ANSI C119.4 Testing of TS Conductor "Ruddy" with AFL Connectors

Mechanical Test Results

NEETRAC Project: 22-132

Final Report

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NEETRAC
National Electric Energy Testing, Research, and Applications Center

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NOTICE

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Connector and Conductor Testing of TS Conductor "Ruddy" with AFL Connectors - Mechanical Test Results

NEETRAC Project 22-132

1.0 SUMMARY

Jeff Phillips from Tennessee Valley Authority requested NEETRAC to perform current cycling, sustained load, and pullout strength tests per ANSI C119.4-2016 on AFL connector part numbers B135010-Y-TS (dead-ends) and B4684-Y-TS (splices) installed on TS conductor "Ruddy," M3 8.5. This report covers the results of the sustained load and pullout strength tests.

While all three samples passed the load hold test, one sample failed the pullout strength test. The location of the failure was at one of the dead-end connectors, which exhibited a core fracture 1.75 inches inside the core grip. Failure of the core within the core grip has never been seen by NEETRAC personnel for any type of connector-conductor combination. The failure could have been caused by some unknown installation process or a latent defect in the conductor. The Section 6 (page 19) discusses the results of the investigation to date.

Table 1 summarizes the mechanical test results. Current cycle testing is expected to commence in October, 2023.

Table 1: Summary of Test Results

Sample ID	Sustained Load Test*	Pullout Strength Test+	Maximum Load prior to Failure	Type of Connector that Failed
Sample 1	Pass	Pass	47.0 kip (111% conductor's RBS)	Dead-end
Sample 2	Pass	Failed	34.4 kip (81% of the conductor's RBS)	Dead-end
Sample 3	Pass	Pass	48.7 kip (115% of the conductor's RBS)	Splice

***Sustained load test requires the sample to survive 77% RBS for 168 hours without pulling out. (Conductor RBS is 42,510 lb.)
+Pullout strength test requires the sample break above 95% of the conductor RBS, which is 40,375 lb. (Conductor RBS is 42,510 lb.)

2.0 INTRODUCTION

Jeff Phillips from TVA requested a modified ANSI C119.4-2016 qualification test on AFL connectors B135010-Y-TS (dead-ends) and B4684-Y-TS (splices) installed on TS conductor, “Ruddy,” M3 8.5. This report includes results for the mechanical tests, which consisted of sustained load and maximum pullout strength tests.

3.0 TEST SAMPLES

In consultation with AFL, TS Conductors, and TVA, it was decided that dead-ends were the most effective gripping means for terminating the splice samples. Consequently, each sample set consisted of one splice terminated with a dead-end on each side. This resulted in testing six (6) dead-ends and three (3) splices. Due to the bed length of NEETRAC’s MTS machine, this resulted in a free-conductor length between the splices and terminating dead-ends that was less than specified by ANSI C119.4. However, this reduced length did not affect the test results.

A typical sample with two dead-ends and one splice can be seen in Figure 1. Sample 1 and sample 2 were installed per AFL’s written instructions, which do not specify crimp orientation. All connectors in Sample 3 were installed using a constant crimp orientation for both the core grip and aluminum sleeve, with the intent of creating a “bow” in the connector. A photo of Sample 3 after assembly can be seen in Figure 2. The maximum chord height of Sample 3 was measured to be approximately 4 inches.

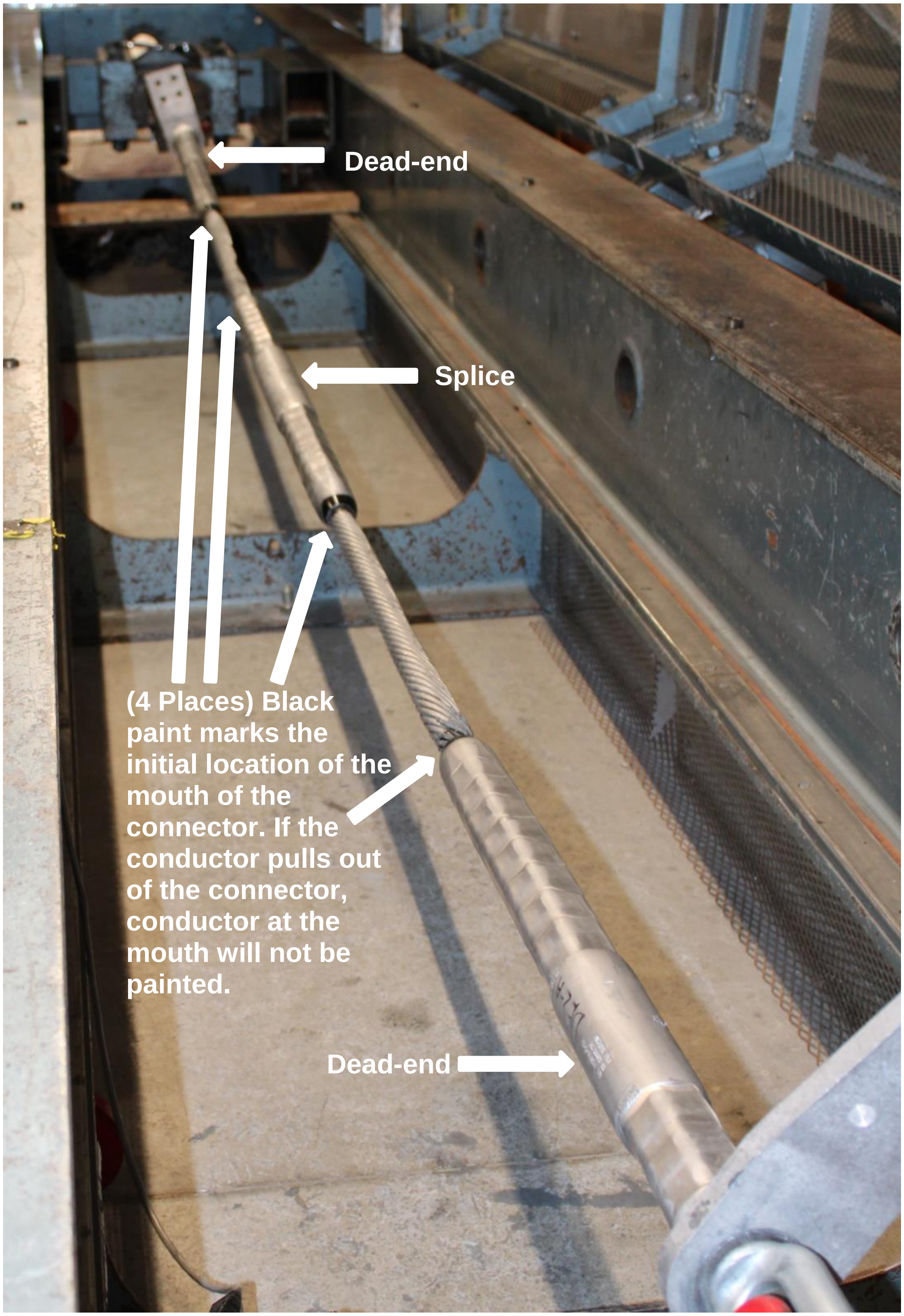

Figure 1: Components of a Typical Sample

Figure 2: Initial Condition of Sample 3 – Crimped without Rotation

4.0 PROCEDURE

All samples were installed in a 150-kip tensile testing machine as seen in Figure 1. A pretension of approximately 1,000 lb was applied. Black paint was applied across the mouth to verify the conductor did not pull out during the load hold test. A load of 32,733 lb (77% of the conductor's RBS) was applied for 168 hours.

After 168 hours the load was reduced to approximately 1,000 lb and the black paint at the connector-conductor interface inspected for pullout.

After inspection, the samples were loaded at a rate of 21,300 lb/min (50% of the conductor's RBS) until failure.

Note: A power failure occurred during the 168-hour load hold portion of Sample 1. This resulted in a loss of electronically recorded data. However, the sample was checked several times a day up until approximately 15 hours before the power outage, which occurred early on a Saturday morning. The time of the power outage was verified on several independent pieces of equipment. During a power outage, the force is slowly relieved over several minutes (pressure equalizes on both sides of the hydraulic cylinder); therefore, the sample did not experience a shock load. The test was restarted the following Monday for the remainder of the required 168 hours load hold.

5.0 RESULTS

5.1 Sample 1

Sample 1 passed the sustained load test with no slippage observed. The data for the sustained load hold test can be seen in Figure 3. Sample 1 passed the pullout strength test with a maximum load of 47.0 kip (111% of the conductor's RBS) prior to failure. For a photo of the test sample after the pullout strength test refer to Figure 4 and Figure 5. The data for the pullout strength test can be seen in Figure 6.

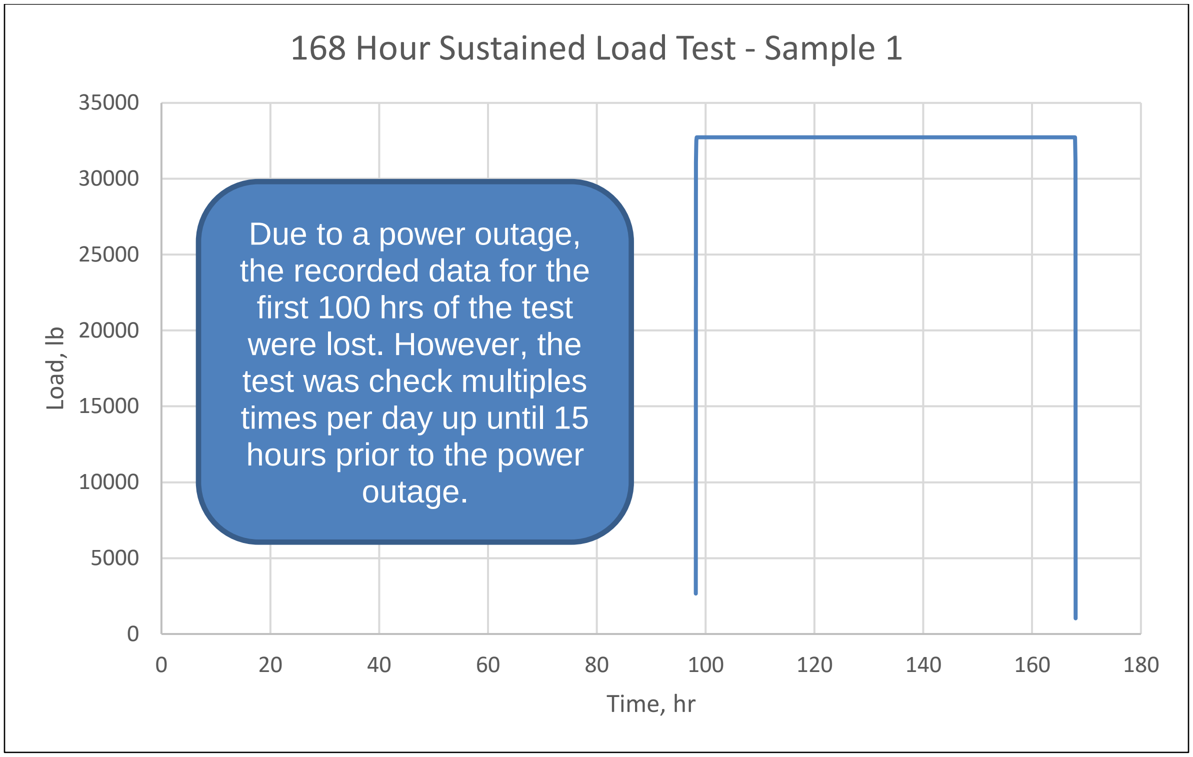

Figure 3: Sustained Load Test Data – Sample 1

Figure 4: Photo of Sample 1 after Pullout Strength Test (1 of 2)

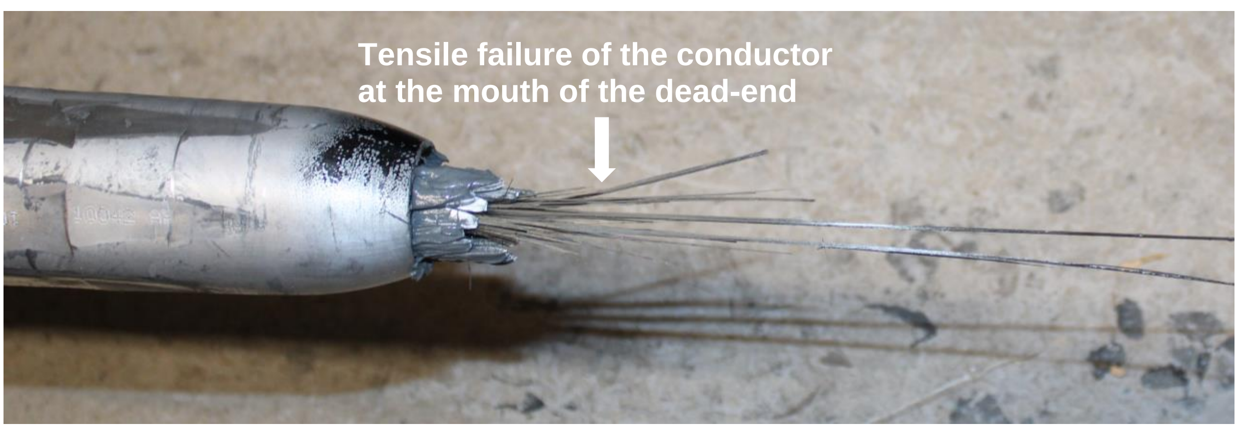

Figure 5: Photo of Sample 1 after Pullout Strength Test (2 of 2)

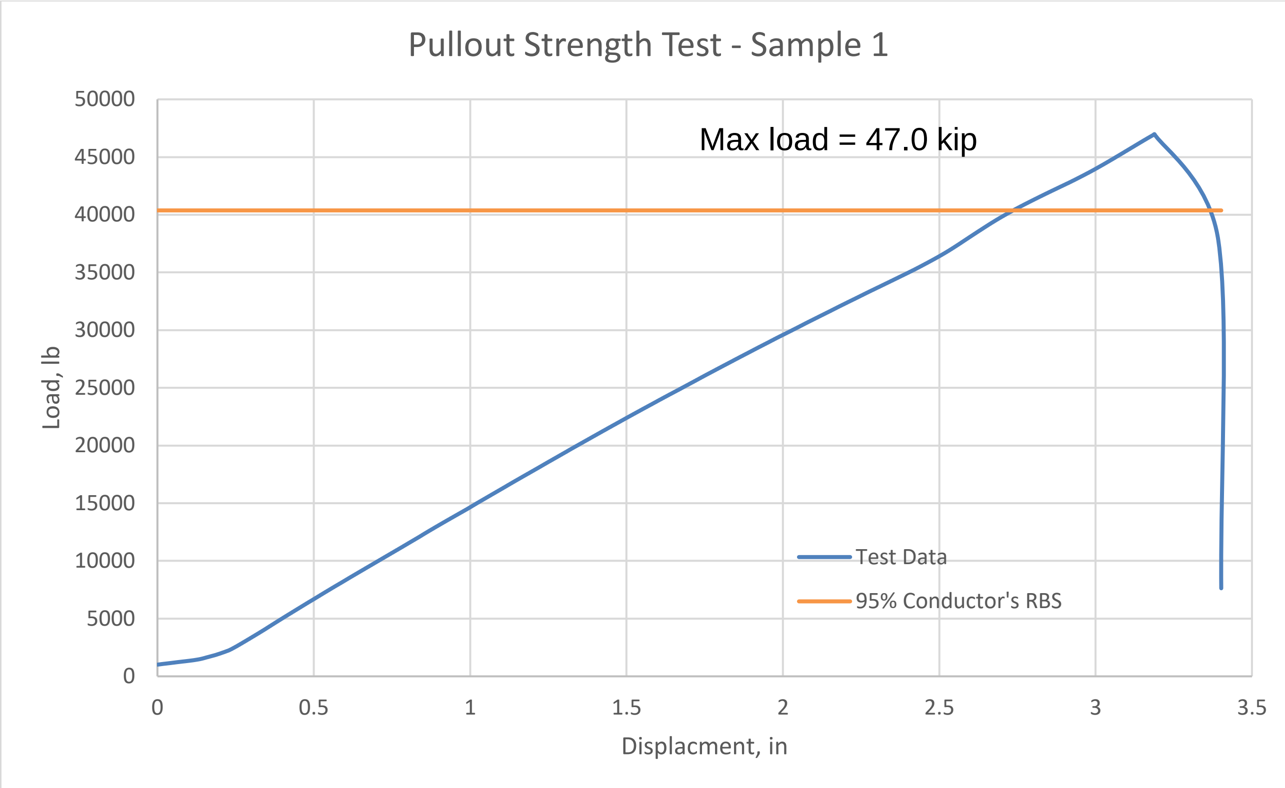

Figure 6: Pullout Strength Test Data - Sample 1

5.2 Sample 2

Sample 2 passed the sustained load test with no slippage observed. The data for the sustained load hold test can be seen in Figure 7. Sample 2 failed the pullout strength test as it did not reach 95% of the conductor's RBS prior to failure. The sample reached a maximum load of 34.4 kip (81% of the conductor's RBS). A photo of the sample after the pullout strength test can be seen in Figure 8. The data for the pullout strength test can be seen in Figure 9. Refer to Section 6 for a discussion of this failure.

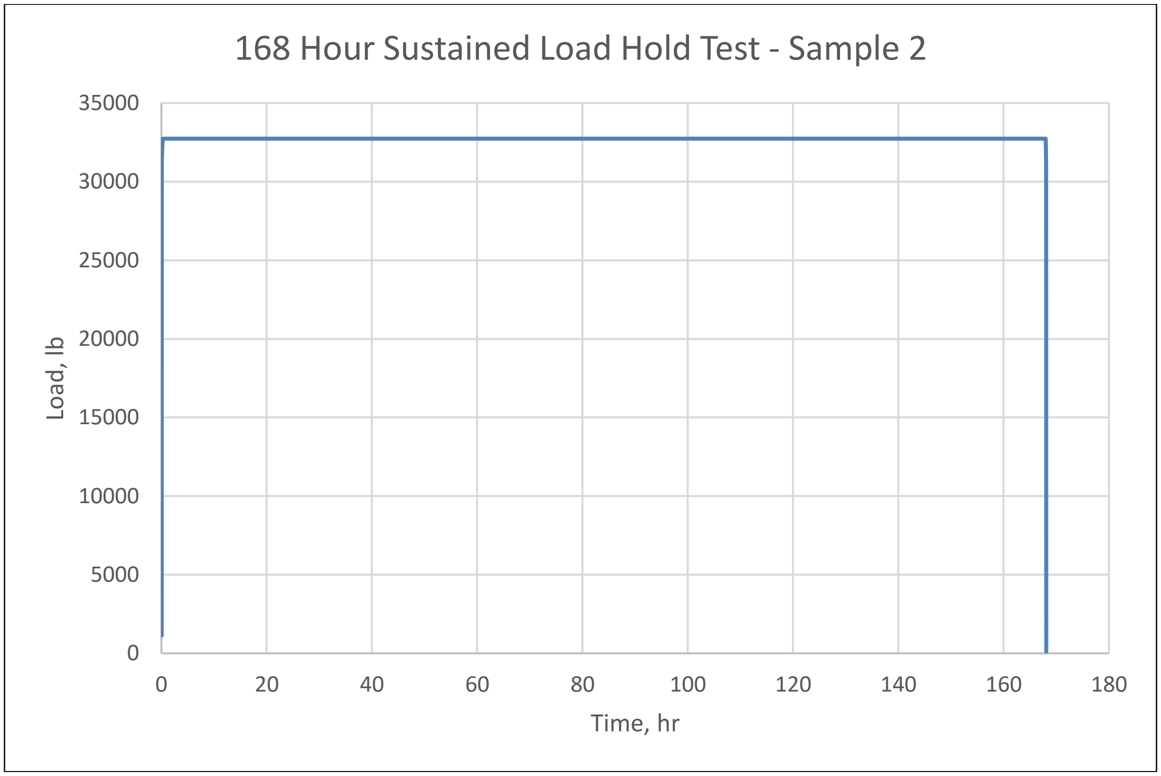

Figure 7: Sustained Load Hold Test Data - Sample 2

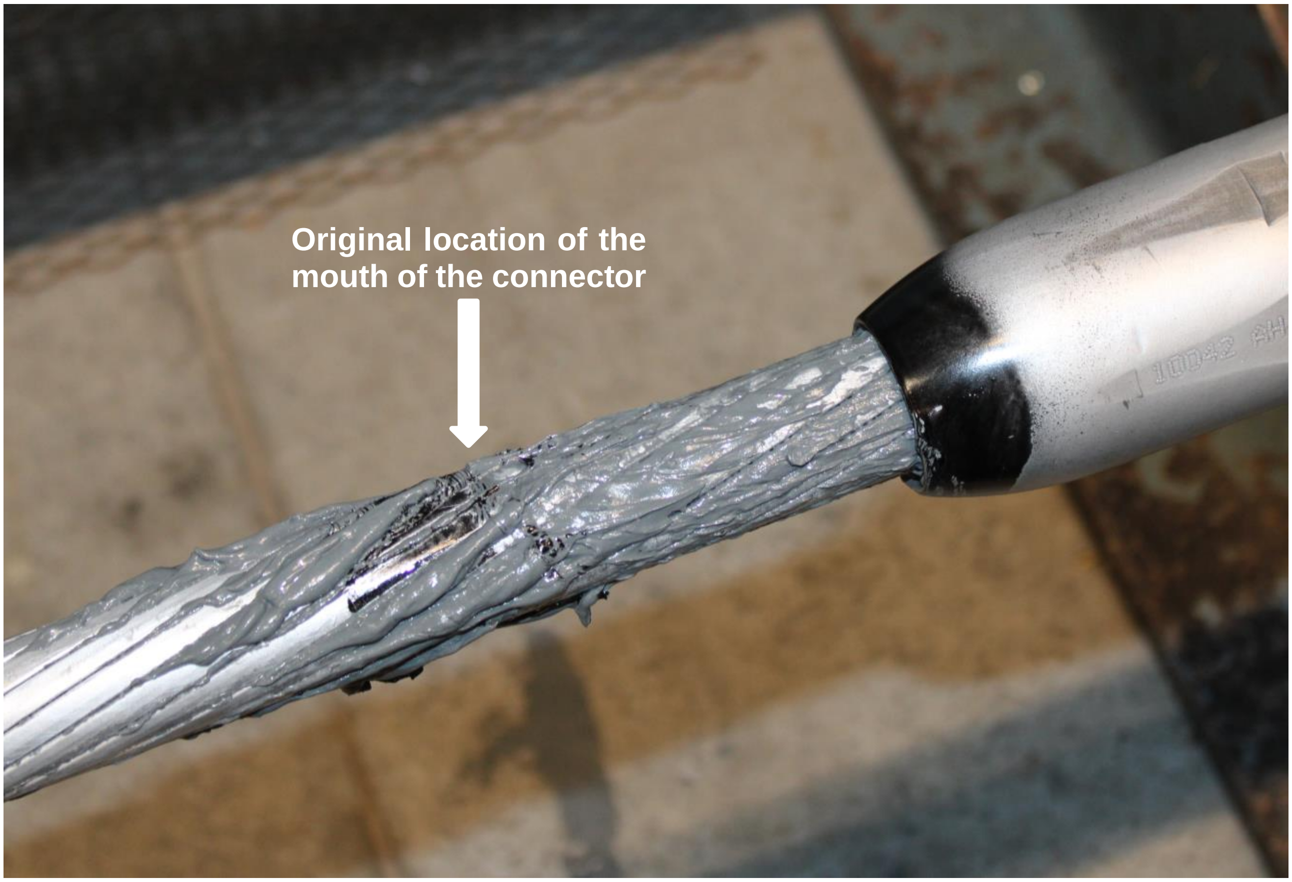

Figure 8: Photo of Sample 2 after Pullout Strength Test

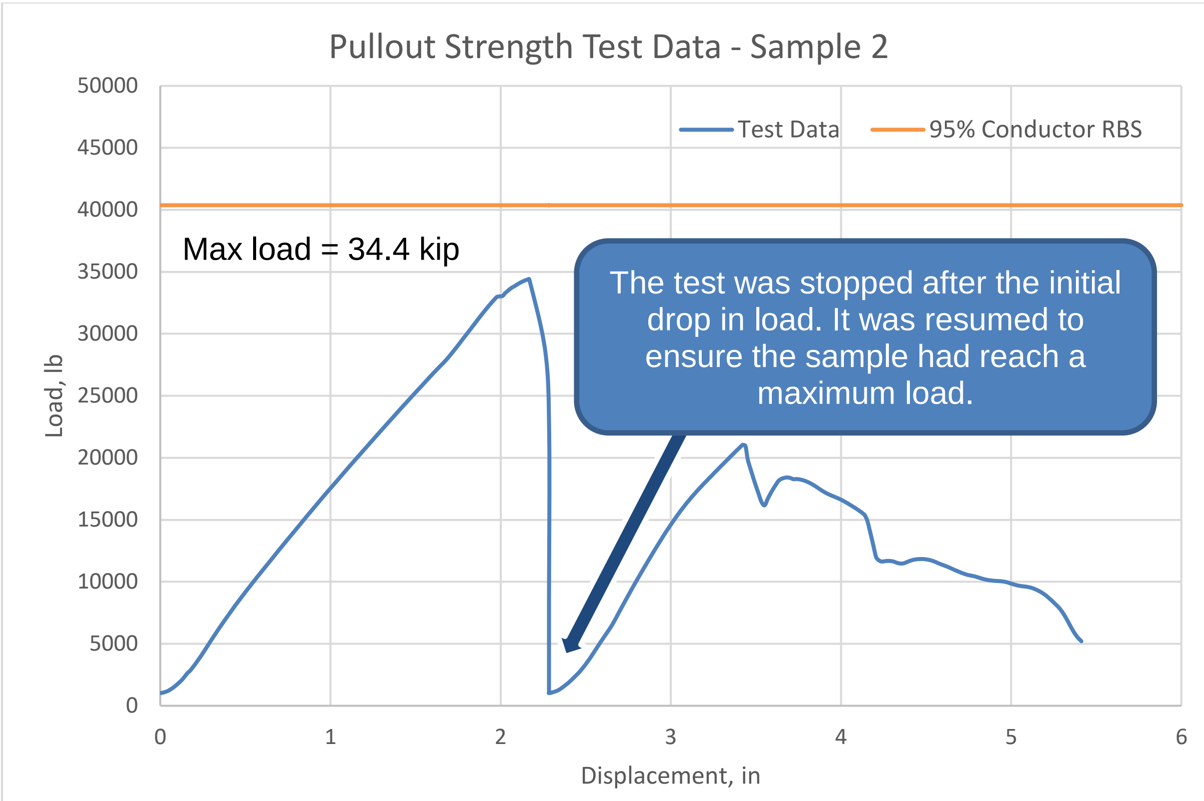

Figure 9: Pullout Strength Test Data - Sample 2

<u>5.3 Sample 3</u>

Sample 3 passed the sustained load test with no slippage observed. The data for the sustained load hold test can be seen in Figure 10. Sample 3 passed the pullout strength test as it reached a maximum load of 48.7 kip (115% of the conductor's RBS) prior to failure. A photo of the sample after the pullout strength test can be seen in **Error! Reference source not found.**. The data for the pullout strength test can be seen in Figure 11.

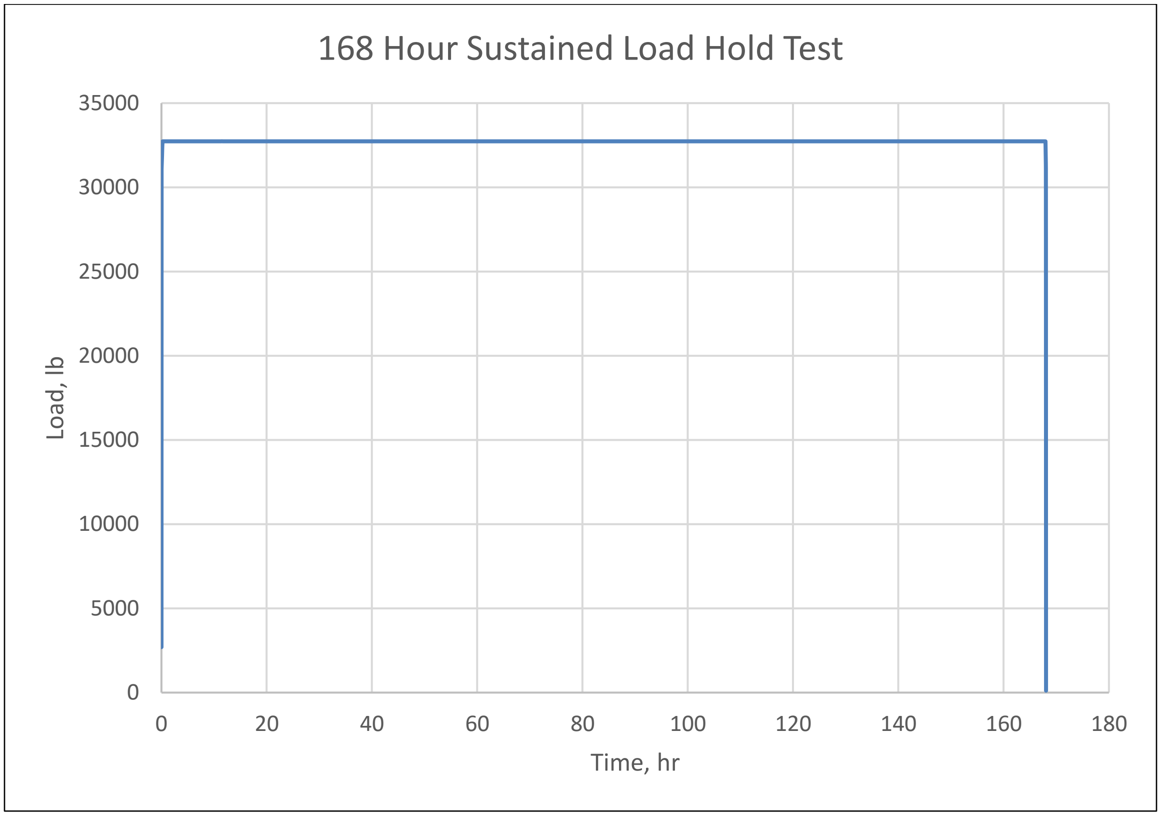

Figure 10: Sustained Load Hold Test Data – Sample 3

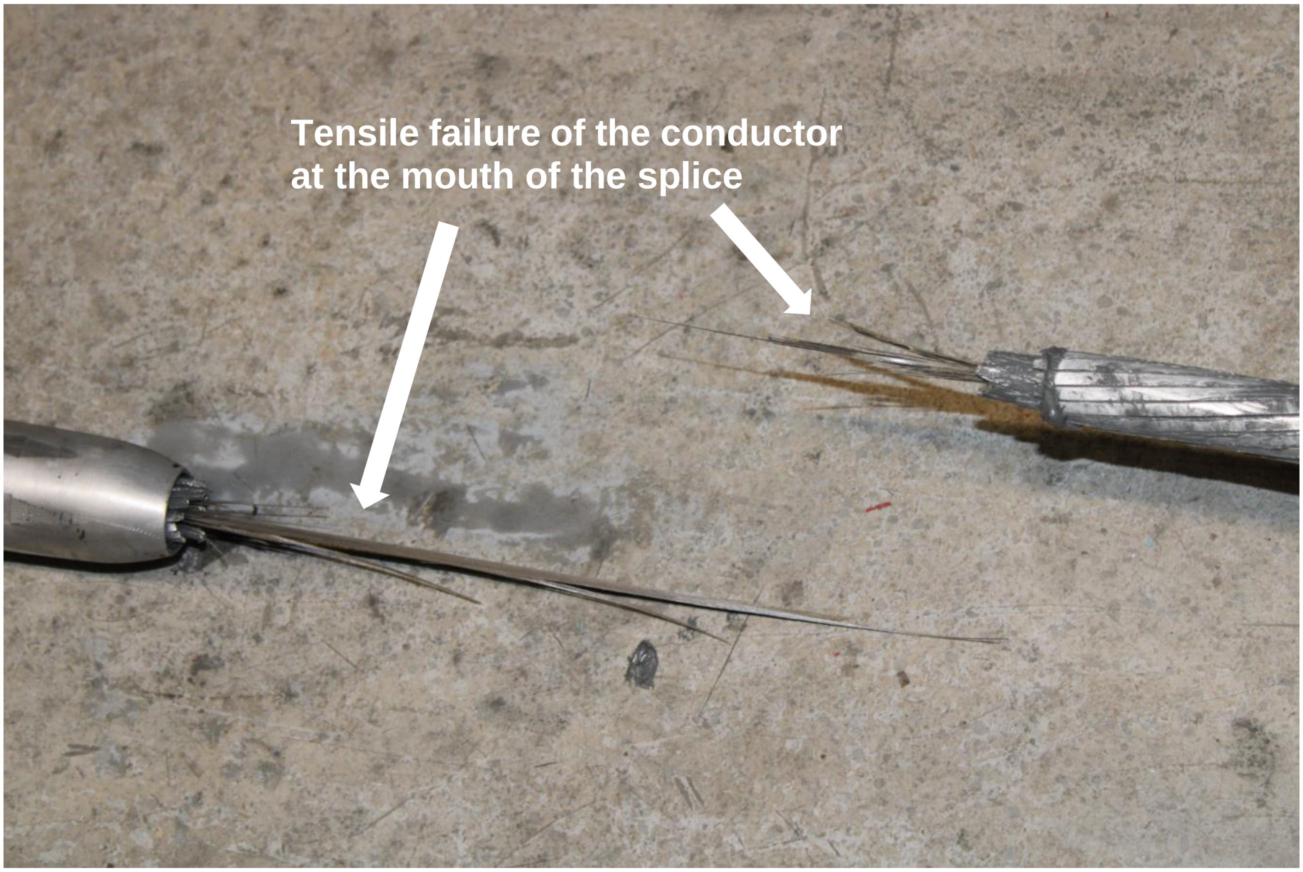

Figure 11: Photo of Sample 3 after Pullout Strength Test

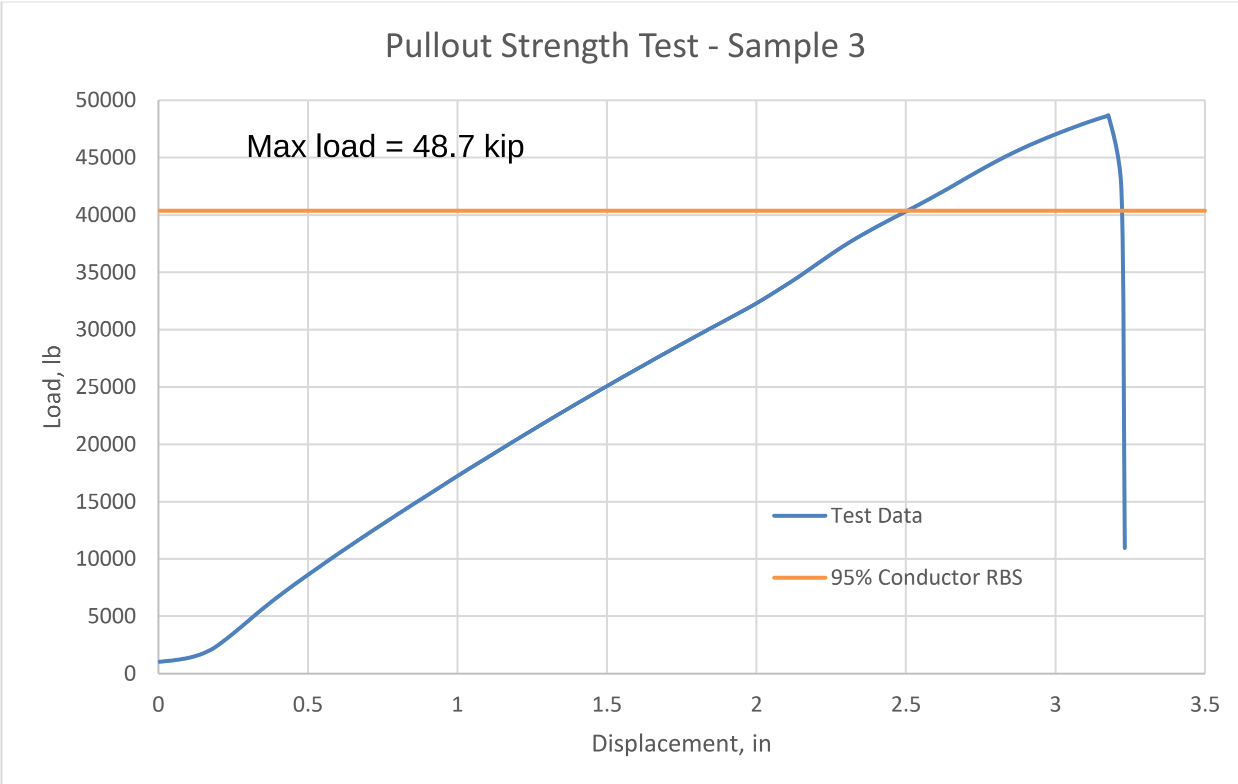

Figure 12: Pullout Strength Test Data - Sample 3

6.0 DISCUSSION OF SAMPLE 2

An examination of Sample 2 was completed as it failed the pullout strength test.

Photos taken prior to compression were reviewed to ensure the aluminum encapsulation of the carbon fiber core did not include any cuts, nicks, or other deformations. The condition of the core with the aluminum encapsulation can be seen in Figure 13.

Figure 13: Photo of the Core of Sample 2 prior to Dead-end Installation

A dissection of the dead-end was performed to understand the nature of the failure. Refer to Figure 14 for a photo of the initial dissection. Upon opening the dead-end, it was determined that the carbon fiber core fractured approximately 1.75 inches inside the mouth of the core retention sleeve

The failure of the core inside the steel barrel can be seen in Figure 15 and Figure 16. Observe that the aluminum encapsulation fractured at a different location. This was most likely caused because aluminum has greater elongation to break than carbon fiber composite. The mating surface of the failed core can be seen in Figure 17. Both sides of the fracture surfaces were visually inspected using an optical microscope; photos from the microscopic examination can be seen in Figure 18 and Figure 19.

On Tuesday, September 5, 2023, a meeting was held to discuss the failure with Jeff Phillips (TVA), Matthew Welborn (AFL), Rodolpho Elzondo (AFL), Jason Huang, (TS Conductor), Joseph Goldenburg (NEETRAC), Kevin Garner (NEETRAC), and Tristen Cline (NEETRAC). Photos of the dissection were reviewed. There was a unanimous consensus that the surface morphology presents as a shear fracture. Additionally, no one present has seen a failure inside the core grip/barrel for any type of conductor that uses a compressed core grip. One typically sees the complete conductor break at the mouth of the connector assembly, as seen in Figure 5. The carbon fiber core appears to have been damage prior to any testing. The damage could be from a latent manufacturing defect or could have been introduced during the compression/assembly process.

NEETRAC will recommend a follow-up test program to attempt to replicate a shear fracture during the assembly process.

Figure 14: Photo of the Dissection of Sample 2

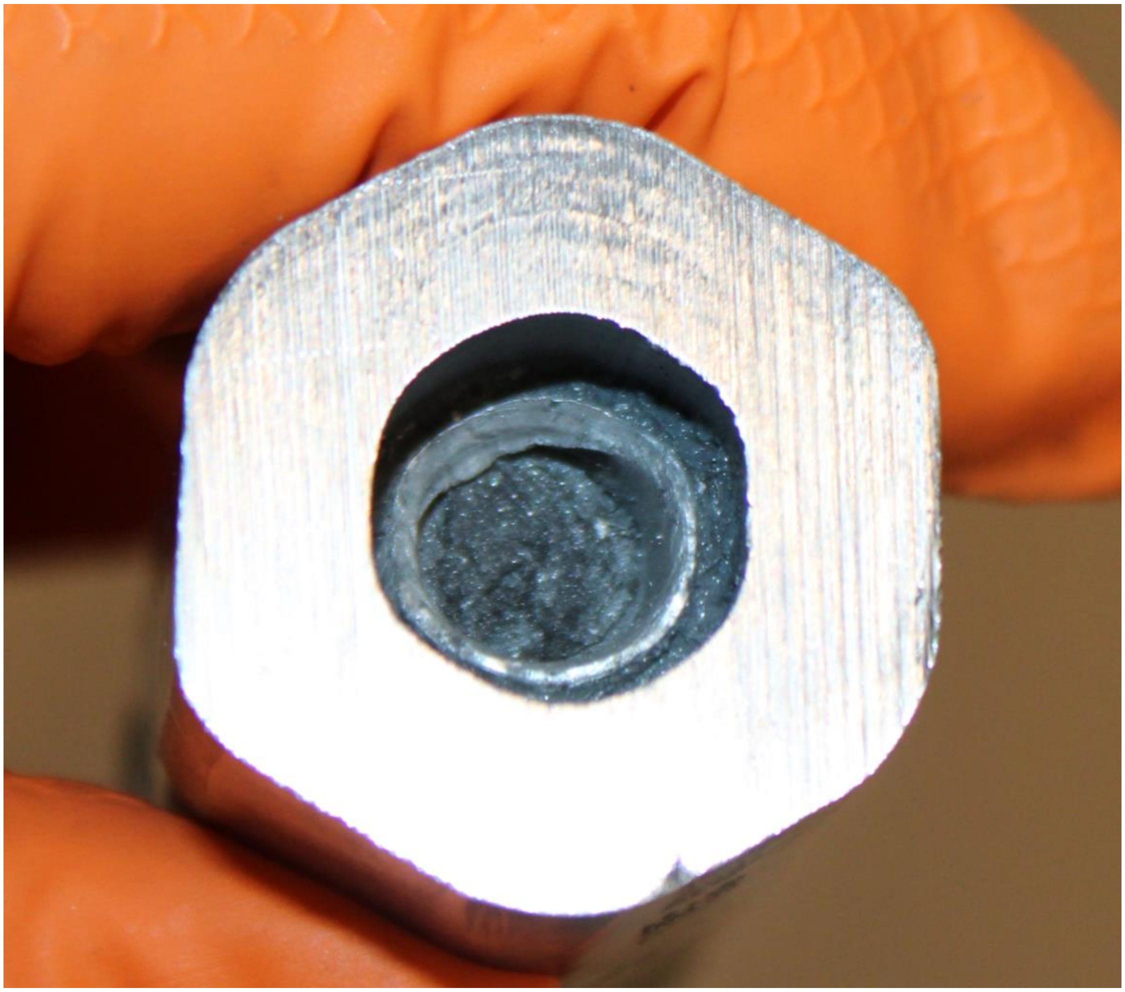

Figure 15: Sample 2 - Location of Failure - Inside of Steel Pin (1 of 2)

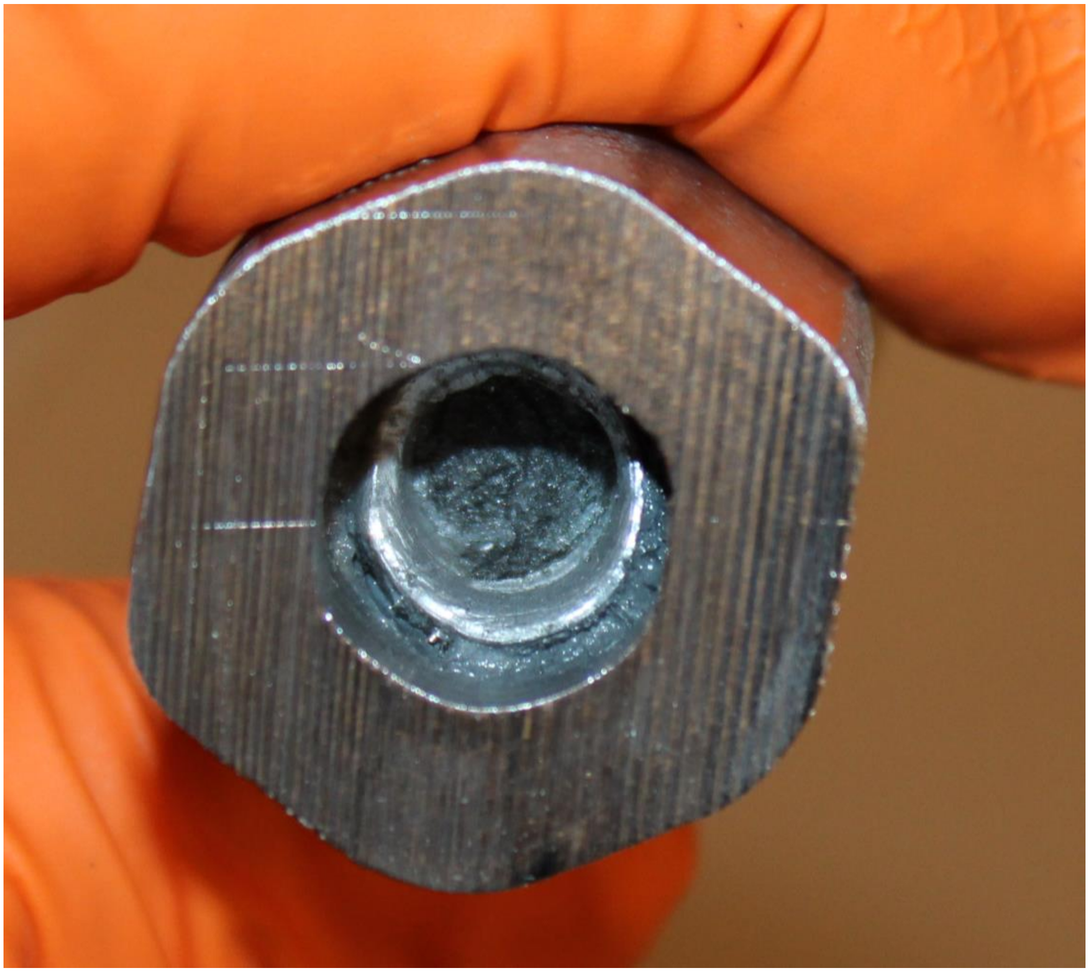

Figure 16: Sample 2 - Location of Failure - Inside of Steel Pin (2 of 2)

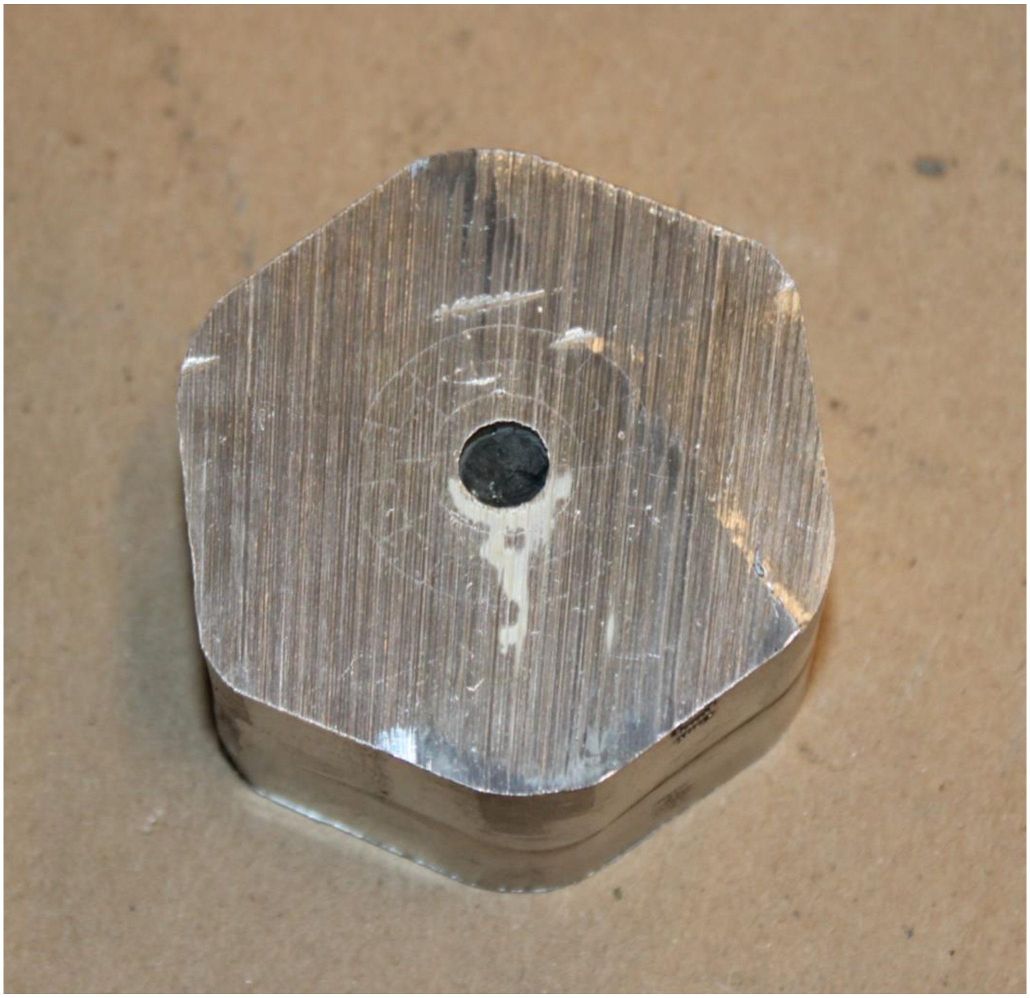

Figure 17: Sample 2 - Location of Failure – Outside of Steel Pin

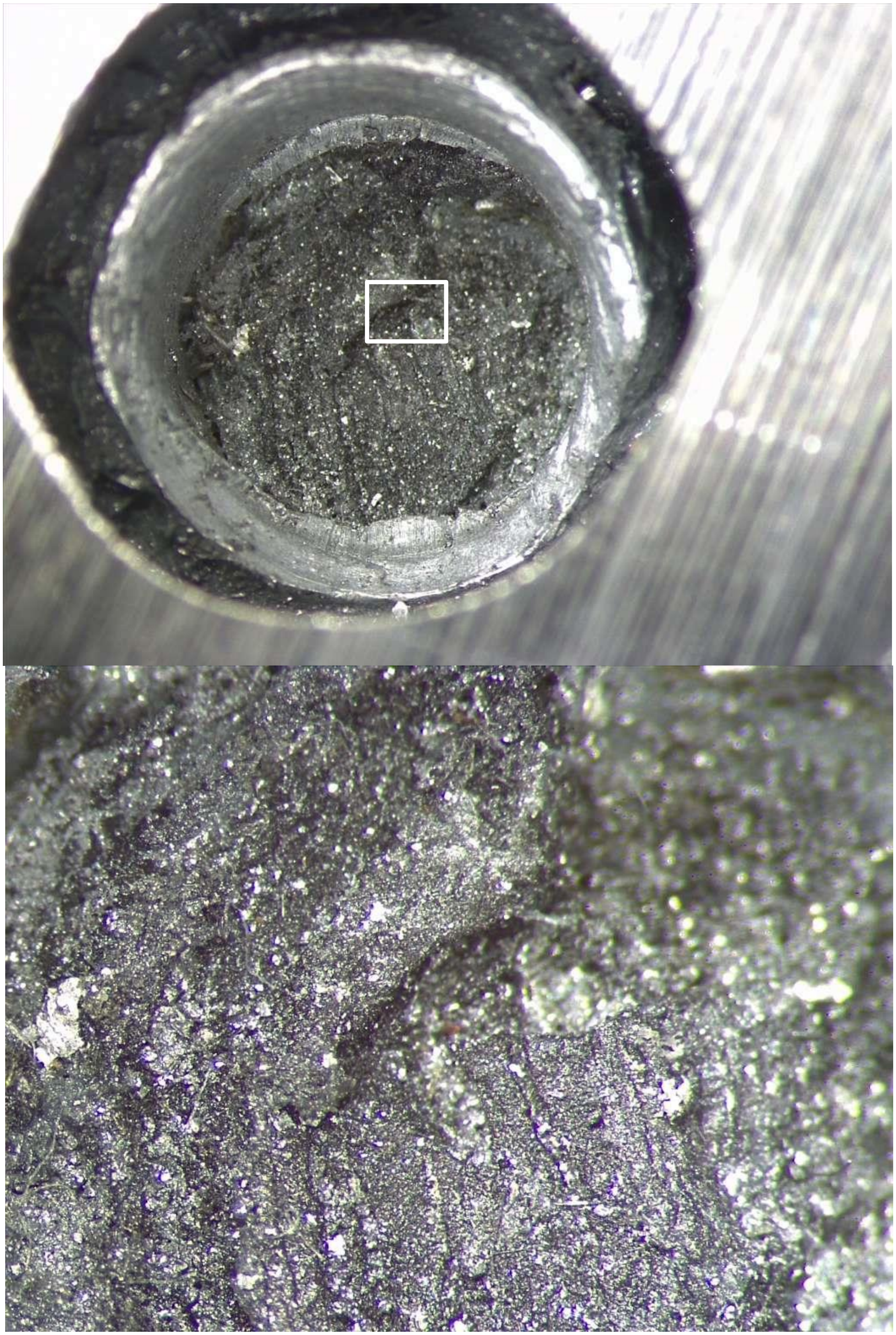

Figure 18: Microscopic Photos of Fracture Surface (1 of 2)

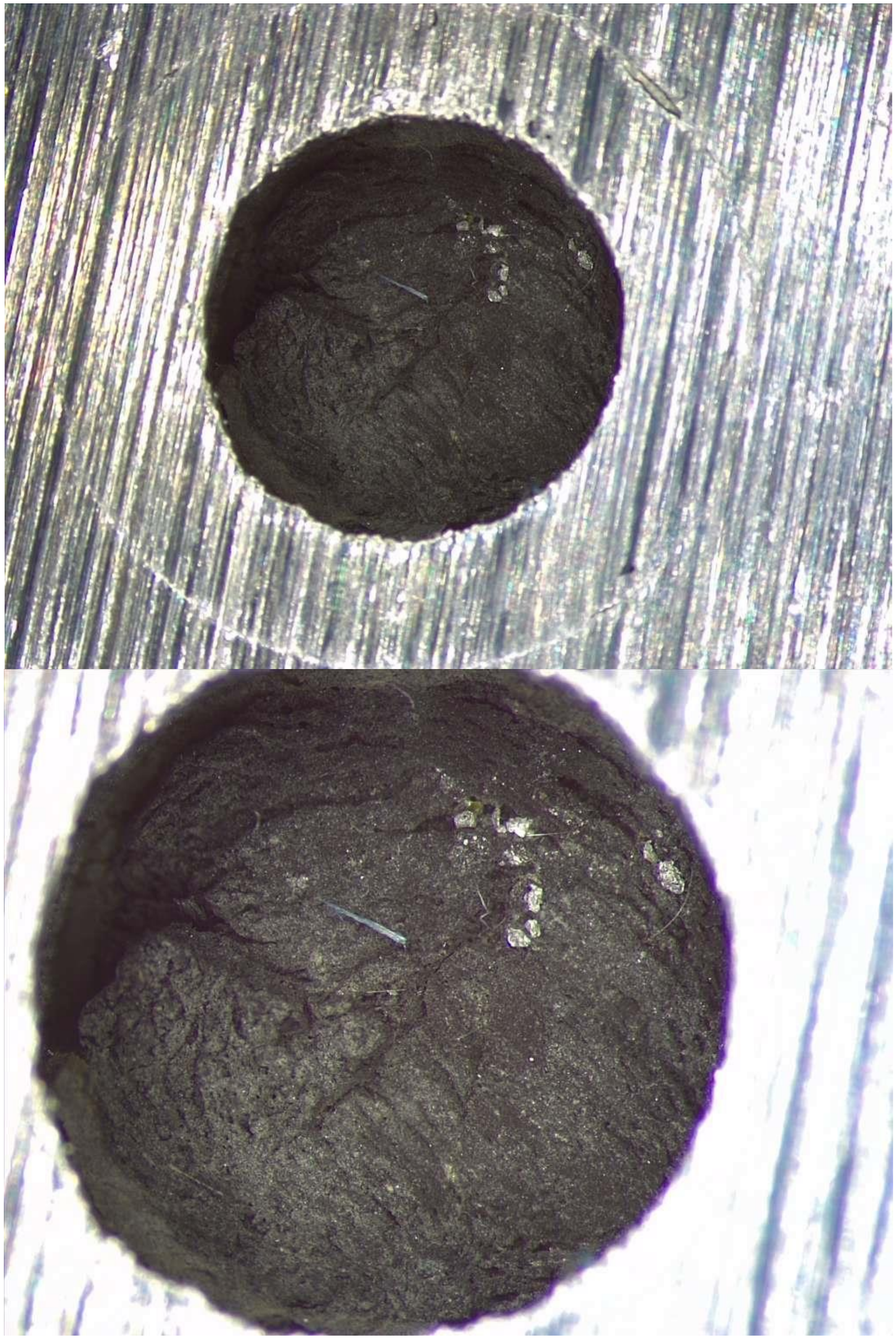

Figure 19: Microscopic Photos of Fracture Surface (2 of 2)

7.0 ANSI C119.4 REQUIRED DECLARATIONS

a. Test dates

  - Sample 1
    - Load hold: 08/08-17/2023
    - Pullout: 08/18/2023
  - Sample 2
    - Load hold: 08/18-25/2023
    - Pullout: 08/25/2023
  - Sample 3
    - Load hold: 08/25/2023-09/01/2023
    - Pullout: 09/01/2023

b. ANSI C119.4-2016 standard used

c. Facility and personnel

  - Test performed at NEETRAC's mechanical test facility located at 22 Kennedy Dr., Forest Park, GA 30297.
  - Personnel
    - Engineer in responsible charge: Joseph Goldenburg, P.E., Principal Research Engineer
    - Other engineering staff:
      - Engineer executing project under supervision: Tristen Cline, E.I.T, Research Engineer I
      - Dylan Summer, Quality Resource Manager, (supervised compression of sample set 1, supervises technicians)
    - Test Technicians:
      - Oscar Rodriguez, Test Technician III
      - Ian Brown, Test Technician III
      - Kevin Garner, Test Technician IV

d. For equipment used refer to Equipment Section.

e. Connectors: AFL connector part numbers B135010-Y-TS (dead-end) and B4684-Y-TS (splice)

f. This report is mechanical only

g. Mechanical Class: Class 1

h. Description of conductor: TS Conductor “Ruddy”; RBS = 42,510 lb & overall diameter of conductor = 1.131 in

i. Description of installation procedure: For installation procedure refer to Procedure Section.

j. This report is mechanical only

k. See section 5.0 for condition of samples after testing

l. This test report is mechanical only

m. This test report is mechanical only

n. Description of optional tests: N/A

o. For installation details refer to Procedure Section.

p. Certifications: N/A

8.0 EQUIPMENT

CQ0915 – MTS Tensile Testing Machines

9.0 STANDARDS

ANSI C119.4 American National Standard for Electric Connectors - Connectors for Use between Aluminum-to-Aluminum and Aluminum-to-Copper Conductors Designed for Normal Operation at or Below 93°C and Copper-to-Copper Conductors Designed for Normal Operation at or Below 100°C