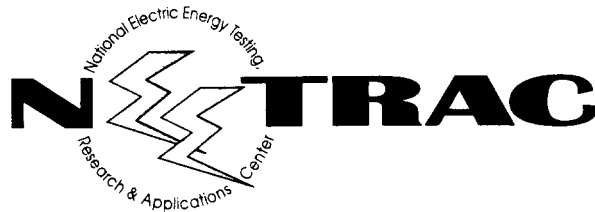


**Impact, Torsion, and Crush Tests for
477 kcmil and 795 kcmil 3M Brand Composite
Conductor**

**3M Company
Purchase Order 0000620410**

NEETRAC Project Number: 02-229

October, 2002



*A Center of
The Georgia Institute of Technology*

Requested by: Mr. Colin McCullough
3M

Principal Investigator: Paul Springer III, P.E.

Reviewed by: _____

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Summary:

3M contracted with NEETRAC for impact, torsion, and crush testing to evaluate the characteristics of conductors with metal matrix composite (MMC) reinforcement. The tests were conducted on 477 kcmil and 795 kcmil conductor samples provided by 3M. The conductors performed well. For the impact tests, both samples exceeding their rated strength. Torsion testing demonstrated that outer aluminum layer strand failures occur well before any core strand failures. The crush test samples suffered no damage detectable by visual inspection. Evaluation of the crush test samples at 3M showed no significant damage to the MMC core or other internal components.

Samples:

- 1) Twenty (20) meters of 477 kcmil, type 16, 3M Brand Composite conductor, from reel received on 8/16/2002.
- 2) Twenty (20) meters of 795 kcmil, type 16, 3M Brand Composite conductor, from reel received on 6/3/2002.
- 3) Preformed Line Products (PLP) formed wire dead end for 477 kcmil ACCR
- 4) Preformed Line Products (PLP) formed wire dead end for 795 kcmil ACCR

References:

- 1) "Proprietary Information Agreement" Dated 3/27/01
- 2) 3M Purchase Order 0000620410.
- 3) IEEE 1138 (testing requirements for optical ground wires).
- 4) PRJ 02-229, NEETRAC Project Plan

Equipment Used:

- 1) MTS Servo-hydraulic tensile machine, Control # CQ 0195.
- 2) National Instruments AT-MIO-16XE-50 computer interface.
- 3) NEETRAC 17,000 ft-lb impact test machine, Control # CN 3054.
- 4) Fluke Model 97 ScopeMeter, Control # CR0033 (impact recordings).
- 5) Fluke Model 99 ScopeMeter, Control # CN3050 (impact recordings).
- 6) Tinius Olsen Universal Testing Machine, Control # CQ0013 (crush tests).

Procedure:

1) Crush Tests:

The crush test is designed to simulate damage to a cable during shipping and installation. A line truck running over the conductor applies loads similar to the crush test load stipulated in IEEE 1138 (optical cable testing). A value of 126 lb/linear inch was used for testing. A 6-inch diameter hardened steel platen was used to support the center section of a 2-ft long sample. A second hardened platen was used to apply the crush load. Load was increased at a rate of 600 lb/min. Load was held at 756 lbs (126 lb/inch) for one minute, and then released. Following the test, there were surface marks where the platens applied pressure, but no detectable deformation or other damage to the sample.

Following the crush tests, the conductor samples were returned to 3M for dissection and evaluation of the condition of the core strands. 3M's Colin McCullough reported that the tensile test evaluation showed full strength retention of the strands. Figure 1 shows load versus anvil displacement for the crush tests.

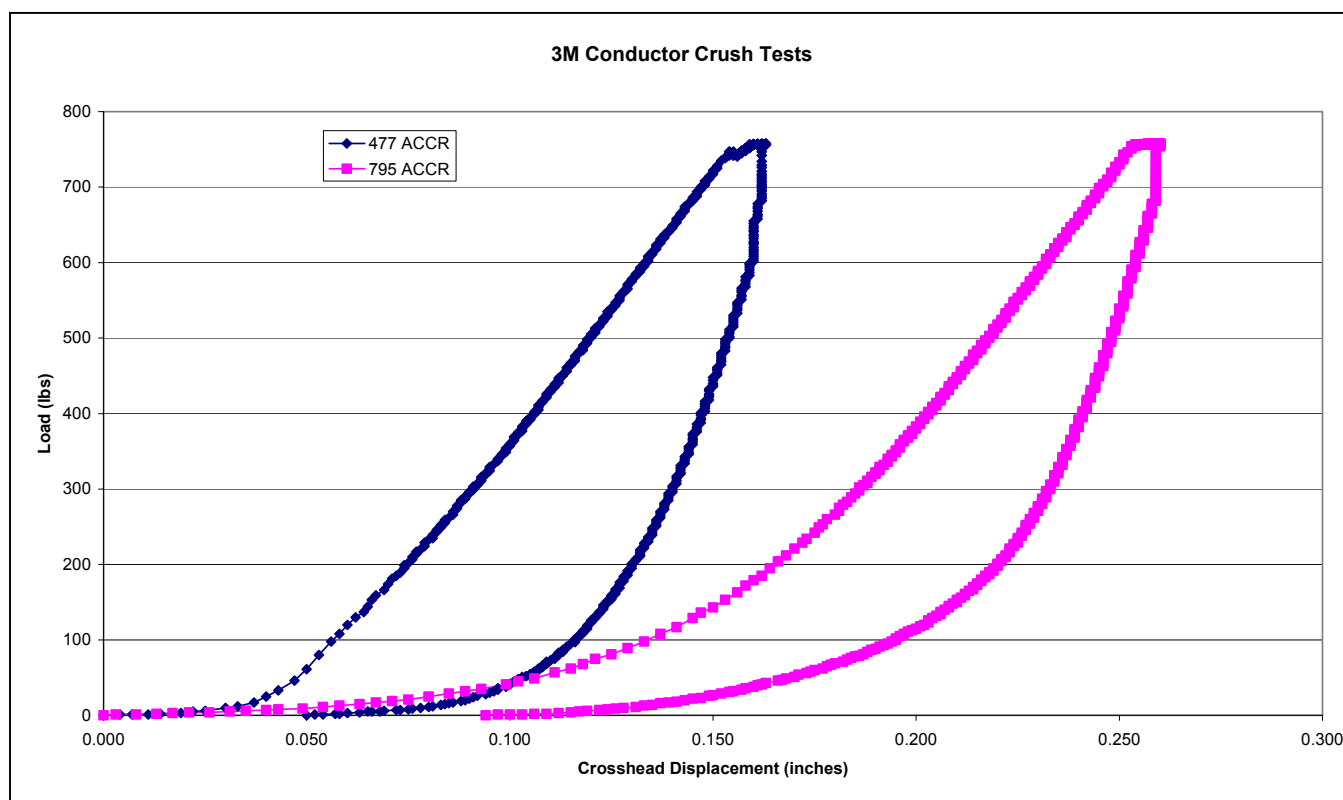


Figure 1, Load versus force for MMC conductor crush tests

2) Torsional Ductility Tests:

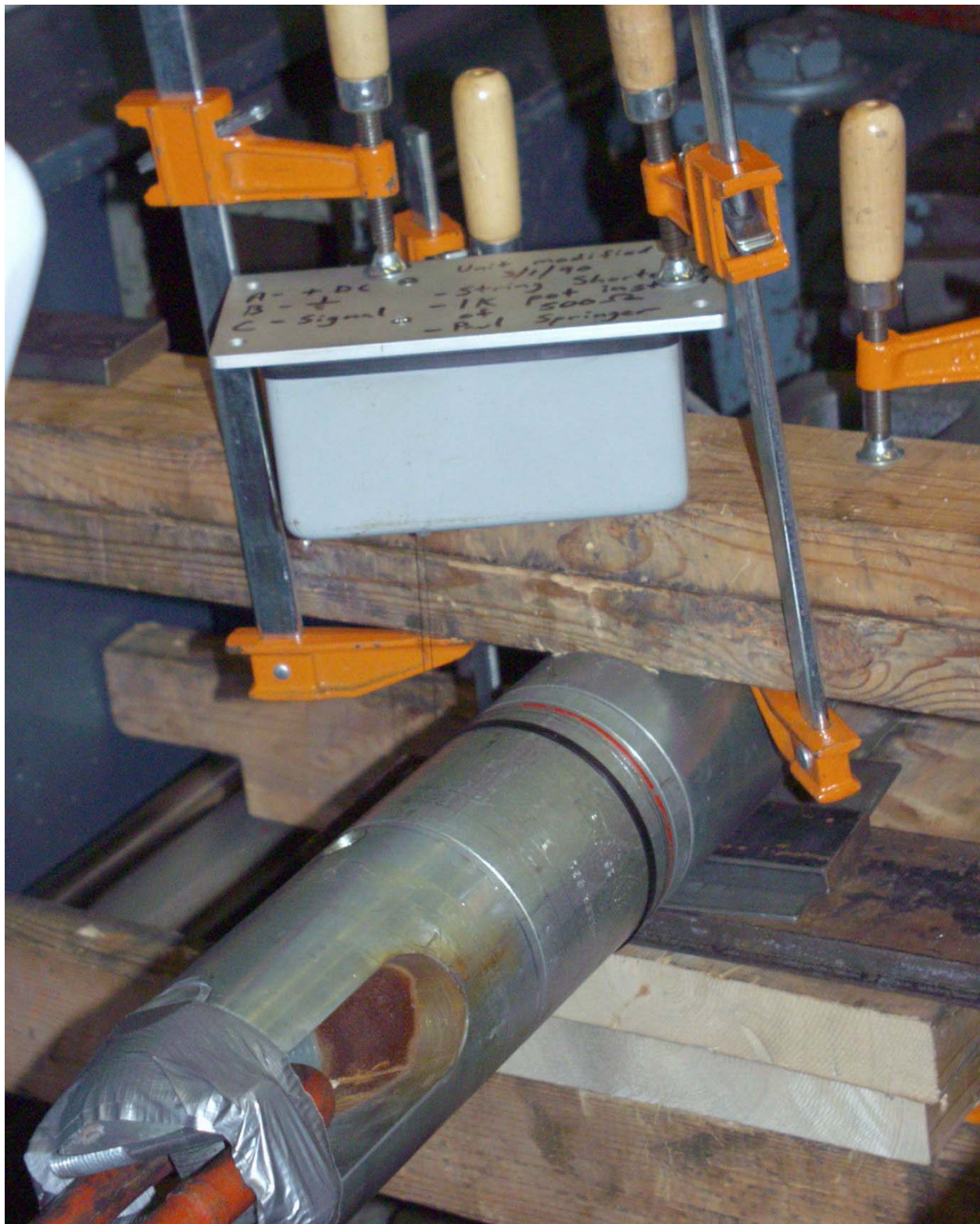
The torsional ductility test was designed to evaluate how well the MMC-reinforced conductor would tolerate twisting loads that occur during installation and, to some degree, in service. One sample of each conductor size was terminated with cast-resin end fittings. The fittings are specially

designed to preserve the “as manufactured” position of the conductor layers. This permits a relatively short laboratory sample to behave in a manner similar to the free conductor in a long field span.

The conductor samples were installed in the MTS tensile machine. One end was fitted directly to the load actuator. The opposite end was connected to a steel link, which was connected to a heavy-duty swivel bearing, which was then pinned to the tensile machine’s fixed crosshead. The arrangement permitted the application of tensile load combined with rotation of one end of the sample. Photograph 1 shows the method used to rotate the sample, and measure torque. Photograph 2 shows the instrument used to measure rotation angle. Photograph 3 shows the sample end opposite the rotation bearing. Wood cribbing was used to prevent rotation at that end. Sample tension was maintained by automatic controls at 25% of the conductor RBS.



Photograph 1, sample rotation and torque measurement (note second pipe wrench)



Photograph 2, rotation angle measured using string potentiometer on rotation bearing



Photograph 3, cribbing used to prevent sample rotation

477 ACCR:

The plan was to determine turns to first break by rotating the swivel bearing +180 degrees (direction that tightens outer aluminum strands), and then 180 degrees in the opposite direction. Automatic data acquisition was used to record tension and rotation angle. Torque required to rotate the conductor was measured manually every 15 degrees by applying a hand-held force gage to the end

of a pipe wrench used to rotate the sample. The pipe wrench was applied to a steel link, and did not contact the sample. The twist angle was increased in 180 degree steps, with the expectation that the conductor would fail within two or three turns. The exposed conductor measured 195.5 inches.

The conductor exceeded expectations by turning past 11 full rotations (3976 degrees), before an outer-layer aluminum strand broke. The rotation counter range was +/- 4 turns (+/- 1440 degrees). The instrument had to be removed and the zero point reset each time the limit was exceeded. The action of rotating the conductor proved to be quite strenuous for the pipe wrench operator. After the first aluminum strand broke, a request was made and granted to revise the procedure to permit removal of the outer aluminum strands to make it easier to continue rotating the sample to core failure. This was done. With the outer layer removed, the inner aluminum layer was extremely slack due to rotation opposite its lay direction. Therefore, all tensile load was on the core. Rotation continued in the positive direction (tighten the core outer layer). An additional five (5) turns were accomplished before the first core strand broke. Sixteen (16) turns from the neutral position were required to fail the core. The test demonstrated that the outer aluminum layer will fail before the MMC core in the event the conductor is twisted. The core fails at twist of one (1) rotation per foot. The outer aluminum layer fails at 0.68 rotations per foot. We were not able to cause the inner aluminum layer to fail. Figure 2 shows the torque, tension, and rotation angle during the 477 ACCR torsional ductility test.

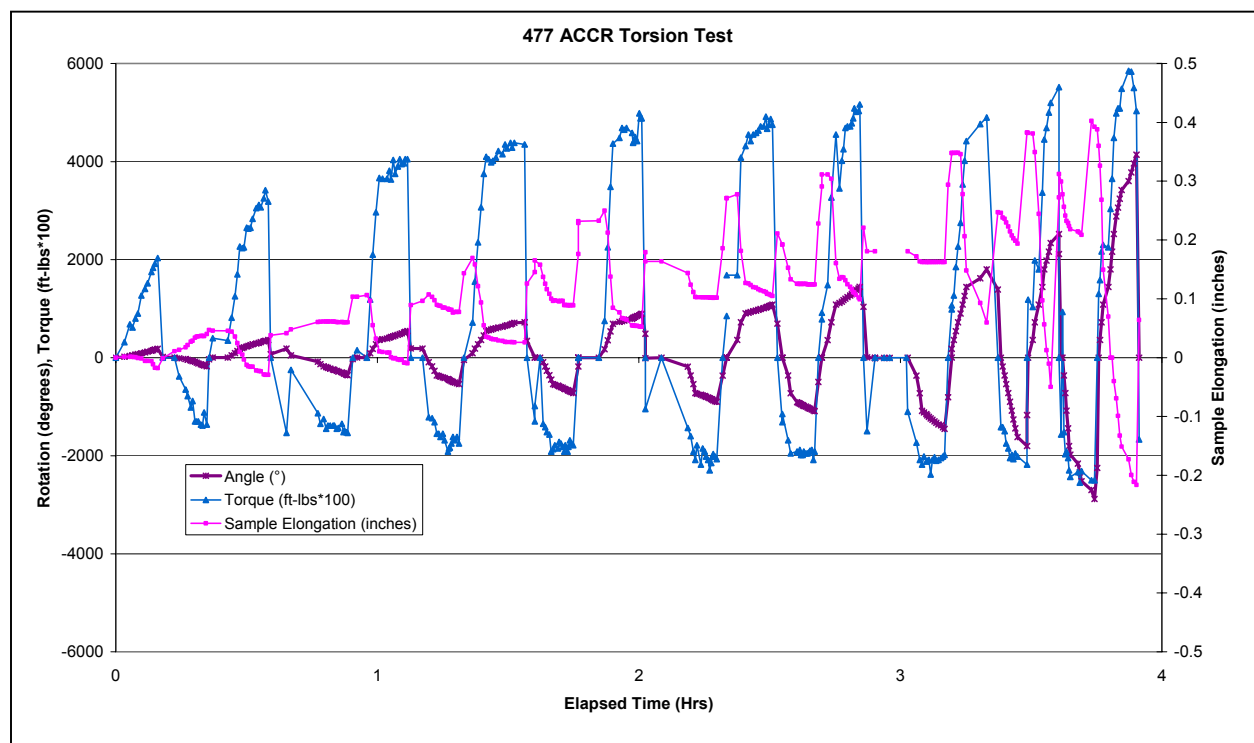
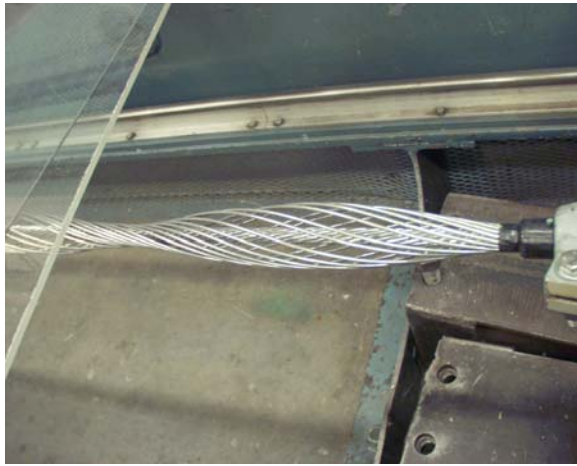
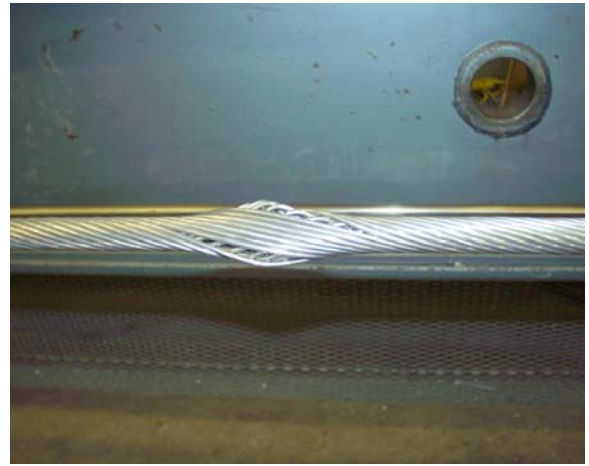


Figure 2, Composite of manual and automatically recorded data during 477 ACCR torsion test

Photographs 4, and 5 document the condition of the conductor prior to any strand breaks. There was significant birdcaging before any strand breaks occurred.



Photograph 4, outer layer birdcaging



Photograph 5, inner layer birdcage

795 ACCR:

Based on experience with the 477 test, it was recognized that the procedure developed for the torsional ductility evaluation would not work for the larger 795 conductor. Manual rotation of the swivel bearing using a pipe wrench was too strenuous. The following plan was implemented:

- 1) Sample preparation and tensile machine configuration are identical to the 477 test
- 2) Tension remains at 25% RBS ($31,134 * 0.25 = 7784$ lbs)
- 3) Record tension, torque and rotation as before, but omit the electronic rotation counter (its range was insufficient for the “as-found” turns to failure)
- 4) Rotate only in the positive direction (tighten the outer aluminum layer, and the outer core layer).
- 5) Twist the conductor until the first strand break is detected. Assuming the break is in the aluminum layer, cut the remaining aluminum strands, and continue twist until the next strand break is detected. The method will show the failure progression in the event of a torsional overload.

The conductor behaved as expected. It was difficult to turn with the two 24” pipe wrenches. At 1440 degrees (4.0 turns), the torque measured 123 ft-lbs (167 Nt-meters). Handle force on the pipe wrenches was 75 lbs, and we were developing gripping problems as the jaws chewed up the steel link. A decision was made to remove the outer aluminum layer at 4 turns to facilitate completing the torsion test on the core. The twist angle was held while all strands in the outer layer were cut using a tubing cutter. The outer aluminum layer pulled back 1.0 inches. The inner aluminum strands were birdcaged, so all tensile load was on the core. The first break in a core strand occurred at 2925 degrees (8.125 rotations). This establishes the torsion limit for the conductor at greater than 88 degrees/ft (0.24 rotations per foot). The limit for core damage is 180 degrees/ft (1/2 rotation per foot). Figure 3 shows the data recorded during the test:

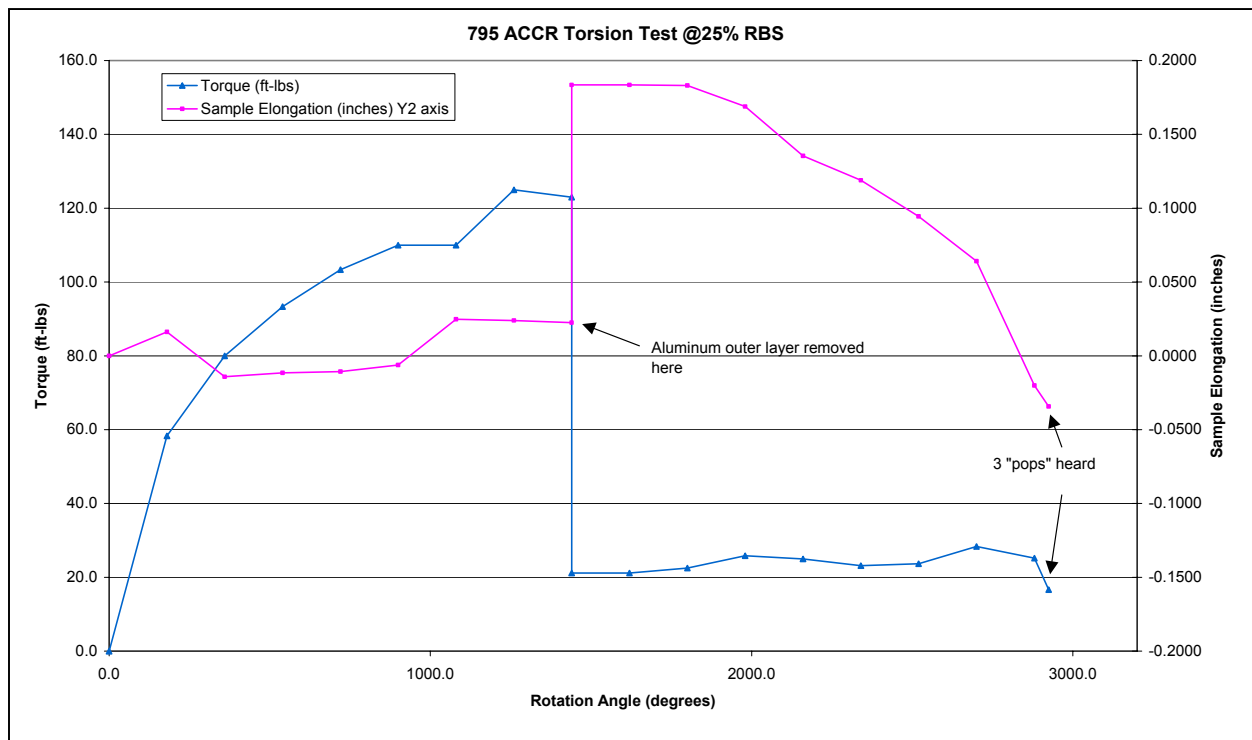


Figure 3, Composite of manual and automatically recorded data during 795 ACCR torsion test

Tests on the 477 and 795 ACCR conductors establish that torsion loading will not cause problems more severe than with aluminum and ACSR conductors. Torque required to reach the torsion limit is larger than can be applied by any realistic field or construction load.

3) Impact Tests:

Impact testing was performed on the PLP formed wire dead end to address two concerns:

- 1) Ability of the formed wire dead end to maintain its grip during shock loads, and;
- 2) Strain rate sensitivity of any component of the ACCR conductor.

An impact test is performed in the same manner as a standard tensile test, except that load is applied by dropping a 1,300 lb weight from an elevation of 12 feet above the sample. The sample is placed in a vertical configuration, and the impact is in the axial (downward) direction. Impact velocity is 24 ft/sec. The sample is pre-tensioned to 400 lbs. The shock load is comparable to loading rate experienced during ice jumps, galloping events, and impact from storm-blown objects.

The sample is pulled to nominal tension using fabric straps fitted to a steel bar through the eye at the end of the formed wire grip. See Photograph 6, which shows the sample with the 1,300-lb drop weight ready to drop. A latch releases to put the weight in guided free fall. Rollers on the drop weight ensure that anvils contact the steel bar and load the sample in tension. The top of the sample is fitted to an impact-rated load cell, which is conditioned by a high-speed amplifier. The output of the load cell is recorded and stored using two Fluke ScopeMeters. One meter is set to record 50,000 samples per second, and will capture the fast transient if the sample ruptures at impact. The second meter is set to capture 5,000 samples per second. That instrument captures data in the event of a long transient due to slipping of the connector. Figure 4 shows the impact load versus time for the 477 sample. Figure 5 shows an estimate of load versus displacement for the 477 ACCR test. Displacement is estimated by making the assumption that drop weight velocity is constant during the impact event. This assumption is valid in

cases where the sample ruptures without slowing the crosshead significantly. The video tape of the 477 test shows no detectable slowing. The 795 ACCR test almost stopped the crosshead, and therefore the force versus displacement is not plotted. Force versus displacement data permits an estimate of energy absorbed to failure.

For the 477 ACCR impact test, energy is calculated from the test data. For the 795 ACCR sample, total energy was absorbed. The sample therefore absorbed more than 15,000 ft-lbs of energy before separating.



Photograph 6, Impact test machine

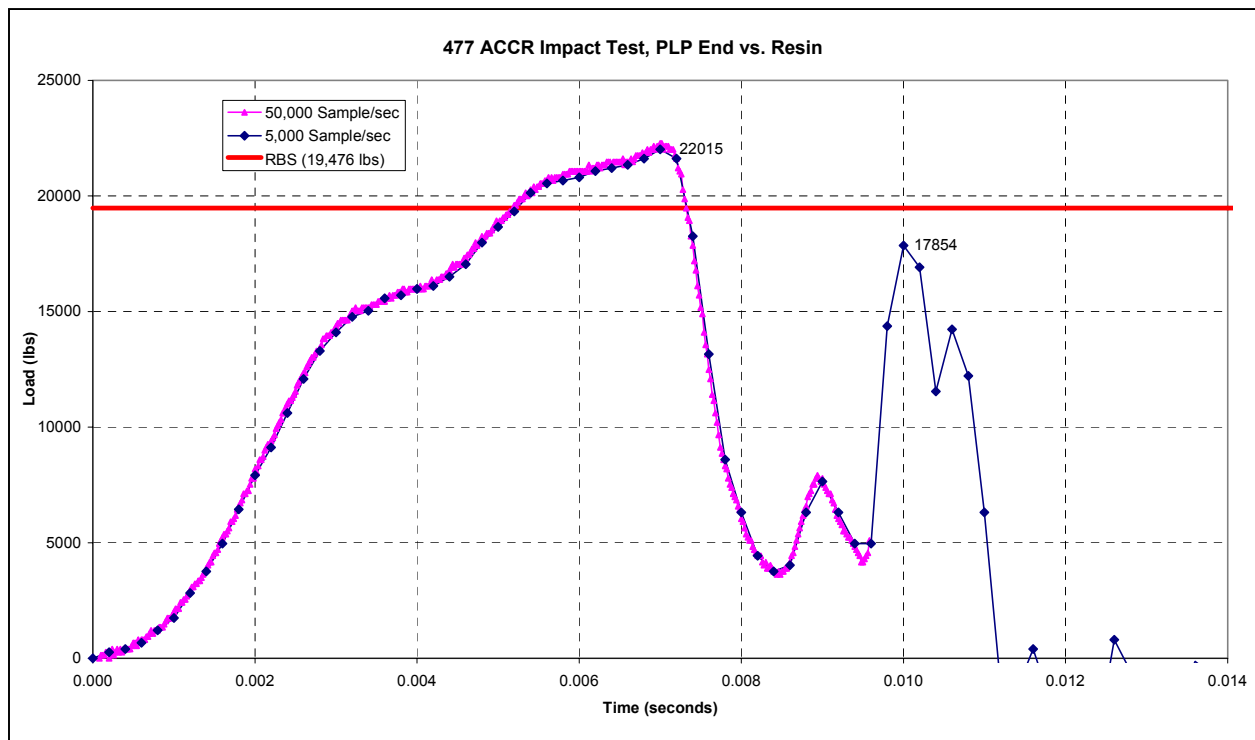


Figure 4, load versus time data for 477 ACCR impact test

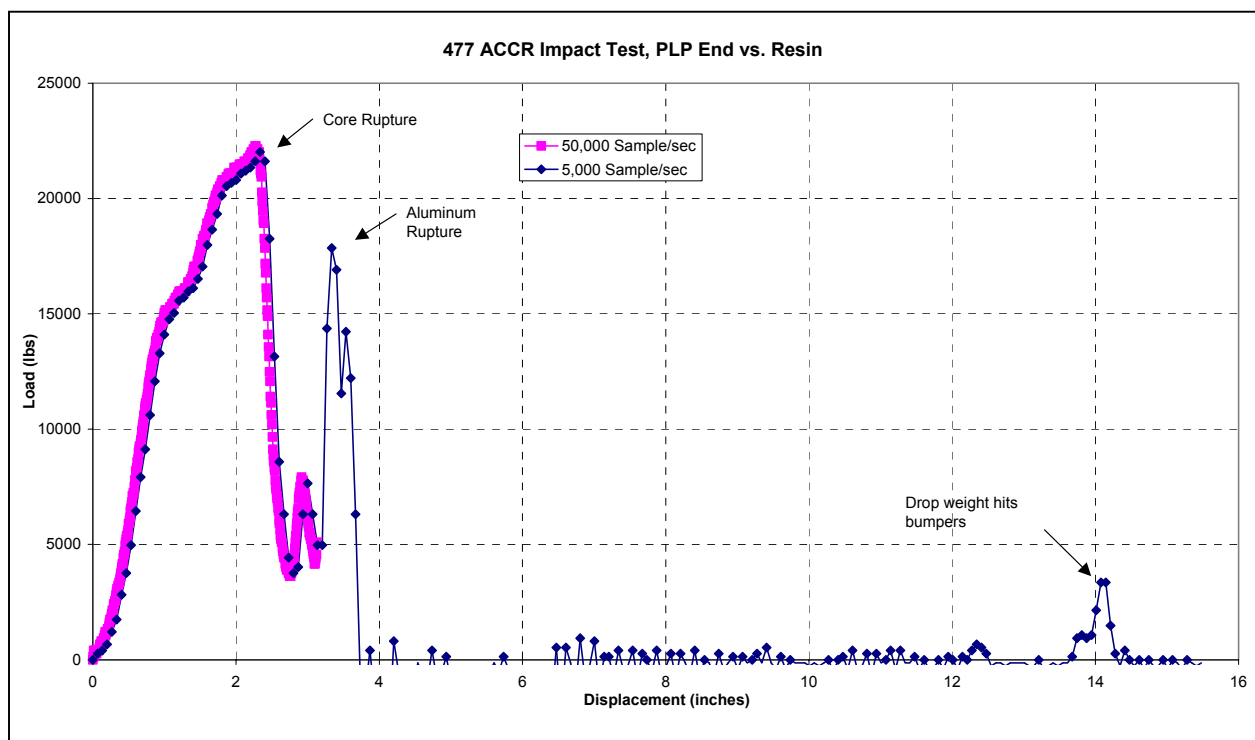


Figure 5, data from Figure 4 formatted or load versus estimated displacement, with range extended to show impact of drop weight on bumpers

Figure 5 permits an estimate of energy absorbed to rupture the 477 sample. The high-speed record missed the second peak, which is believed to be the rupture of the aluminum layers. The first peak is likely the load at first break, which is assumed to be the core strand rupture. Energy absorbed during the

high-speed record is 3185 ft-lbs. Energy absorbed based on the slow speed record is 3695 ft lbs. The reason for the larger value in the longer record is that the aluminum rupture is captured in the longer record. Peak load for the 477 ACCR sample is 22,015 lbs (113% RBS).

The x-axis on Figure 5 is extended to show the peak at 14 inches. The stop bumpers for the drop weight are located 14 inches below the end of the sample. That peak is the response of the load cell to the shock of the drop weight hitting the bumpers. The location of that peak confirms that the estimate of drop weight displacement is accurate.

The 795 ACCR test data was inadvertently clipped due to errors setting the voltage range and offset on the ScopeMeters. It was agreed that the test was acceptable provided that the peak load could be estimated, and shown to be greater than RBS. Analysis of the video record shows deceleration of the drop weight to nearly a stop before the sample separated. Separation appears to occur at 6 inches after impact, which means the average load during deceleration is 30,000 lbs (total energy is 15,000 ft-lbs). Unclipped data shows peaks well above the average value, which means that the peak load almost certainly exceeded the 31,134 lb RBS by a comfortable margin. A more precise estimate is possible by extrapolation of valid (non-clipped) data. Figure 6 shows the impact test data for the 795 ACCR sample. Also shown is the extrapolation of the data. The first clip likely contains two stick-slip events, both exceeding the conductor RBS. The third stick-slip was a single event, and extrapolation permits estimation of the peak load at greater than 32,800 lbs (105% RBS).

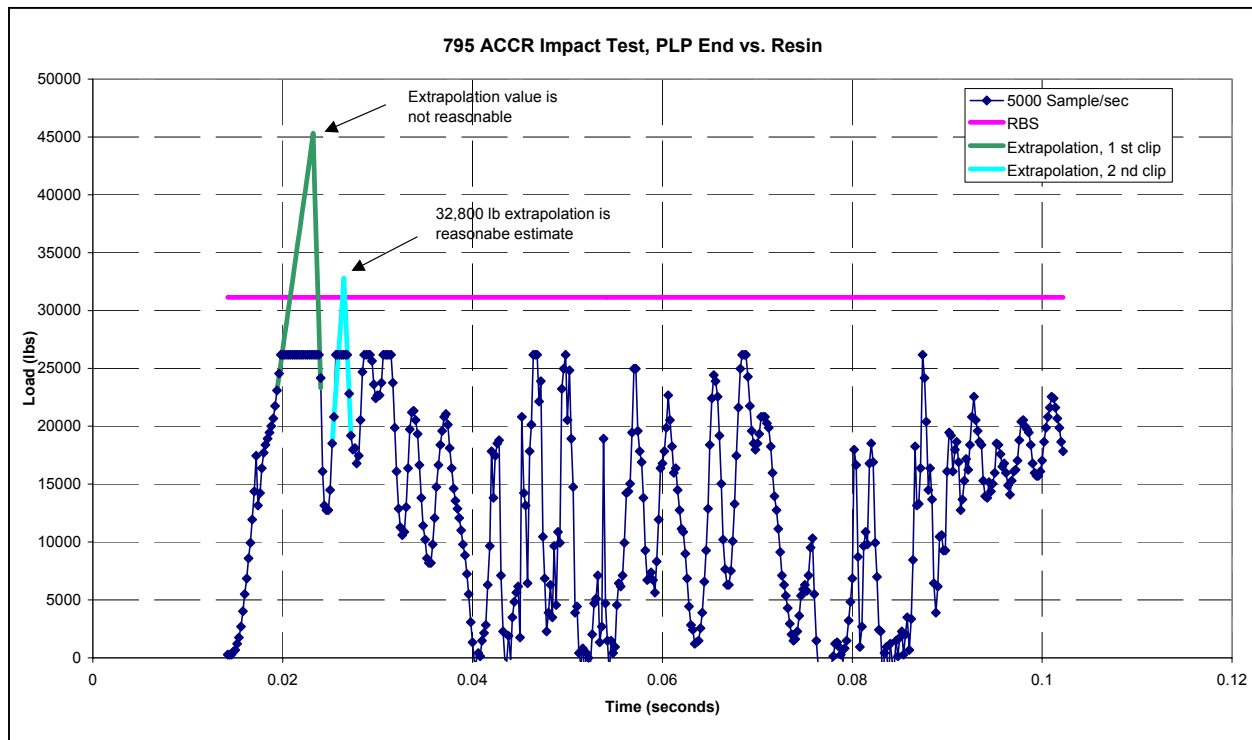


Figure 6, impact test data for 795 ACCR conductor

Conclusions:

Crush, torsional ductility, and axial impact tests were conducted on samples of 477 ACCR and 795 ACCR. Results indicate that conductor performance equals or exceeds expected performance of AAC and ACSR conductors. Therefore, there should be no new problems during field installation and operation of the new conductor type.