

Elevated-Temperature Stress-Strain Results

Aluminum Zirconium (ACCR) Conductor

This section describes testing results obtained from Southwire ACCR C⁷ conductors made of Celanese C⁷ core and aluminum zirconium (Al-Zr) trapezoidal wires.

Sample Specific Test Procedure

For the high temperature testing, a current transformer was configured to provide current to increase the temperature of the test sample to 180°C. A 600V variable transformer (Variac) supplied current to the current transformer. The motor-driven Variac was controlled by a data acquisition system to provide the necessary current to increase and maintain the temperature in the sample. Additionally, a capacitor bank was connected to the primary side of the current transformer to balance the impedance of the test sample.

A schematic of the high temperature stress-strain test setup is illustrated in Figure 4-14.

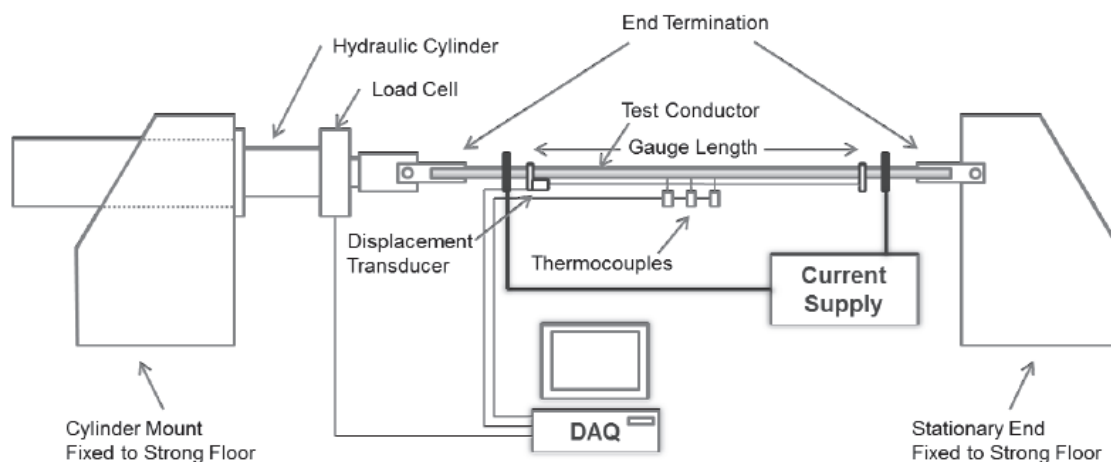


Figure 4-14. Setup for high temperature stress-strain test (schematic)

Photos of the actual Southwire ACCR C⁷ samples for the high temperature test installed in the test bed are shown in

Figure 4-15.

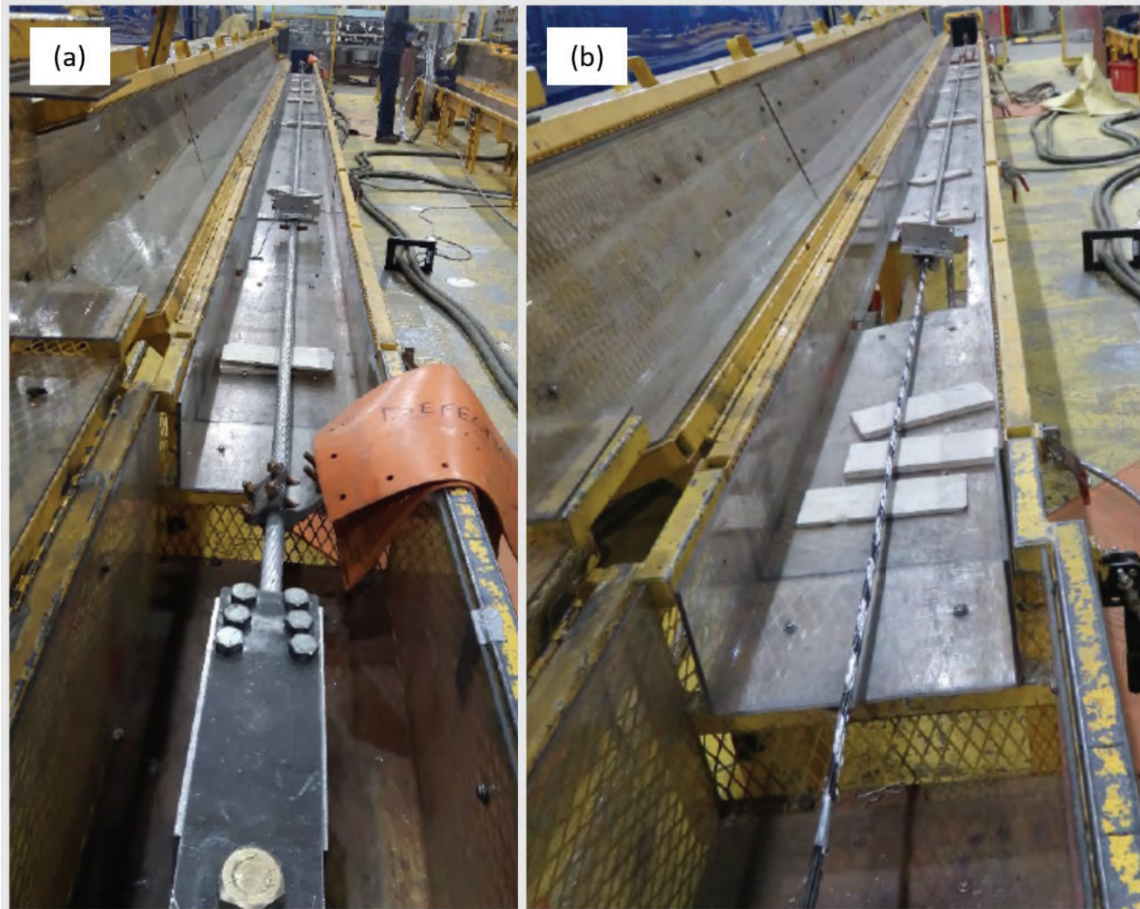


Figure 4-15. (a) Southwire ACCR C⁷ conductor and (b) conductor core samples installed for high temperature stress-strain test

For the high temperature test, the Southwire ACCR C⁷ conductor's UTS at testing temperature was used in place of the conductor's RBS. The following loading schedules were used when evaluating the Southwire ACCR C⁷ whole conductor and core samples at room temperature. The pre-load value (2% of the Southwire ACCR C⁷ conductor's UTS at the testing temperature of 180 °C) was 531 pounds, and the loading rate was 3,986 pounds per minute.

Table 4-9. Loading schedule for Southwire ACCR C⁷ high temperature whole conductor sample

Whole Conductor HT UTS = 26,570 lb (118.2 kN)				
Step	% HT UTS	Load		Hold, minutes
		lb	kN	
Preload	2%	531	2.36	-
1	30%	7,971	35.5	30
2	2%	531	2.36	1
3	50%	13,285	59.1	60
4	2%	531	2.36	1
5	70%	18,599	82.7	60
6	2%	531	2.36	1
7	85%	22,585	100.5	60
8	2%	531	2.36	1

Table 4-10. Loading schedule for Southwire ACCR C⁷ high temperature core sample

Step	Elongation		Hold, minutes
	inch	mm	
Preload	-	-	-
1	1.073	27.26	30
2	-	-	1
3	1.351	34.31	60
4	-	-	1
5	1.863	47.33	60
6	-	-	1
7	2.543	64.60	60
8	-	-	1

Test Results

The strain data for the Southwire ACCR C⁷ conductor and core samples has been corrected because the elongation measurement was taken to be zero at the pre-load value. The samples would have zero strain only when under zero tension, so this adjustment was necessary. Using a straight-line regression of the stress-strain data during step 1 of loading, the corrected strain at pre-load for the Southwire ACCR C⁷ conductor and core samples was 0.0326% and 0.0457%, respectively.

Stress plotted against strain for the Southwire ACCR C⁷ whole conductor and core sample is shown in Figure 4-16 and Figure 4-17 respectively. The points contributing to the stress-strain curve are taken at the end of each hold period as described in IEC 61089, Annex B. The difference in strain from the beginning and end of the stress-strain test is smaller than for the room temperature tests. The high temperature strain after the first loading (step 1 in Table 4-12) is nearly double the room temperature strain (nearly 0.40% compared to slightly above 0.20%). The high temperature strain after the second loading (step 3) is slightly higher than the room temperature strain. However, with each subsequent loading cycle, the strain on the high temperature sample is less than that of the room temperature sample. This may be due to increased difficulty in maintaining tension as the conductor experiences high temperature sag. The stress on the Southwire ACCR C⁷ conductor at each step is also lower than for the room temperature ACCR test.

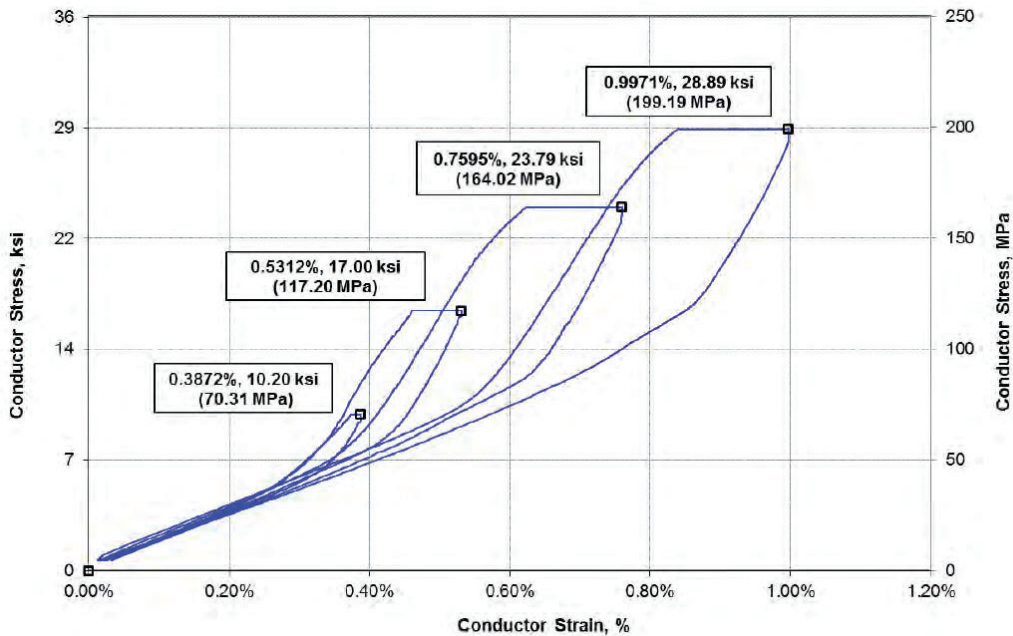


Figure 4-16. Stress vs. conductor strain during Southwire ACCR C⁷ high temperature stress-strain test

The Southwire ACCR C⁷ conductor core deformation is more elastic than the whole conductor, but it is more plastic than at room temperature. This suggests that the glass transition temperature T_g of the carbon-fiber composite (C⁷) core is below the testing temperature of 180 °C. Raising the temperature of the core above its T_g allows its molecules to move more freely, resulting in a softer, more flexible material. It may have a lower strength, but it is also less brittle.

The Southwire ACCR C⁷ core evaluated at high temperature experiences lower stress and lower strain values at each step compared to room temperature, except for step 1 and 3. Again, in step 1, the strain for the high temperature sample is higher. In step 3, the strain for the two tests is similar.

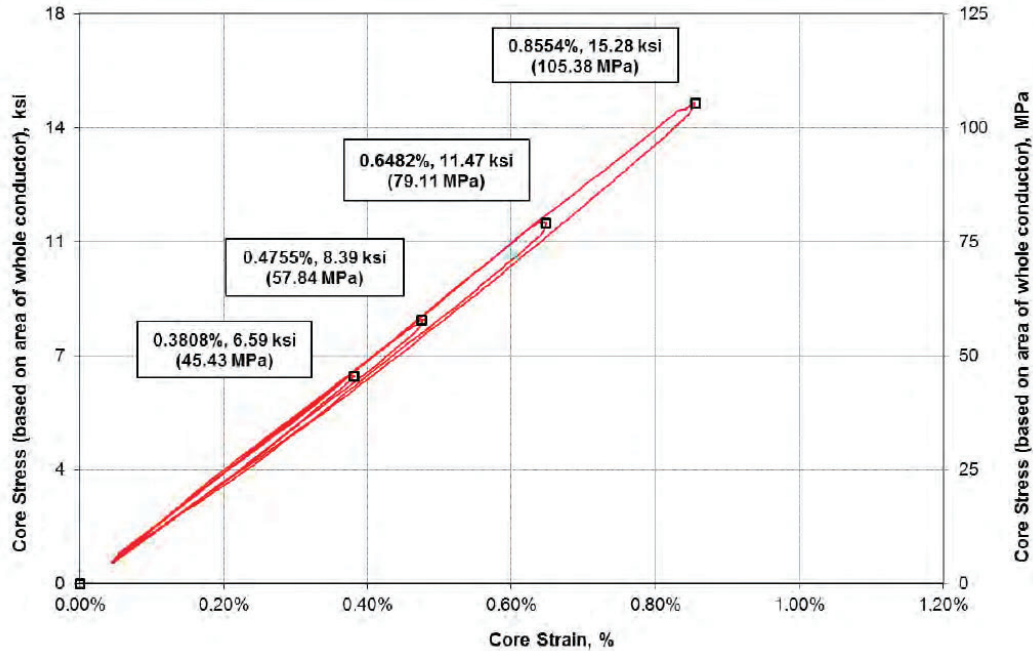


Figure 4-17. Stress vs. core strain during Southwire ACCR C⁷ high temperature stress-strain test

The modulus of elasticity (MOE) can be obtained from the slope of the unloading segment from the last hold for the Southwire ACCR C⁷ whole conductor and core, respectively. The MOE of the aluminum layers is calculated by subtracting corresponding data points of the Southwire ACCR C⁷ whole conductor and core. The MOE of the Southwire ACCR C⁷ whole conductor was found to be 8,192 ksi, whereas the MOE of the conductor core was found to be 1,854 ksi. The MOE of the whole Southwire ACCR C⁷ conductor at high temperature is 1,890 ksi lower than at room temperature. The MOE of the cores is similar regardless of testing temperature.

The best fit curve of the data points gathered at the end of each hold period was a 3rd order polynomial, instead of the 4th order polynomial fit to the room temperature Southwire ACCR C⁷ data. For this reason, the a₄ coefficient from Equation 4-1 was set to zero, resulting in the following equation:

Equation 4-2. General form of the stress-strain curve for the high temperature ACCR test

$$y = a_3x^3 + a_2x^2 + a_1x + a_0$$

where

y (MPa) is stress

x (%) is strain

a₃, a₂, a₁, a₀ (MPa) are the coefficients of the stress-strain polynomial

The stress-strain curve calculated from the gathered data for T13 ZTACCR/TW/C⁷ components is shown in Figure 4-18.

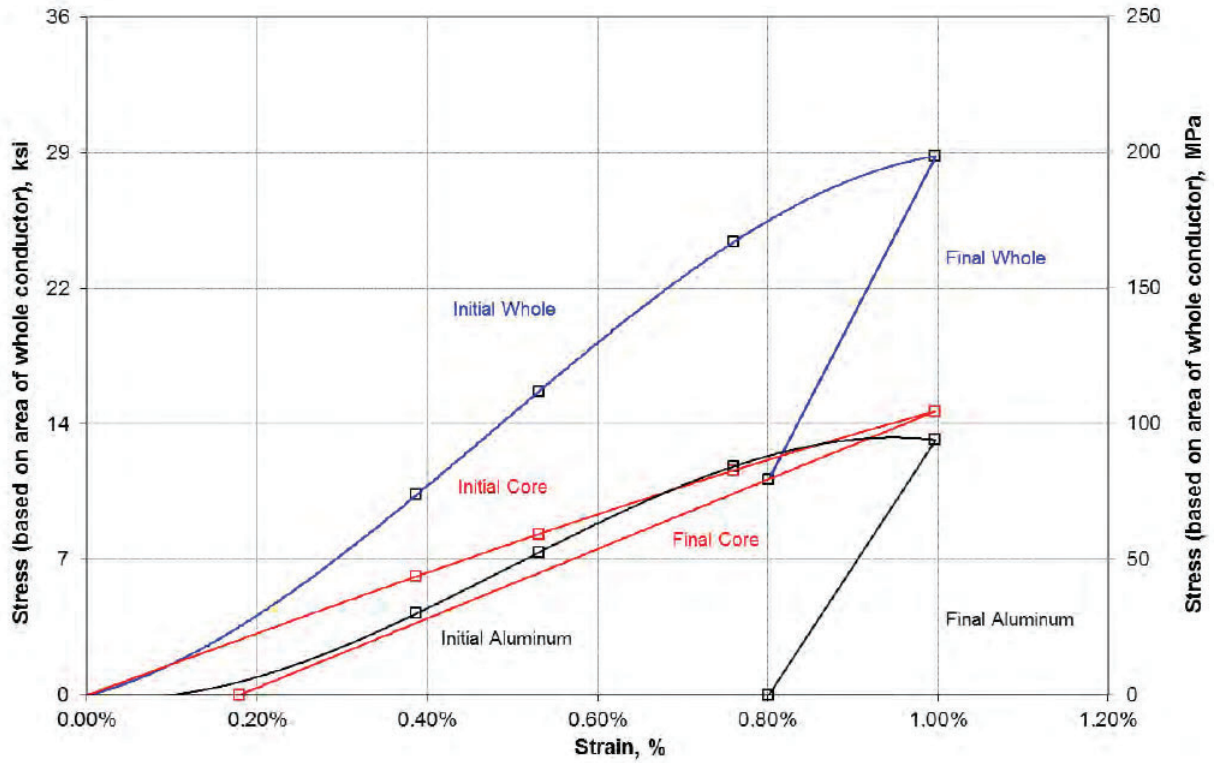


Figure 4-18. Stress-strain curve at 180 °C for T13 ZTACCR/TW/C⁷ (Southwire ACCR C⁷) conductor

The calculated MOE and coefficients of the stress-strain polynomial are shown Table 4-11. The values for the aluminum components of the Southwire ACCR C⁷ conductor are found by subtracting the core from the whole conductor.

Table 4-11. Summary of Southwire ACCR C⁷ high temperature stress-strain test results

Value	Whole Conductor		Core Only		Aluminum Only	
	ksi	MPa	ksi	MPa	ksi	MPa
a ₄ (x ⁴)	0.00	0.00	0.00	0.00	0.00	0.00
a ₃ (x ³)	-39.11	-269.66	-1.49	-10.28	-37.62	-259.38
a ₂ (x ²)	56.11	386.88	0.17	1.14	55.95	385.74
a ₁ (x)	11.86	81.74	16.53	113.96	-4.67	-32.22
a ₀	-0.04	-0.28	0.00	-0.01	-0.04	-0.27
MOE based on Area of Conductor	8,192	56,484	1,854	12,780	6,339	43,704
MOE based on Area of Component	N/A	N/A	14,033	96,752	7,303	50,355

Tension plotted against time for the Southwire ACCR C⁷ whole conductor sample is shown in Figure 4-19. The conductor broke at 30,584 lb. (136.0 kN). The failure occurred near the center of the effective sample length as shown in Figure 4-20.

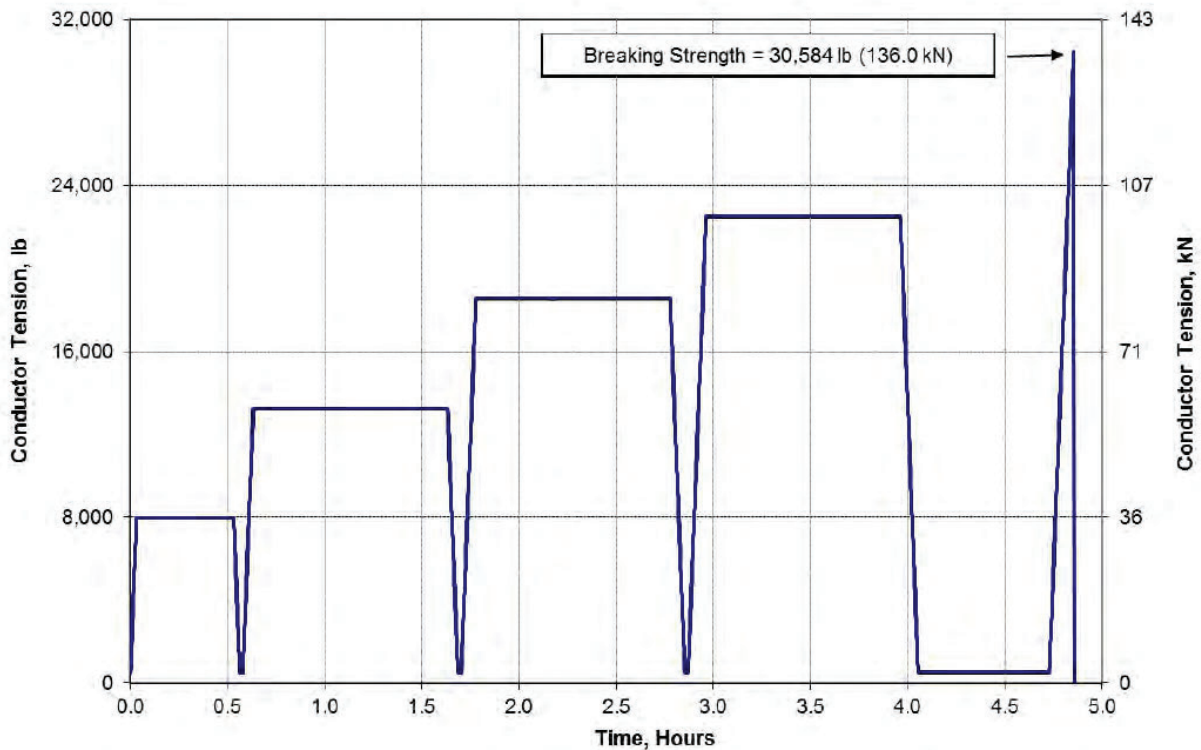


Figure 4-19. Loading history for the Southwire ACCR C⁷ high temperature stress-strain test



Figure 4-20. T13 ZTACCR/TW/C⁷ (Southwire ACCR C⁷) conductor at failure location for high temperature test

O-Temper Aluminum (ACCS) Conductor

This section contains results from testing Southwire ACCS C⁷ conductors made of Celanese C⁷ core and annealed aluminum (1350-O) trapezoidal wires.

Sample Specific Test Procedure

For the high temperature test, the conductor's UTS at testing temperature was used in place of the Southwire ACCS C⁷ conductor's RBS. The following loading schedules were used when evaluating the Southwire ACCS C⁷ whole conductor and core samples at room temperature. The pre-load value (2% of the conductor's UTS at the testing temperature of 180 °C) was 670 pounds, and the loading rate was 5,024 pounds per minute.