Al-Zr Alloy Strand for ACCR Conductor
Experimental Measurement of Resistance Temperature Coefficient

NEETRAC Project Number: 04-235b
3M Purchase Order #0001562911

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A Research Center of the
Georgia Institute of Technology

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SUMMARY

Strands of Al-Zr alloy used in 3M's ACCR conductors were tested to determine the volume resistivity and the temperature coefficient of resistance from room-temperature to 250° C. The purpose is to collect data to better predict the temperature and sag-tension behavior of of ACCR conductor in transmission lines operated at elevated temperature.

KEY FINDINGS

1) The resistance temperature coefficient is linear with respect to temperature up to 250° C. A value of 0.361%/°C was measured. For reference, the Southwire Conductor Manual value for EC alloy 1350-H19 aluminum used in ACSR conductors is 0.404%/°C.
2) Resistivity of Al-Zr alloy at 20° C measured 2.833 μΩ-cm. For reference, the Southwire Conductor Manual resistivity value for EC alloy 1350-H19 aluminum is 2.817 μΩ-cm.

SAMPLES

1) Three (3) strands of Al-Zr aluminum received from Nexans received in January 2005.

PROCEDURE

DC resistance measurements are typically quoted for 20° C conductor temperature. Elevated temperature resistance must be known for ampacity calculations. The 1994 Southwire Conductor Manual provides the following expression for resistance change with changing temperature:

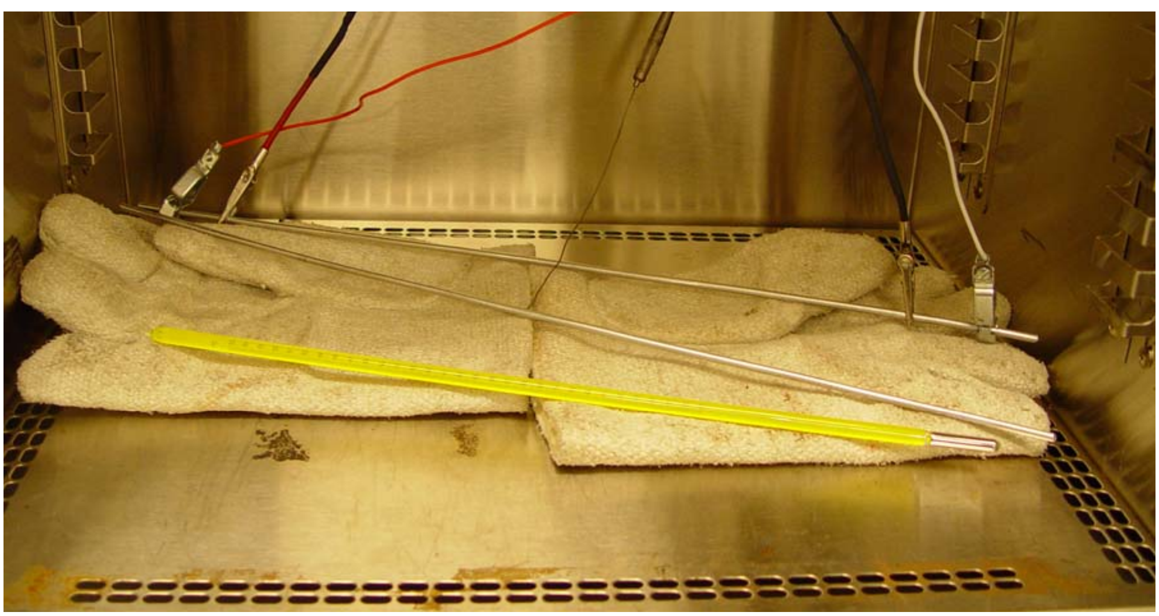
$$\mathbf{R_{T2} = R_{Tref}\,[1+\alpha_{ref}(T_2 - T_{ref})]}$$

where:

α_{ref} =	temperature coefficient of resistance
R_{Tref} =	dc resistance at reference temperature (typically 20° C)
T_2 =	temperature at which new resistance is desired
R_{T2} =	dc resistance at temperature T_2

A test was designed to measure the change in resistance from room temperature to 250° C. Nexans Cables provided Al-Zr strands that had not been stranded into conductor. The strands were relatively straight as-received, but straightening was needed to get close to an ideal test sample. Strand diameter and gage length were measured to provide data for volume resistivity calculations. Taper and ovalness of the test sample were accounted for by measuring diameter at 5 locations along the sample, and in 3 directions at each location (15 total measurements). A jeweler's file was used to make gage marks at two locations on the sample. A caliper micrometer was used to measure distance between the gage marks. A measurement error of +/- 0.020 inches is estimated for a gage section that is nominally 14 inches. This estimate includes an allowance for any residual curvature in the sample. System error due to gage length measurement is, therefore, 0.14%. Two electrical clip leads used to connect the votage leads of the 4-wire resistance instrument to the sample. The clip leads were modified with a die grinder to provide a line contact against the gage marks, and thereby define the active section in the resistance measurement. The two current leads of the 4-wire instrument were connected to the sample ends using standard electrical clip leads.

The test was run in a Blue-M laboratory oven. The oven has forced-air circulation to ensure uniform temperature. Temperature control is on/off only, but it is possible to wait for stable periods where the temperature change was on the order of 0.2° C per minute. To ensure that accurate temperature data was obtained, a set of reference standard thermometers with accuracy certified +/- 0.1° C were placed in the oven as near as practical to the test sample. The thermometers were read visually through the oven window with satisfactory results. A second Al-Zr strand identical to the test sample was prepared. A hole was drilled to the center, and a Type T thermocouple was placed in the center of the sample. The purpose for the second sample was to have a temperature reference with identical thermal properties to the test sample. The test sample could not be directly instrumented for temperature for fear that the local resistance value would be affected by the thermocouple hole. The "dummy" sample was used to monitor temperature stability, and ensure that data was recorded only when the test sample and the more massive glass thermometer were in thermal equilibrium. The samples were placed on heat-resistant fabric gloves to provide electrical isolation from the metal oven parts. Photograph 1 shows the sample arranged in the oven prior to testing.



Photograph 1, test sample (top), dummy with thermocouple (middle), and glass thermometer (bottom)

RESULTS

I) Resistance Temperature Coefficient:

Fifteen evenly-space measurements of the strand diameter showed the minimum and maximum diameters are 0.1520 inches and 0.1525 inches, respectively. This shows the sample is reasonably round and free of taper. The average diameter measures 0.1523 inches. The nominal gage section was 14 inches. A gage section length of 14.015 inches could be consistently measured using a micrometer. Length and average diameter measurements were used to convert the resistance readings to volume resistivity in μΩ-cm.

The glass thermometer is more accurate than a thermocouple temperature indicator, but has lead/lag effects due to thermal time constant larger than the aluminum strand. Therefore, the temperature needed to be stable to ensure that the thermometer correctly reflected the strand temperature. The thermocouple in the dummy sample was used to verify stable temperature. Once stability was confirmed, the glass thermometer was read to the nearest 0.1° C. A total of seven (7) different thermometers were needed to cover the full temperature range. Because of viewing conditions through the oven window, it was not feasible to interpolate an additional decade of resolution. One reading at 217° C fell outside a reasonable range, and was discarded as an anomalous data point. All other data points are used as-recorded. No attempt was made to adjust the sample dimensions for temperature change (all resistivity values are based on room-temperature dimensions). Figure 1 shows the heat-up curve, along with the calculated volume resistivity based on the room-temperature dimensions of the test sample.

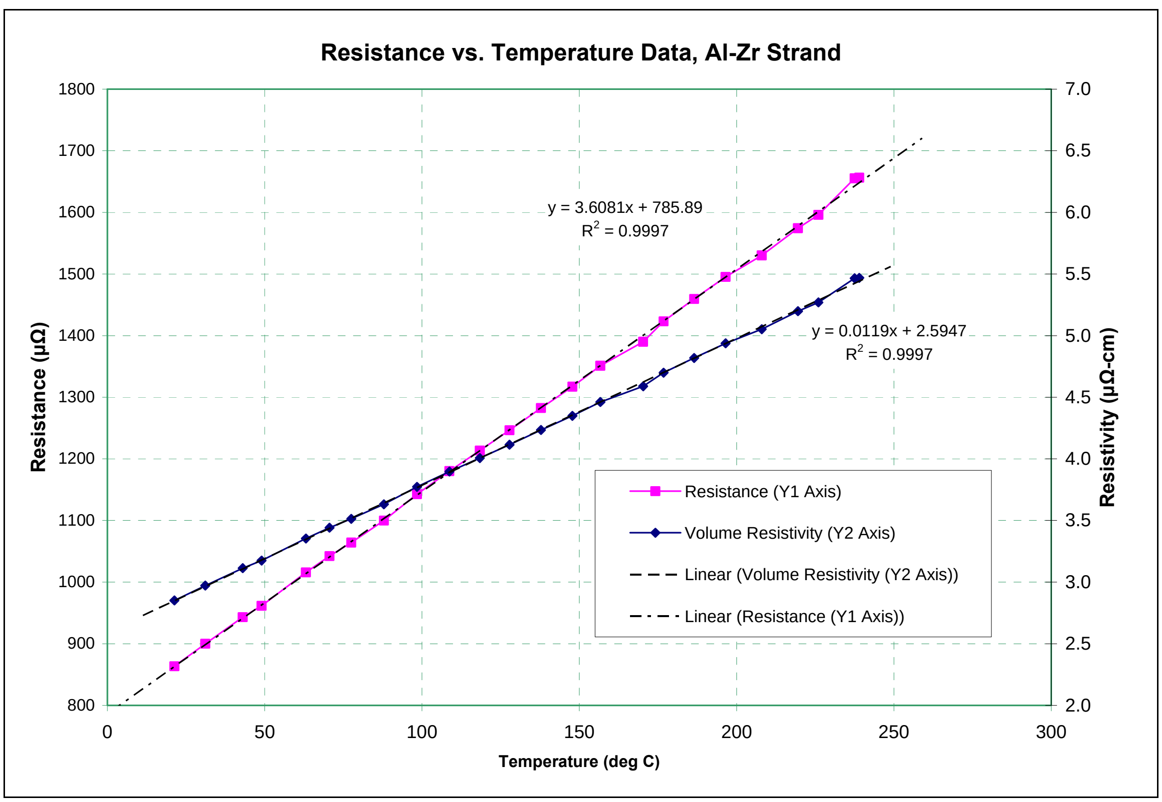


Figure 1, data and linear fits for resistance vs. temperature data

Additional data was recorded during the cool-down of the sample from 250° C. In this case, the glass thermometer fell below range at 240° C. Because the door needed to remain closed to minimize thermal gradients, only the dummy-sample thermocouple could be recorded. Figure 2 shows the heat-up and cool-down data for the thermocouple in the dummy sample. This data is considered less reliable than the data based on the reference standard thermometer set.

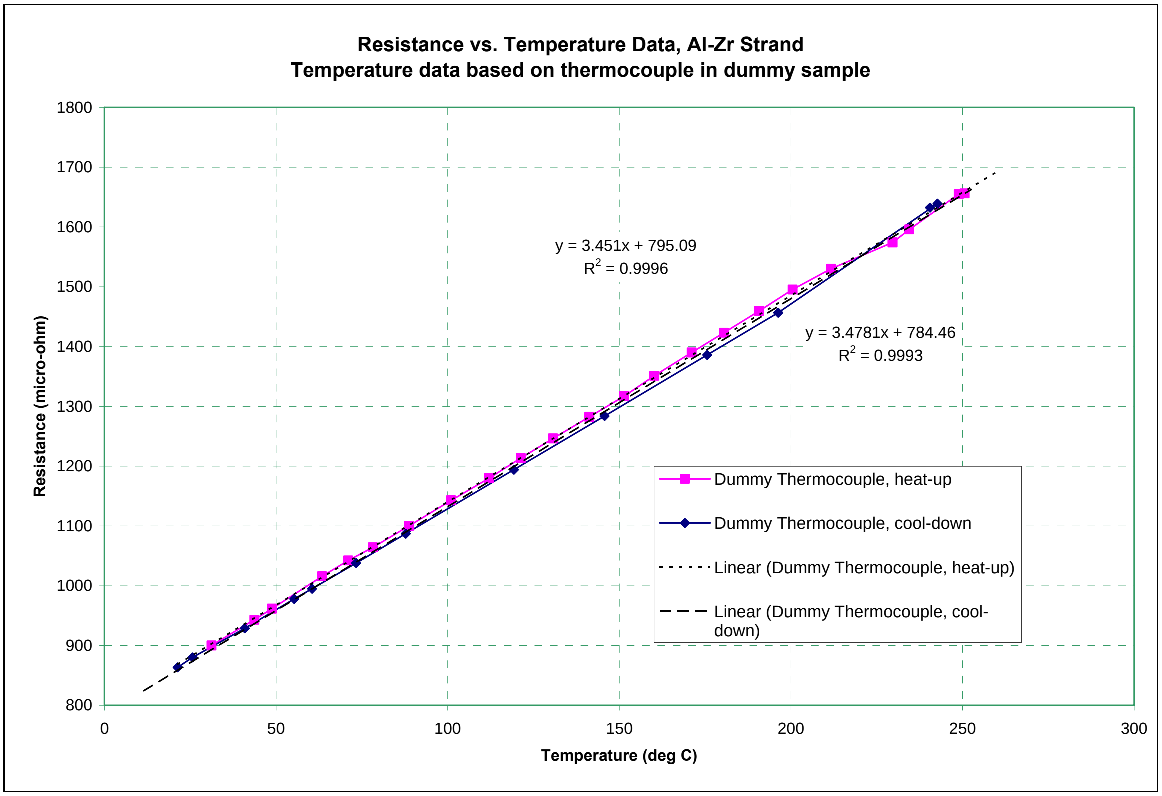


Figure 2, resistance temperature coefficient based on thermocouple temperature data (considered less reliable than data from glass thermometer)

Summary of resistance temperature coefficient:

1) Reference thermometer data imply $\alpha_{ref} = 0.003608$
2) Thermocouple data imply $\alpha_{ref} = 0.003451$ to 0.003478
3) Volume resistivity of the Al-Zr strand is 2.833 μΩ-cm at 20° C

CONCLUSION

The temperature coefficient for resistance, α_{ref}, measures 0.00361 based on a linear fit through the test data. Polynomial fits through the test data fail to improve the correlation coefficient. Therefore, the coefficient is linear with respect to temperature. Published values of α_{ref} for 1350-H19 EC grade aluminum range from 0.00403 to 0.00423. According to the Southwire reference, values of α_{ref} depend on the conductivity of the aluminum.

EQUIPMENT LISTING

1) AVO/Biddle Digital Low Resistance Ohmmeter, Calibration Control #CQ 1092
2) Fluke 77 thermocouple reader, Calibration Control # CQ 0173
3) Starrett digital caliper micrometer, Calibration Control # CQ 3046 (diameter measurements)
4) Starrett vernier caliper micrometer, Calibration Control # CQ 0144 (length measurements)
5) Brooklyn Reference Standard Thermometer Set, Calibration Control # CN 0155