# Project #103-14: Thermal Compression Testing of EVRlock QB1-HT and API Buttress Connections

## Overview

To compare the effects of thermal loading on the EVRlock QB1-HT and API Buttress, two of each connection were threaded onto 7”, 26# API L80 Type 1 casing. They were subjected to thermal compression at ~350ºC until failure.

## Scope and Objectives

This trial was conducted to compare the performance of QB1-HT to the API Buttress under thermally-induced compression. The main objectives were:

- To test the thermal compression limit of QB1-HT and API Buttress under high temperature and strain conditions
- To compare the actual strength of QB1-HT to an API Buttress connection of similar grade, size, and weight
- To demonstrate that QB1-HT is superior to the API Buttress and the L80 pipe body

## Materials and Methods

A total of four connections were tested: two EVRlock QB1-HT semi-premium connections and two API Buttresses. Connections were machined on standard EVRAZ ERW 7” OD 26# Grade L80 Casing produced at EVRAZ Calgary. To reduce stress concentration from end effects, casing was machined to a final minimum length of 33.1”. All connections were made up as defined by the EVRAZ EVRlock QB1-HT running procedures and API 5C1.

Figure 1 illustrates the setup for all four experiments. Test specimens were welded into a two million pound test frame and a Miller ProHeat induction unit was used to achieve the desired final temperature. As shown in the Figure 1, temperature was monitored by thermocouples at five locations, with locations 2 and 3 acting as control points for the Miller ProHeat unit. Strain was measured locally by both linear variable displacement transducers [LVDTs] and extensometers placed above and below the connection.

Prior to testing, each test specimen was cycled between +/- 20,000lbs (~2.5 ksi) of force at room temperature. This was achieved using the test frame’s load cylinder acting in position control. This verified the operation of the extensometers and was considered to have a negligible effect on the final performance of the test specimen. After mechanically cycling, the load was brought back to zero and the cross-head and actuator locked before specimen heating. All thermal expansion and the strain generated in the test string is constrained by the test frame. Heating began from room temperature and continued at a rate of 1°C / minute until 350°C. Upon reaching the final maximum temperature, the heating was adjusted to ensure that the test specimen was held at a constant temperature. In all four test specimens, the load in the test frame dropped significantly once the test string reached maximum temperature. At this point, a mechanical strain was applied to the test frame to exaggerate the location and mode of failure.

## Results

### Temperature at Failure

Table 1 compares the peak loads to temperatures at different specimen locations. Due to reduced yield strength with increasing temperatures, plastic deformation is expected to occur at locations with the highest temperature readings. When specimens are compressed, the casing will attempt to equalize load by shedding strain into weaker locations. As a result, locations of higher temperature fail due to lower resistance to strain. Of the four trials, two results were inconsistent with these hypotheses: the QB1-HT (1) and API Buttress (2). The resulting locations of failure for all trials, with respect to temperature, are presented in Figure 2.

In the case of the QB1-HT, failure occurred on the pipe body rather than the connection. Since the casing and connection are composed of the same material, the ability of the QB1-HT to withstand failure at higher temperatures, and lower yield strength, demonstrates a stronger structural geometry. The design of the QB1-HT ensured that stresses were localized on the pipe body; therefore, failure was prevented at the connection despite the weakened material.

The opposite is true for the API Buttress, with failure occurring on the connection rather than the upper pipe body. Given that failure occurred at the location of higher strain resistance, it is indicative that stresses localized in the Buttress connection. Therefore, while the actual strength of the QB1-HT is inconclusive, it is suggested to be greater than the L80 casing and API Buttress due to a more optimized geometry.

### Failure Geometry

Visual examination showed a difference in the geometry of the deformations. Based on the general shape, it is noted that both QB1-HT specimens failed symmetrically as opposed to the API Buttress, which had a “kink” in the connection.

The failure geometry of the QB1-HT specimens is a “rolled-over” structure as seen in Figures 3 and 4. Uniform axial collapse suggests that failure occurred as a result of high strain, but with even stress distribution. Moreover, results agree with Euler’s hypothesized behavior for a column with both ends fixed. While API Buttress (1) also had a rolled structure above the connection, there was an evident lack of symmetry overall which suggests failure at a point.

Sections were taken from locations of plastic deformation to ensure that failures were not caused by defects. A total of four sections were analyzed from each specimen; these consisted of one along the weld and at 90, 180, and 270 degrees respectively.

When comparing the failed sections near the connection, both API Buttresses showed signs of deflection. As seen in both Figure 5 and Figure 6, the API Buttress appears to angle slightly when compared to the QB1-HT in Figure 4. Closer inspection also reveals that deflection becomes increasingly evident along the last few threads. Based on this observation it is possible that the point of failure, noted from the geometric comparison, initiated from the connection on the last engaged thread.

Graphical Analysis

To further understand the deformation, particularly with API Buttress (2), stress strain graphs were analyzed. An analysis of QB1-HT (1) is shown in Figure 7 and graphs for all trials can be seen in Figures 8 and 9.

Table 2 summarizes the values of strain at failure- determined from the graphs. Since the specimens are under compression, greater negative strain corresponds to greater plastic deformation. With the API Buttress (2), the strain for both top and bottom coincide, indicating deformation occurring at both locations. In contrast, there is an inclination for deformation at either the top or bottom for the remaining specimens.

When comparing specific values of stress and strain at failure, an anomaly was observed in results for API Buttress (2). While both the QB1-HT and Buttress (1) failed elastically (<0.05% strain), Buttress (2) failed in the elastic/plastic transition zone of ~0.5% strain. This disparity is most likely due to discrepancy in test setup. As noted in Table 1, API Buttress (2) had issues in maintaining a consistent temperature across the test string, with a temperature difference of ~100°C between the top and the remaining points. Aside from this variance, the remaining tests agree with expectations, with both QB1-HT test strings surpassing the API Buttress (1) in strain and stress capacity at failure.

Stress was also plotted relative to temperature and compared to a previous high temperature characterization of EVRAZ standard Grade L80 casing by Noetic Engineering. A total of six data points were plotted using the yield stress of the L80, and a polynomial trend line was used to determine theoretical stresses at corresponding temperatures of the connections. As shown in Table 3 and Figure 9, all results were relatively close to the theoretical values: QB1-HT (1) and (2) failed at 84.5% and at 87.2% of the hypothetical L80 yield strength, while AP1 Buttress failed at 62.3% and 116.8% respectively. These values confirm that the performance of the

QB1-HT is consistent with the expected yield strength of the L80; whereas, the API Buttress (1) had significantly lower strength.

## Summary

The failure locations of four thermal compression test strings, consisting of two EVRlock QB1-HT and two API Buttresses, were analyzed and compared. Findings for the trials can be summarized as follows:

- For both API Buttress test strings, plastic failure occurred at the connection. After sectioning the test connection, the point of failure was confirmed to have started and completed at the last engaged thread of the pin.
- High temperature yield strength of the L80 pipe body was estimated to be ~460,000 lb/ft at 300°C, which is consistent with values determined from previous studies (Noetic L80 Report).
- The actual strength of the EVRlock QB1-HT in thermal compression is inconclusive, but based on the failure of the pipe body, it is determined to be greater than the L80 due to its superior geometry.
  - In comparison, the API Buttress was shown to be weaker than the L80 pipe body in thermal compression.

## Recommendations

- Current FEA models used to determine the thermal compressive strength of the API Buttress connection have been inconclusive. The test data from this evaluation will be made available upon request for use in calibrating existing Buttress models.
- While there are no plans to conduct further trials for EVRlock QB1-HT, testing procedures will be reviewed to improve the quality of future experiments.

## References

Allen, M. (2010). *Material Characterization of EVRAZ L80*. Noetic Engineering 2008 Inc.

Table 1: Temperatures at peak load

| | TC 2 – Top (°C) | TC 1 – Mid (°C) | TC 3 – Bot (°C) | Peak Load (lbf) | Peak Load (psi) |
|---|---|---|---|---|---|
| QB1 HT (1) | 274.1 | 316. | 291.7 | 437,526 | 64,218 |
| QB1 HT (2) | 322.1 | 312. | 330.0 | 414,265 | 62,244 |
| AP1 Buttress (1) | 362.0 | 365. | 361.8 | 298,781 | 38,976 |
| AP1 Buttress (2)* | 337.9 | 221. | 207.8 | 534,113 | 80,251 |

Table 2: Location of plastic deformation with relation to strain

| | Expected Location | Actual Location | Strain at Failure (Cable Ext.) | Strain at Failure (LVDT) |
|---|---|---|---|---|
| QB1 HT (1) | mi | to | -0.008% | - |
| QB1 HT (2) | bo | mid-bottom | 0.010% | - |
| AP1 Buttress (1) | mi | mid-top | 0.044% | 0.096 |
| AP1 Buttress (2)* | to | mid- | -0.486% | - |

Table 3: Stress comparison to L80 performance results from Noetic

| | Temperature (°C) | Stress at Failure (psi) | Noetic Yield Strength (psi) | % Knockdown |
|---|---|---|---|---|
| QB1 HT (1) | 274. | 64,218 | 76,034 | 84. |
| QB1 HT (2) | 322. | 62,244 | 70,133 | 87. |
| AP1 Buttress (1) | 362. | 38,976 | 62,512 | 62. |
| AP1 Buttress (2)* | 337. | 80,251 | 68,730 | 116. |

** Discrepancy in test setup due to issues maintaining a consistent temperature across test string.*

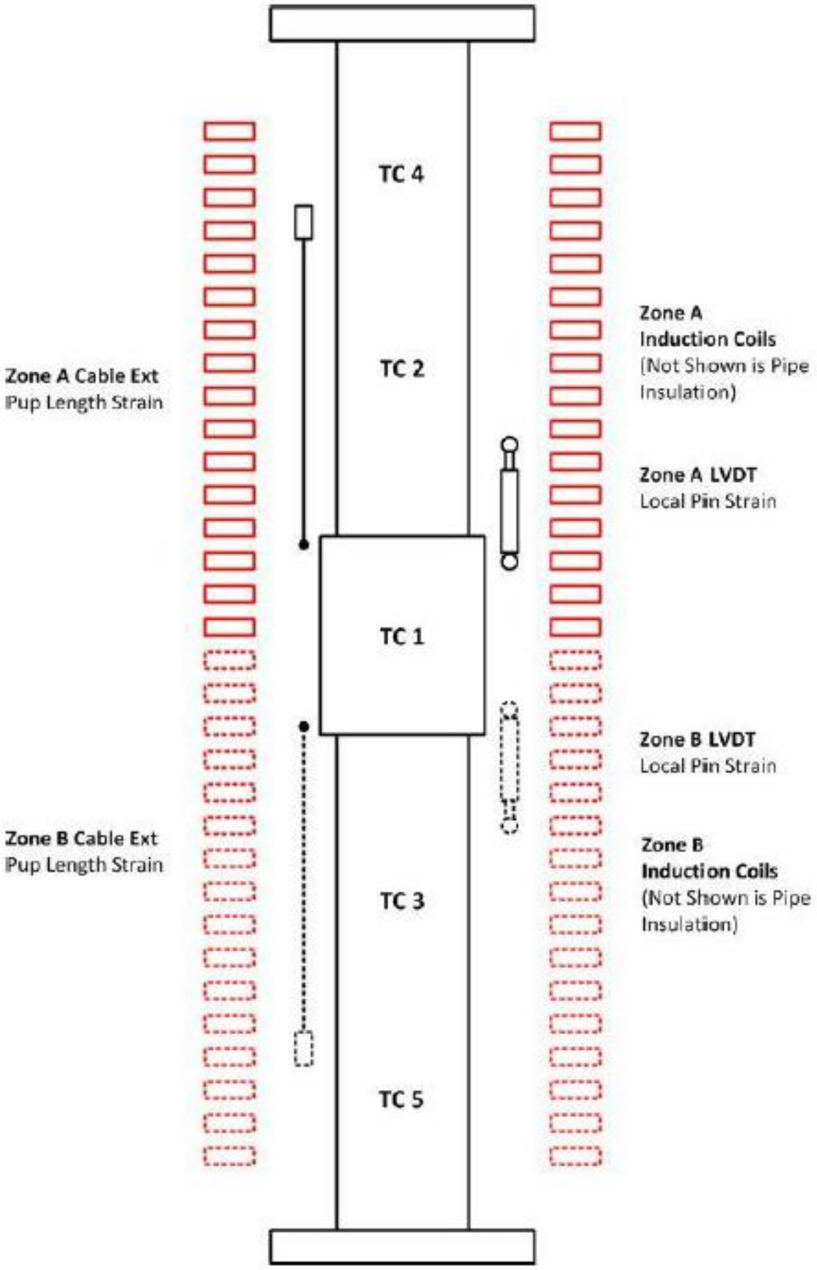


Figure 1: Thermal compression test setup

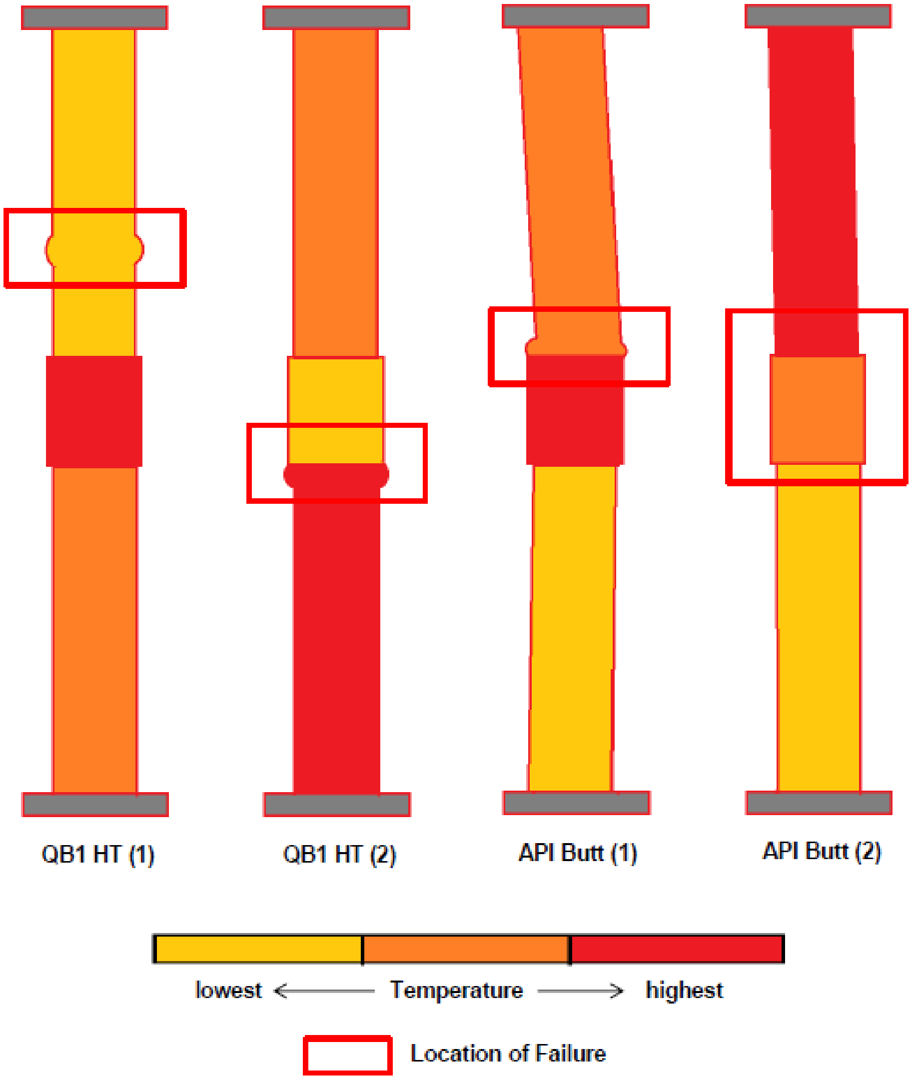


Figure 2: General comparison of temperature to location of failure

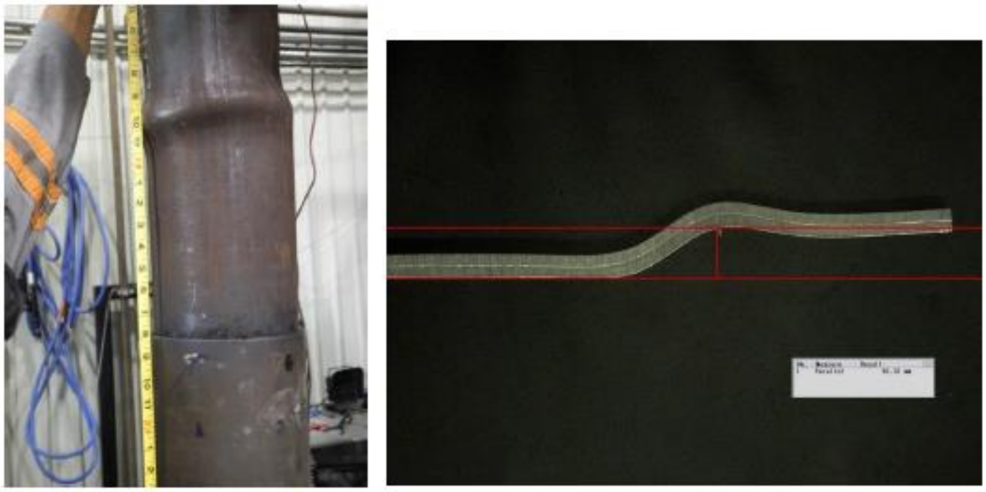


Figure 3: Plastic deformation for QB1-HT trial 1

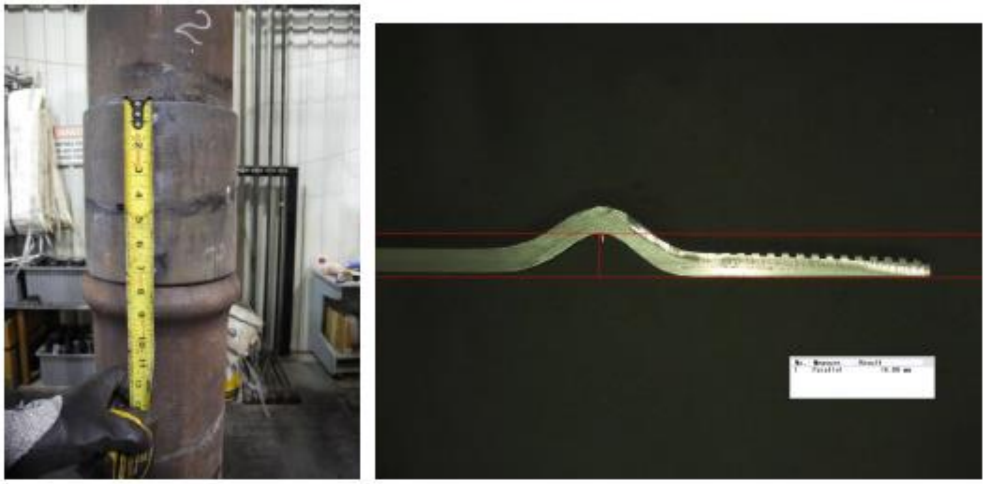


Figure 4: Plastic deformation for QB1-HT trial 2

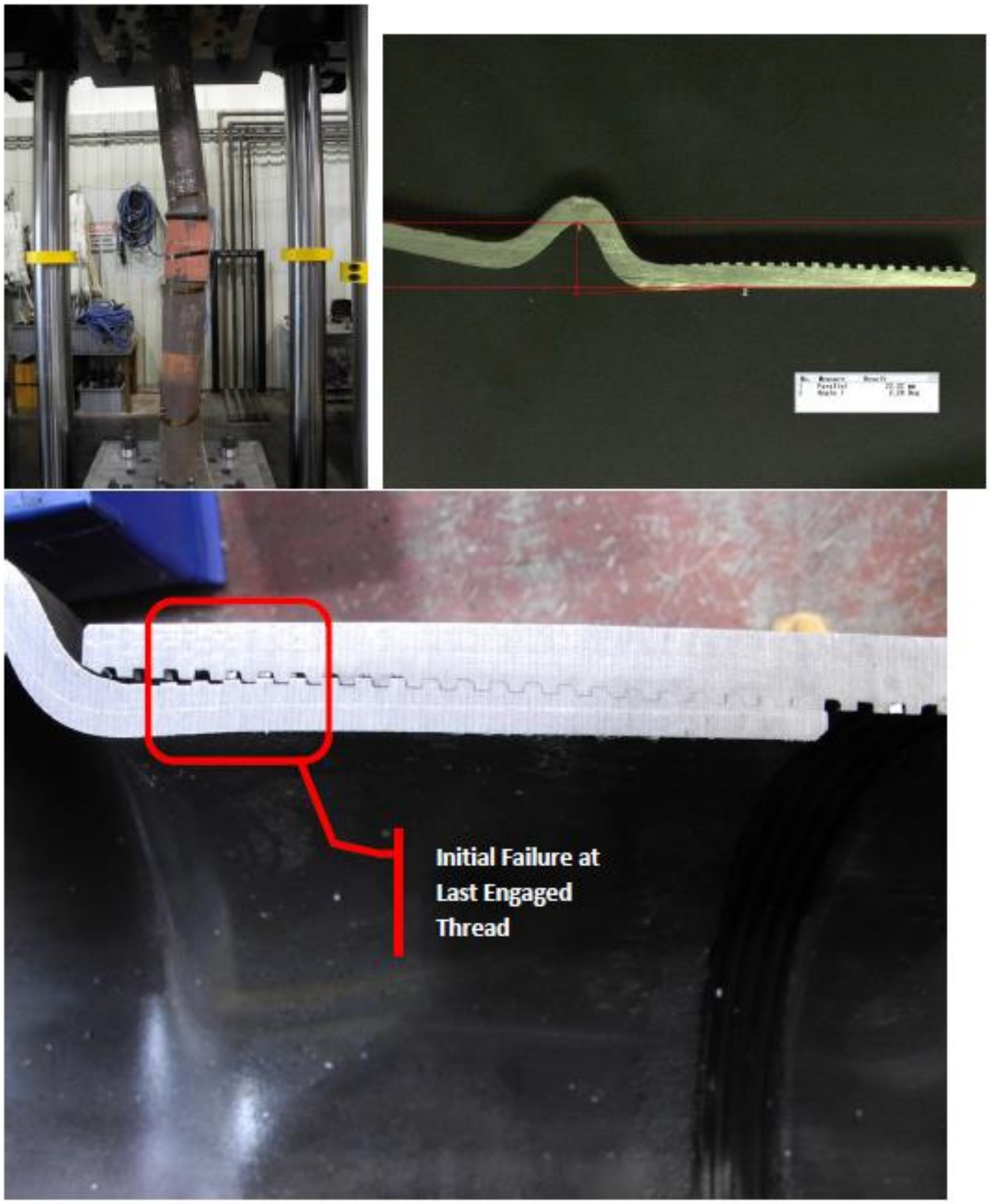


Figure 5: Plastic deformation for API Buttress trial 1

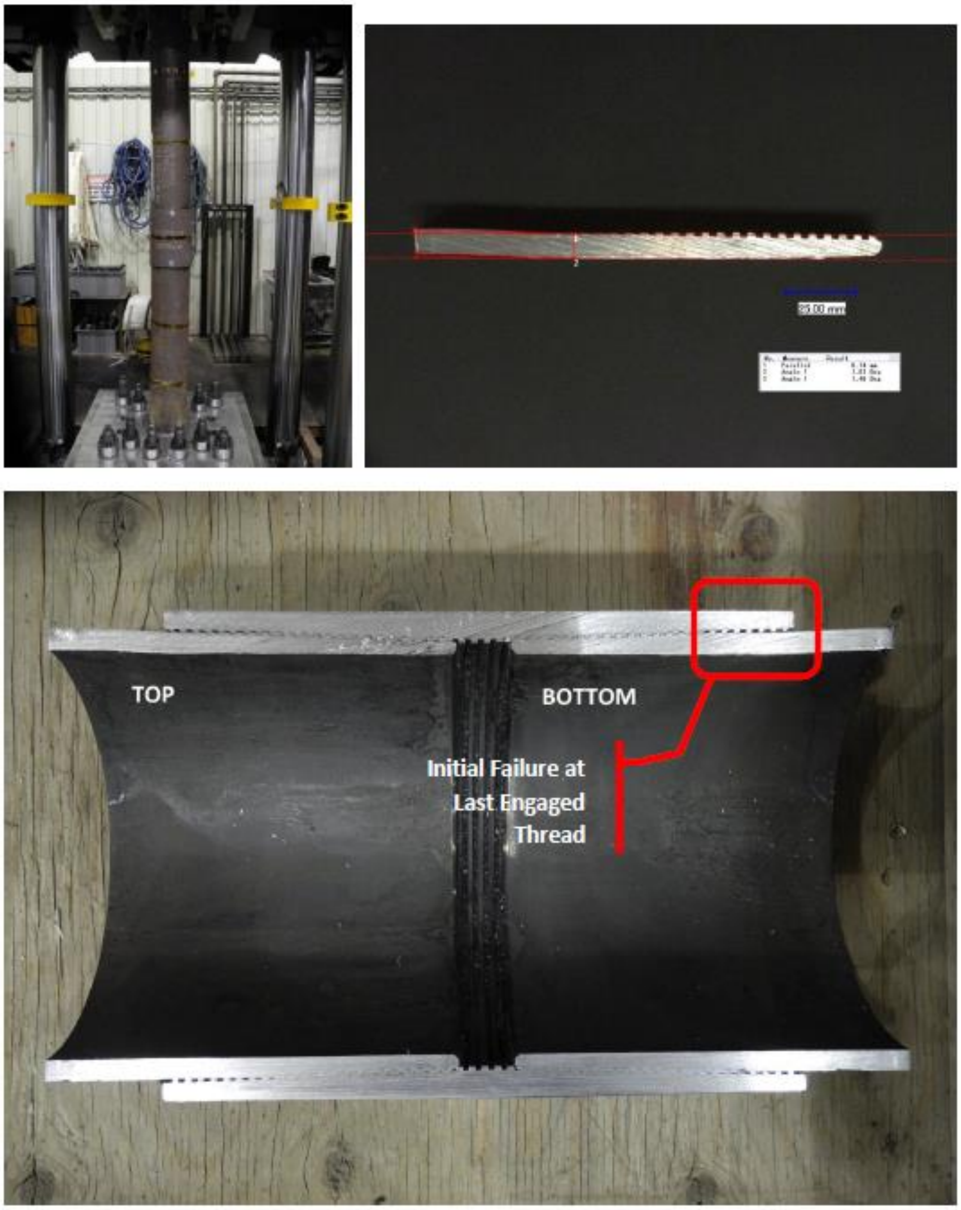
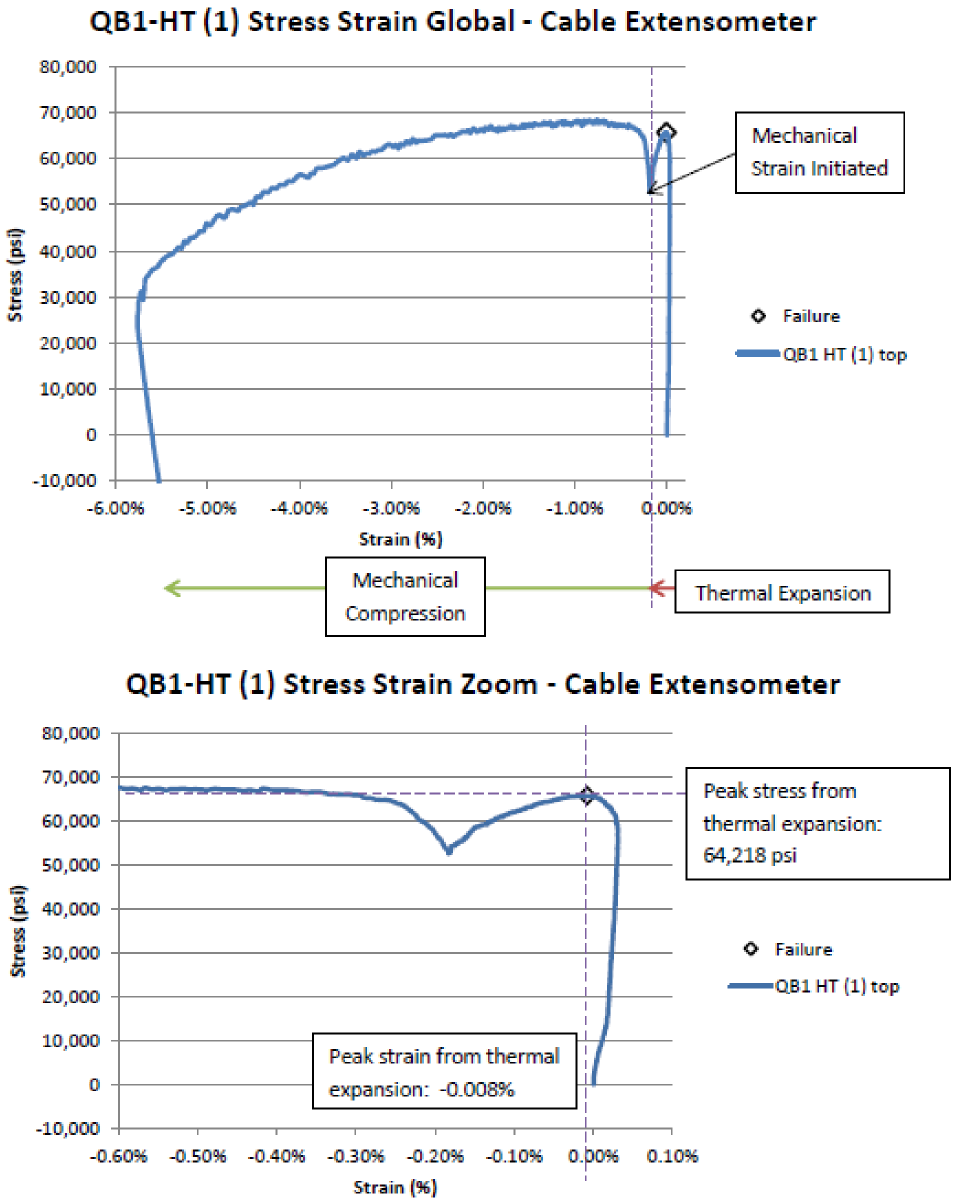


Figure 6: Plastic deformation for API Buttress trial 2



Mechanical Strain Initiated

Mechanical Compression

Thermal Expansion

Peak stress from thermal expansion: 64,218 psi

Peak strain from thermal expansion: -0.008%

Figure 7: Analysis of a Stress vs. Strain graphs for QB1-HT (1)

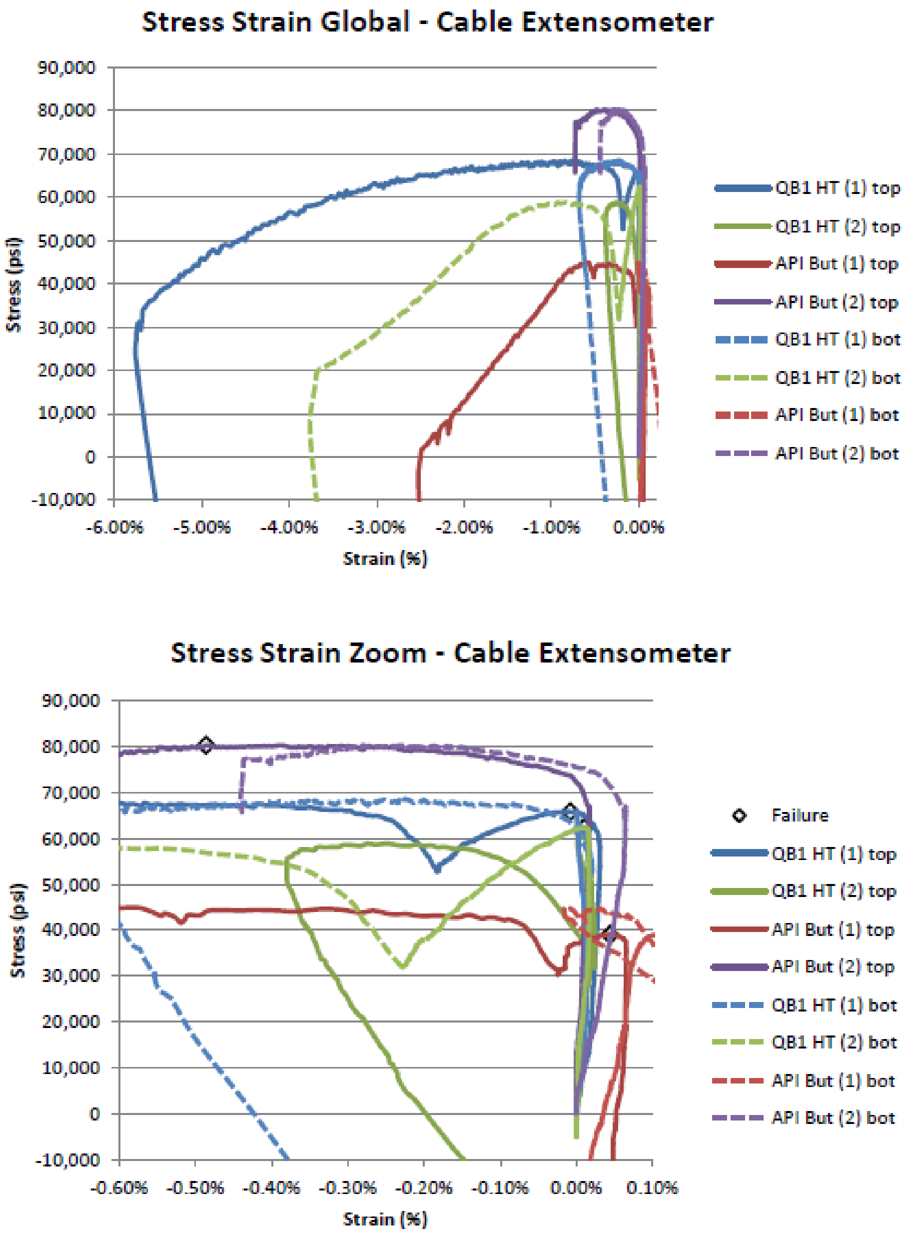


Figure 8: Stress-strain graphs from cable extensometers

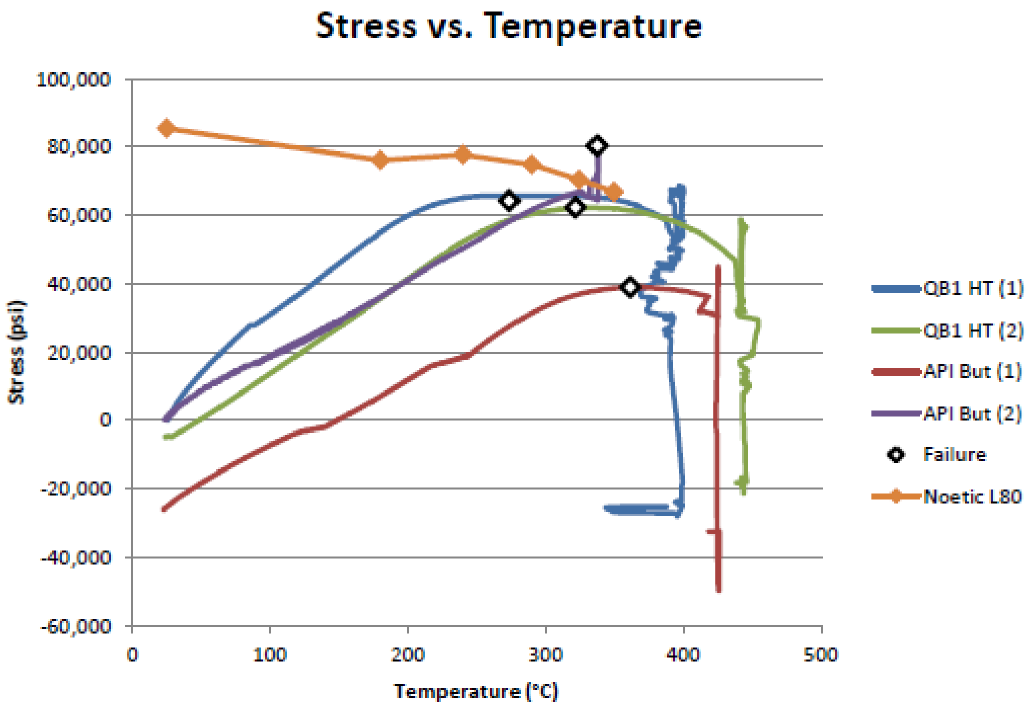


Figure 10: Stress vs. temperature comparison to L80 trials conducted by Noetic