was damaged under the grips. After consultation with Idaho National Labs (INL) technical staff, a bending test was developed to evaluate the compressive failure strength of the core strands. (Composites in bending fail by compression on the inner side of the bend).

A total of 12 conductor samples were subjected to crush testing: 4 crush load levels with 3 replicates per load level. A thirteenth (13th) identical sample was cut for reference values and was not subjected to crush testing.

2.0 SAMPLES

Thirteen (13) samples each three (3) feet long were harvested from a reel of 995 kcmil ACCS/TW/C7 conductor from Lower Colorado River Authority (LCRA). This conductor's construction is 1350-O-temper aluminum trapezoidal-wire outer strands over a 7-strand C⁷ core. The conductor's nominal outer diameter is 1.108 inch.

3.0 EQUIPMENT

Tinius Olsen Universal Testing Machine (UTM), Calibration Control # 0013

4.0 CRUSH TEST

Thirteen (13) samples, each 3 ft (1 m) long, were cut from the shipping reels. Each sample was labeled with a unique identifier to track the sample through each test, and to track the test data through to the final report. The crush test was in accordance with Cigre Technical Bulletin 426 and IEC 60794-1-2:

1. The sample was placed in the test machine, and centered under a hardened-steel compression platen designed to load the sample along a defined 4 in (101.6 mm) middle section. The load was increased to the target level, and held for ten (10) minutes.
2. A total of 12 samples were subject to crush loads. An additional sample was cut for reference (no crush load) values.
3. Once all of the samples had completed the crush test, each sample was visually examined for external damage, and then dissected to the level of individual strands. Each core strand was evaluated for indents, cracks, delamination, or other signs of damage caused by the crush test.
4. From each of the 13 samples (12 from crush testing plus one reference sample), the center strand and three (3) strands from the outer layer were tested to determine the residual strength. A bending radius test was used for the strength measurement after excessive difficulties with gripping for a tensile test.

Figure 1 shows the crush test apparatus with a sample under test.



Figure 1: Conductor Crush Test Apparatus

Figure 2 shows example data for each of the crush loads. There is a relatively “soft” response as the strands settle, followed by a linear elastic region after the load exceeds 100 lb.

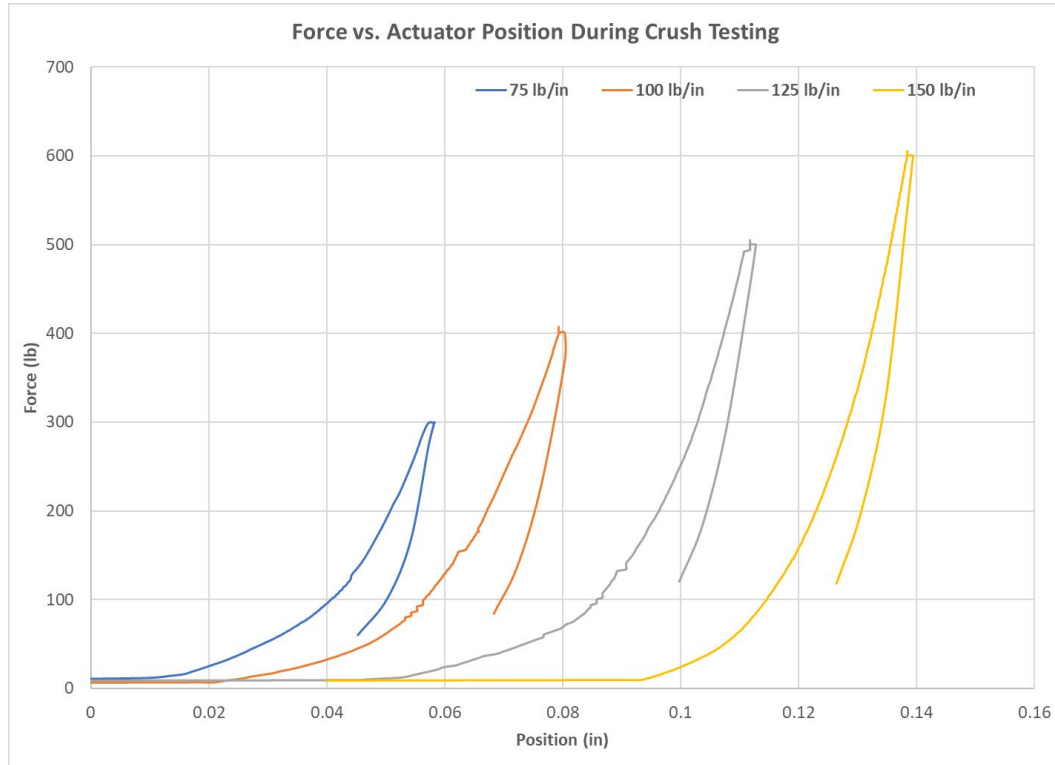


Figure 2: Data Recorded During Crush Testing

5.0 DISSECTION AND EVALUATION

Each crush-test sample and the reference sample were visually examined before dissection down to the individual strands. Figure 3 shows the samples before dissection in order of increasing test load with the reference sample on the left, and the 150 lb/in sample on the right.

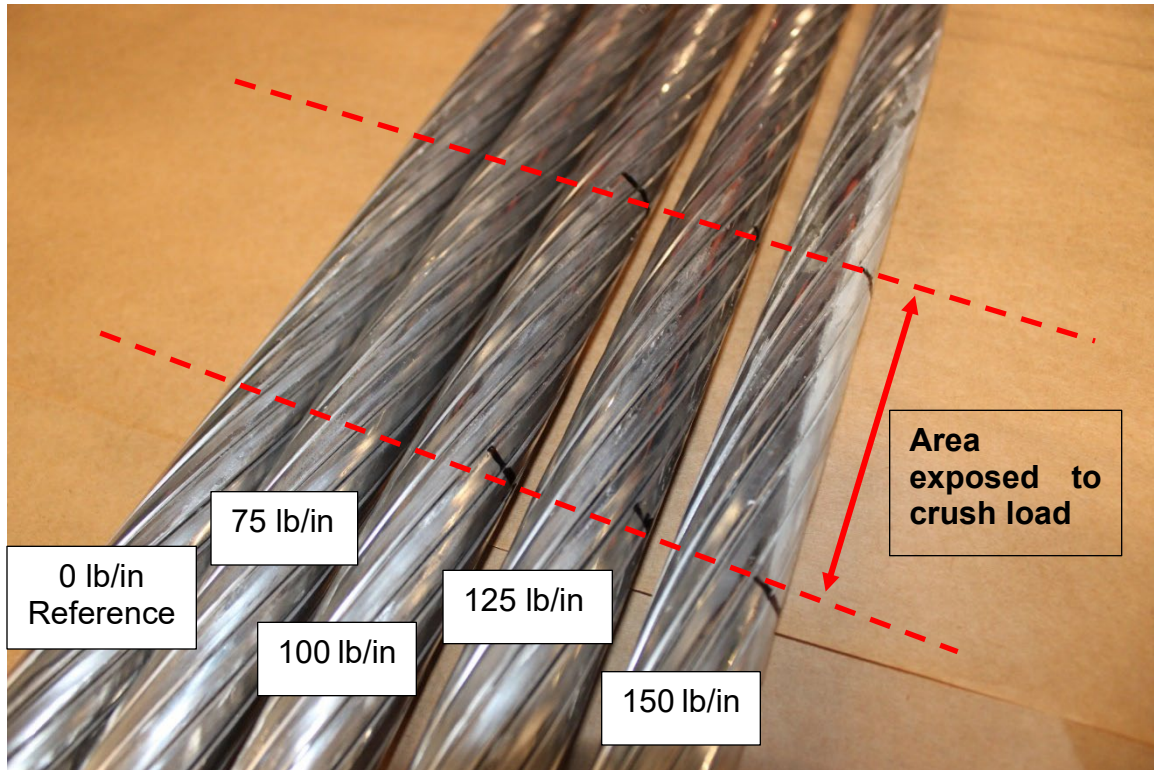


Figure 3: Conductors Following Crush Test

Figure 4 through Figure 7 show damage to the outer surface of the conductors, which was limited to minor abrasions and compression yielding of the outer strands.



Figure 4: Abrasions from the 75 lb/in Crush Load



Figure 5: Abrasions from the 100 lb/in Crush Load



Figure 6: Abrasions from the 125 lb/in Crush Load



Figure 7: Imprints from the 150 lb/in Crush Load

Hidden damage from manufacturing or construction is a significant concern to electric utilities. To evaluate this risk, the samples were dissected and visually examined for damage. The 7-strand C7 core is wrapped with a tape to maintain geometry during manufacturing. The tape left a residue that needed to be removed for a surface inspection. Close inspection of the cleaned strands revealed only minor damage that could be attributed to the crush loads. Figure 8 shows the most severe damage found. Damage is limited to scuffing of the outer protective layer by sliding of an aluminum strand. By far the largest visual indications are associated with the resin in a molten state during manufacturing. Figure 9 shows a gouge visible on all samples, including the reference sample that was not subjected to crush loads. The gouge is caused by an amber (solidified material) caught in the sizing die. The amber does not appear to have damaged the underlying carbon fibers. Abrasions visible in Figure 8 are probably caused by sliding of an aluminum strand during the crush test. The absence of any significant imprints even at the maximum crush load shows that fully-annealed aluminum is softer than the composite strand.

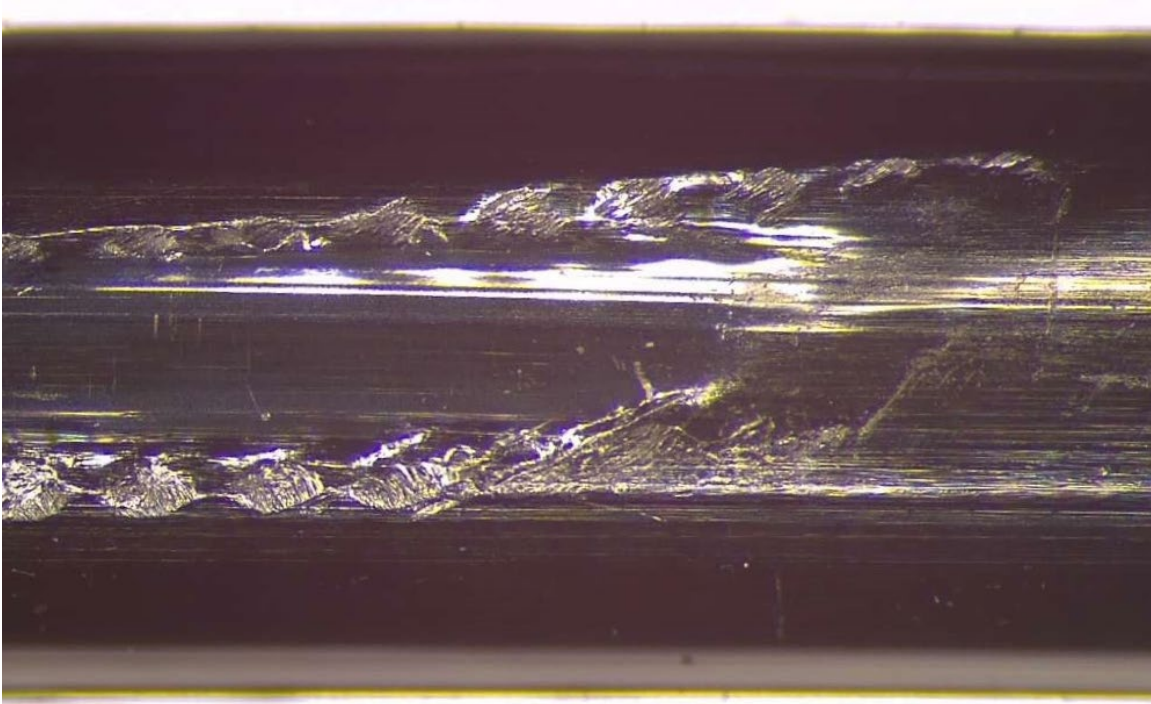


Figure 8: Helix Strand from Sample 100-3 (100 lb/in Crush Load)

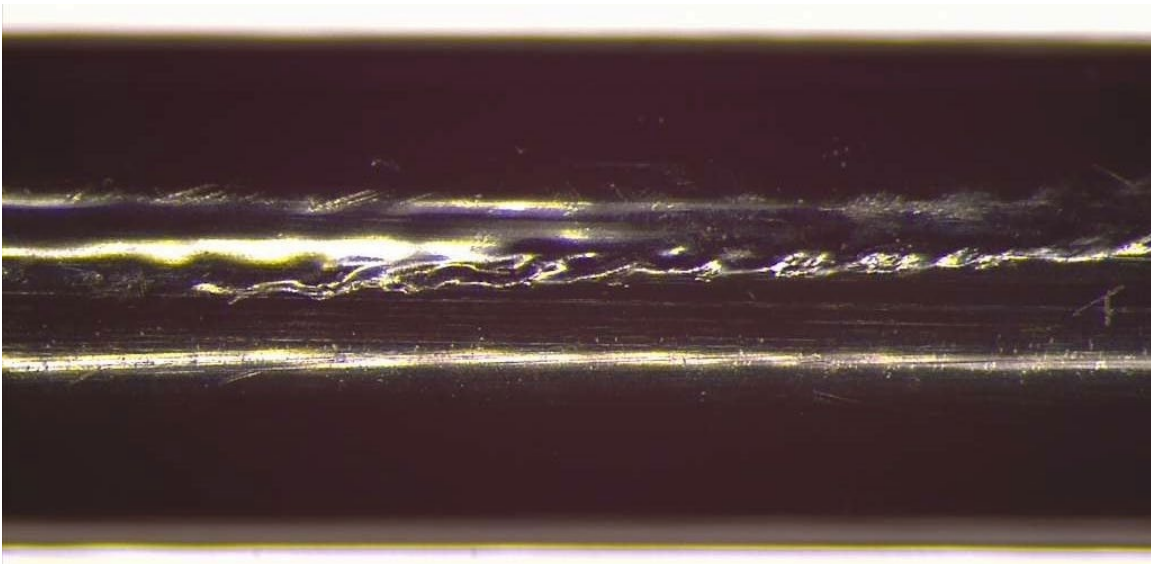


Figure 9: Manufacturing Damage from an Amber in the Sizing Die (All Strands)

6.0 RESIDUAL STRENGTH TESTS:

Following the visual inspection, residual strength was to be determined by a tensile test. However, the C7 matrix proved too soft for vee-wedge grips typically used to test round samples. INL staff agreed to use a radius bend test to evaluate residual compression strength.

Four (4) C7 strands from each sample, including the reference (not crushed) sample were tested to determine the strength loss caused by the crush load. A template with circles was drafted to provide a reference for the bending radius. A video of each bending test was taken to capture the moment of rupture. Freeze-frame editing software was used to capture the final frame before the strand ruptured. The image was then used to determine the minimum bending radius (maximum fiber stress) before rupture. This method proved quite robust as the bent shape was circular, and the number of pixels in the diameter of the fixed 8-in circle was used to determine the radius of curvature of the C7 strand.

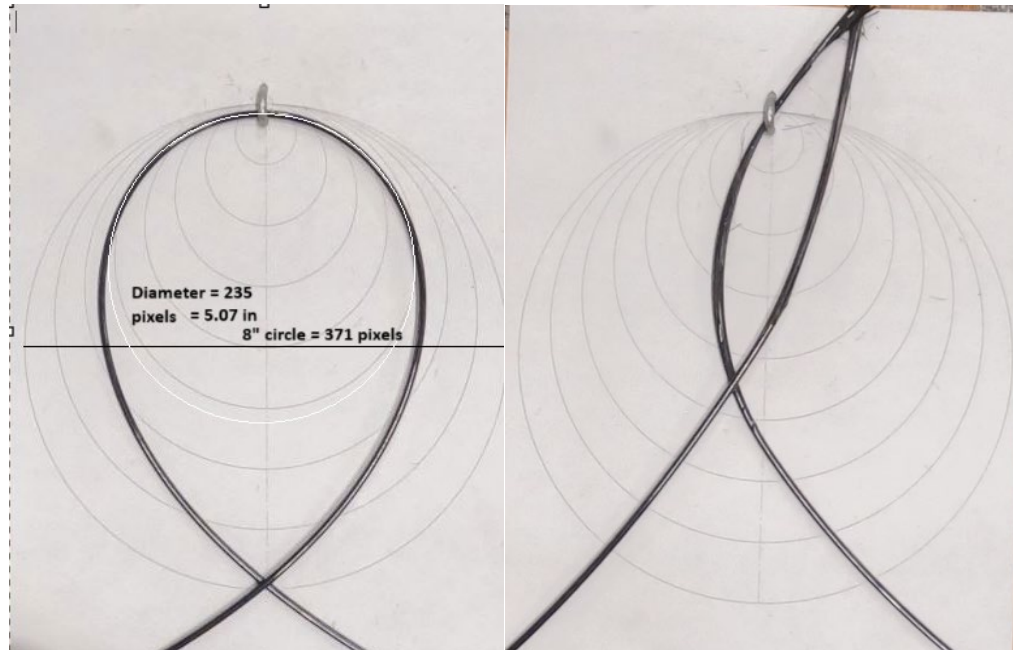


Figure 10: Image at Rupture (Left) and Immediately After (Right)

The white circle visible in the right image of Figure 10 was drawn using graphics software. The straight black line represents the diameter of the 8-in circle. Based on the pixel resolution, the resolution of the bending radius measurement is 0.02 in (0.4% of the 5-inch measured circle).

An elegant beam formula is available to compute the maximum fiber stress based on the bending radius, elastic modulus and the distance of the fiber from the neutral axis:

$$\sigma = Ey/R$$

Where σ : stress (psi)

E : elastic modulus (psi)

y: distance from the neutral axis of bending (in)

R: radius of curvature (in)

7.0 ANALYSIS

The fiber stress at rupture data was analyzed using Minitab® statistical analysis software. Basic statistics for the fiber stress at rupture are:

Results for Crush Load (lb/in) = 0

Statistics

Variable	Location	N	N*	Mean	SE Mean	StDev	Minimum	Q1	Median	Q3
Fiber Stress (psi)	Center	1	0	277879		*	277879	*	277879	*
	Helix	3	0	222199	51760	89651	125439	125439	238711	302445

Variable	Location	Maximum
Fiber Stress (psi)	Center	277879
	Helix	302445

Results for Crush Load (lb/in) = 75

Statistics

Variable	Location	N	N*	Mean	SE Mean	StDev	Minimum	Q1	Median	Q3
Fiber Stress (psi)	Center	3	0	277116	5682	9841	265839	265839	281545	283964
	Helix	9	0	212742	19170	57509	126206	162234	219200	258303

Variable	Location	Maximum
Fiber Stress (psi)	Center	283964
	Helix	291873

Results for Crush Load (lb/in) = 100

Statistics

Variable	Location	N	N*	Mean	SE Mean	StDev	Minimum	Q1	Median	Q3
Fiber Stress (psi)	Center	3	0	231069	11075	19183	209073	209073	239806	244328
	Helix	9	0	235689	16442	49326	142898	201492	238711	280110

Variable	Location	Maximum
Fiber Stress (psi)	Center	244328
	Helix	287114

Results for Crush Load (lb/in) = 125

Statistics

Variable	Location	N	N*	Mean	SE Mean	StDev	Minimum	Q1	Median	Q3
Fiber Stress (psi)	Center	3	0	234125	34885	60422	164390	164390	267099	270886
	Helix	9	0	240128	13533	40600	188799	206437	239630	273442

Variable	Location	Maximum
Fiber Stress (psi)	Center	270886
	Helix	303920

Results for Crush Load (lb/in) = 150

Statistics

Variable	Location	N	N*	Mean	SE Mean	StDev	Minimum	Q1	Median	Q3
Fiber Stress (psi)	Center	3	0	226447	21140	36616	193647	193647	219741	265952
	Helix	9	0	222827	25593	76778	125360	143838	265122	293101

Variable	Location	Maximum
Fiber Stress (psi)	Center	265952
	Helix	306767

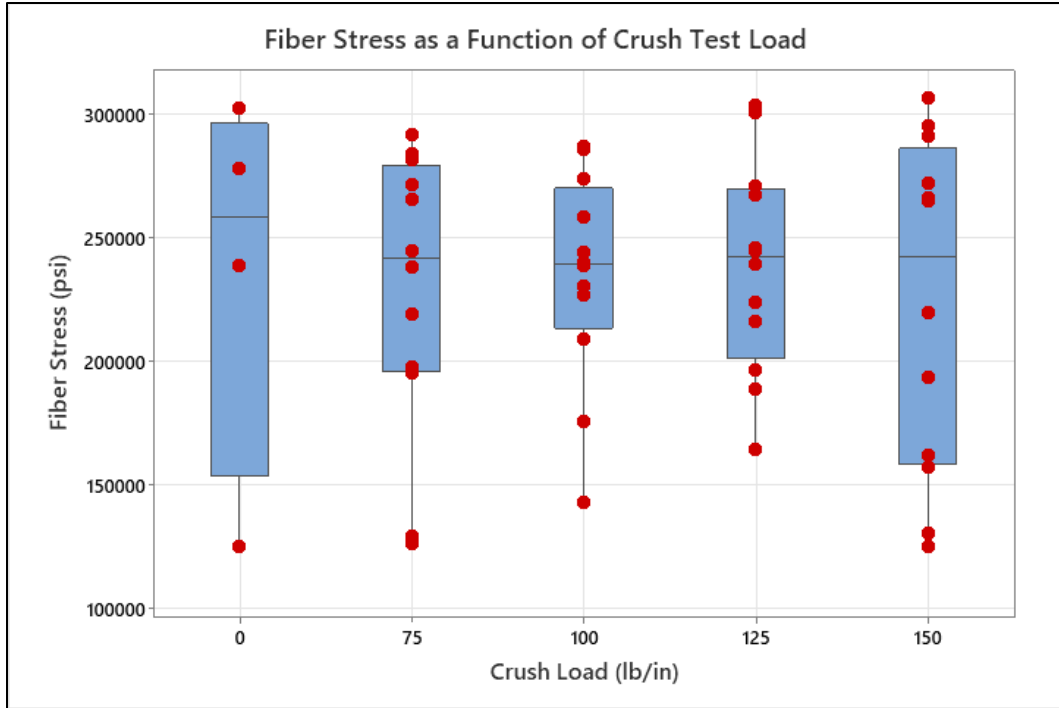


Figure 11: Residual Strength Data vs. Crush Load

Figure 11 suggests that the crush load does not have a significant effect on the mean fiber stress at rupture. Figure 12 shows that the mean fiber stress is not affected by whether the strand was at the center or in the helix.

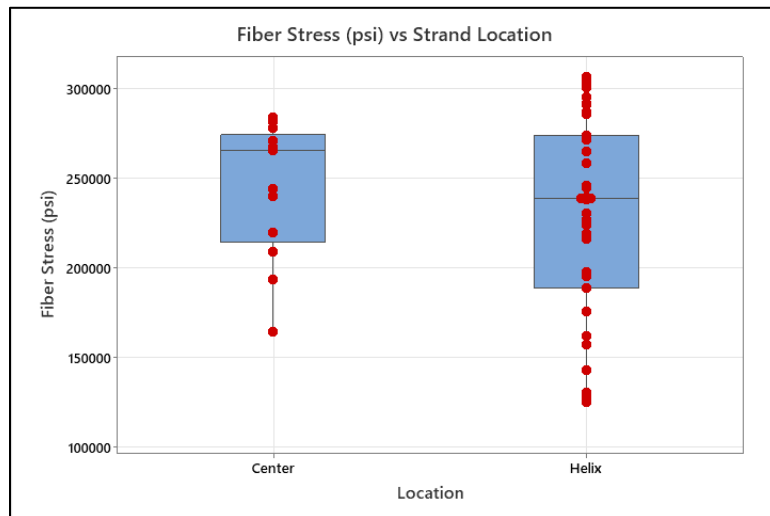
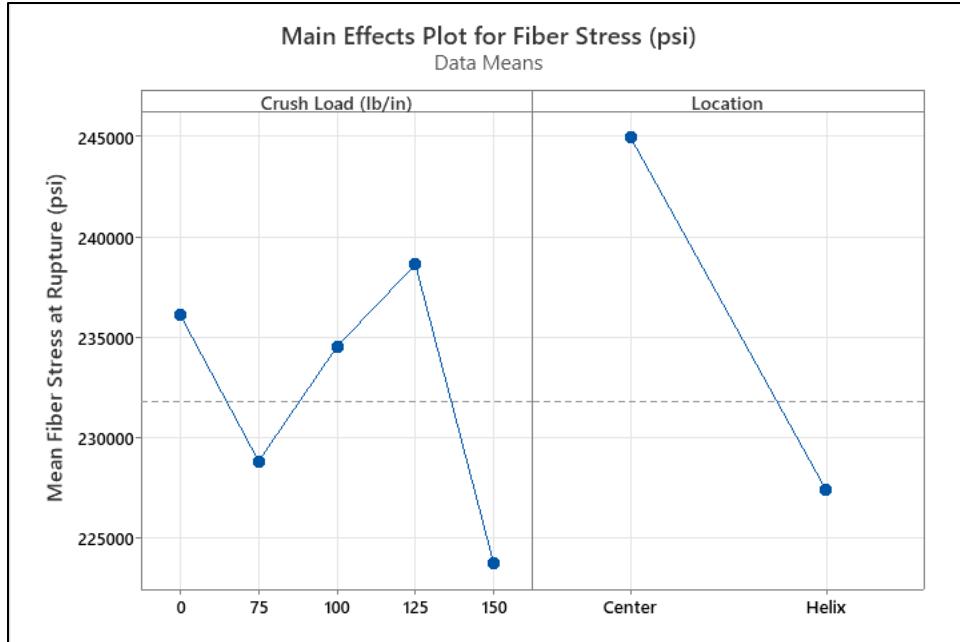


Figure 12: Residual Strength Data by Strand Location



An ANOVA was also performed, and resulted in the same conclusions as the interval plots with a p-value for location of 0.33 and a p-value for crush load of 0.97. Additional data would allow one to detect smaller differences between means; however, it is important to ask if statistical significance has practical significance. Figure 13 plots the 95% Confidence Interval (CI) for the mean breaking strength of both factors.

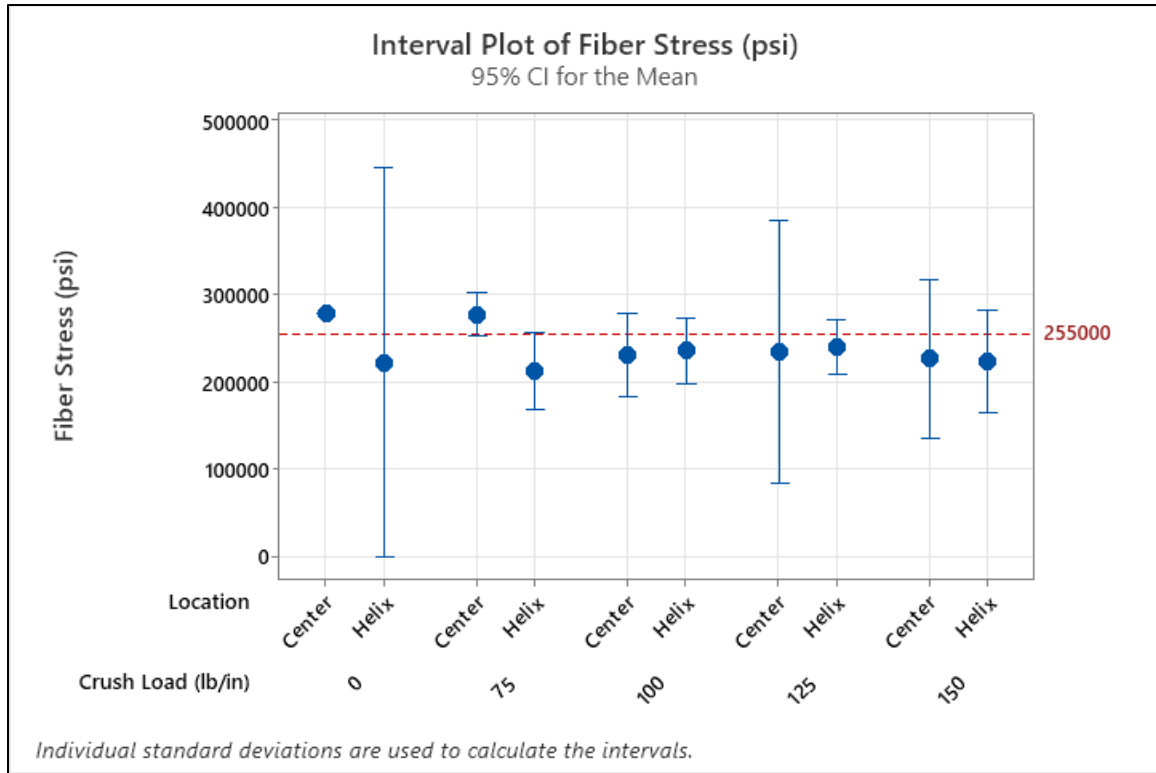


Figure 13: 95% Confidence Intervals for Fiber Stress Effect of Location and Crush Load

Note the center strand of the reference (no crush test) sample is a single point and therefore has no confidence interval.

8.0 CONCLUSIONS

A conductor crush test in accordance with CIGRE Technical Bulletin 426 did not produce any statistically significant change in the strength of the composite core strands. Additionally, there was no statistically significant difference in breaking strength between the central core strand and the outer (helix) strands.

An overall conclusion is that crush damage to the composite core strands is easily detected by observing for damage to the outer aluminum layer. Incidents that do not seriously damage the aluminum outer strands are unlikely to result in hidden damage in the core strands. Manufacturer-provided installation instructions include an instruction to inspect for outer-layer damage, and remove any conductor sections that exhibit kinking or strand deformations.