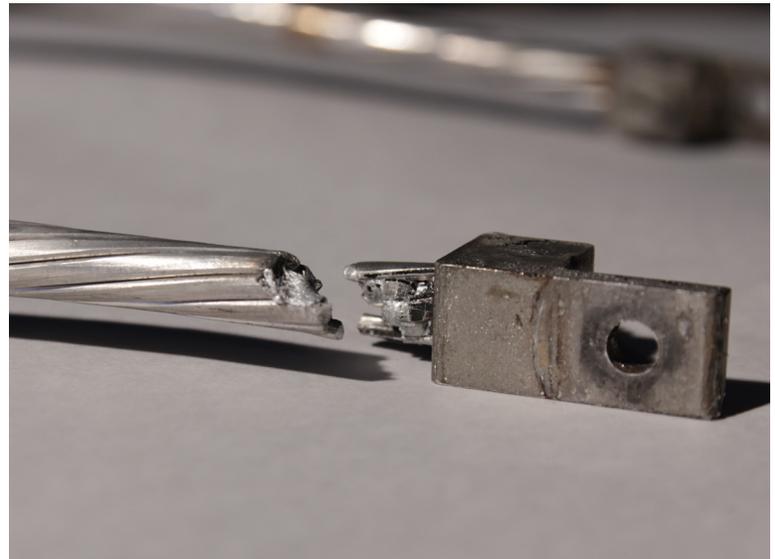
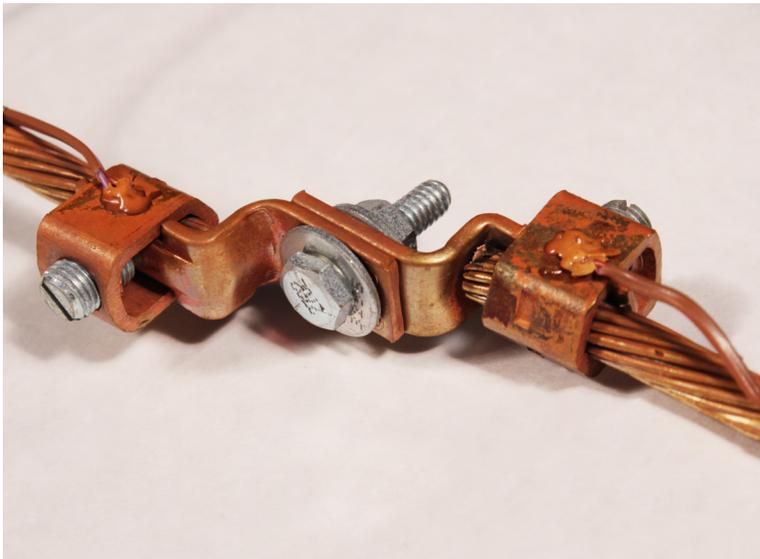




Copper Development
Association Inc.
Copper Alliance

Copper or Aluminum: Connectability Counts



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Knowing the connectability of copper and aluminum alloy conductors is important to safety and reliability. Their dependability is directly related to how they are terminated. And, the long-term performance of the conductors and connectors is critical to your selection and design process. What follows is a brief look at what you need to know before taking on your next engineering/installation project.

Probably the most used wire sizes for low-voltage (less than 1,000 volts) electrical power distribution applications are #1 AWG copper and #2/0 AWG aluminum. These two products are widely used because they are comparable in resistance and conductivity. Aluminum wire conductivity is approximately 61% that of copper, so the resistance of aluminum wire is nearly the same as that of a copper wire 2 AWG sizes smaller (about 63% of the area size of aluminum).

To assess their performance in a circuit, Powertech Labs of Surrey, British Columbia, Canada, tested multiple samples of the two types of conductors and two types of mechanical screw-type connectors. Compression connectors were not considered, because at some point in every circuit a screw-type connection is required, and failures are more likely at screw-type connections. The wires and connectors used in the study were standard, stock products from commonly available manufacturers and sourced from local North American suppliers

What was tested?

Three wire/connector combinations were used in the study:

- Copper wire (1/0 AWG, 600V) with CU copper connectors
- Copper wire (1/0 AWG, 600V) with AL/CU dual-rated aluminum body connectors
- Aluminum wire (2/0 AWG, 600V) with AL/CU dual-rated aluminum connectors

Multiple sets of wires were connected using 70%, 100% and 125% of rated torque applied to the set screw. Copper wire samples were prepared without wire brushing or abrasion of the wire or connector, and no oxide inhibitor was used. For aluminum wire samples, three different preparation methods were used and were based on the manufacturer's installation instructions where appropriate:

- Wire brushing/abrasion of the bare wire surface and application of an oxide inhibitor (contact lubricant)
- Application of oxide inhibitor only
- No oxide inhibitor and no abrasion

Neither oxide inhibitor nor any other lubricant was used on the set screw threads.



Figure 1: Typical connector sample. Aluminum wire and AL/CU dual-rated connector shown.

Test set-up and procedure.

Four reference or control conductors were used, two each of aluminum and copper. Sixty test samples were suspended in air on wooden rails (for natural convection cooling) and connected together in a series loop, so the same current level could be passed through all samples simultaneously. In order to test all possible combinations of wires, connectors, connector preparation and torque ratings, the study used four samples for each of 15 variations of connection (24 related to copper wire and 36 related to aluminum alloy wire). The testing of the connections was based on IEC 61238-1 (2003–05), with connections made in accordance with ANSI C119.4-2011.

The samples were subjected to 1,500 heating/cooling cycles. Each cycle consisted of 1 hour of heating by applying high current followed by 1.25 hours of natural cooling with no current applied. The current level used (280 A) heated the samples to a rise of 100°C–105°C above the ambient temperature (25°C–30°C). The tests were conducted in a high-humidity environment (greater than 90% RH, non-condensing).

A one-time short-circuit current was applied to each sample after the 200th current cycle to achieve 250°C–270°C on the reference conductors, as called for in the IEC test method. The DC resistance of the connectors was measured about every 100 cycles or less, and the temperature of the connectors and reference conductors was closely monitored. Temperatures were measured using thermocouples attached to the surface of the connector body with thermally conductive epoxy. Connection performance was evaluated by the change in the corrected DC resistance and temperature rise above that of the control conductor over the course of the test.

The results.

Overall, good performing connectors should exhibit a trend of stability of resistance and temperature readings throughout the testing. **Figures 2 (resistance) and 3 (temperature)** show the results of each of the 60 tested connections. (The full study contains the labelling of samples regarding the preparation and torque.)

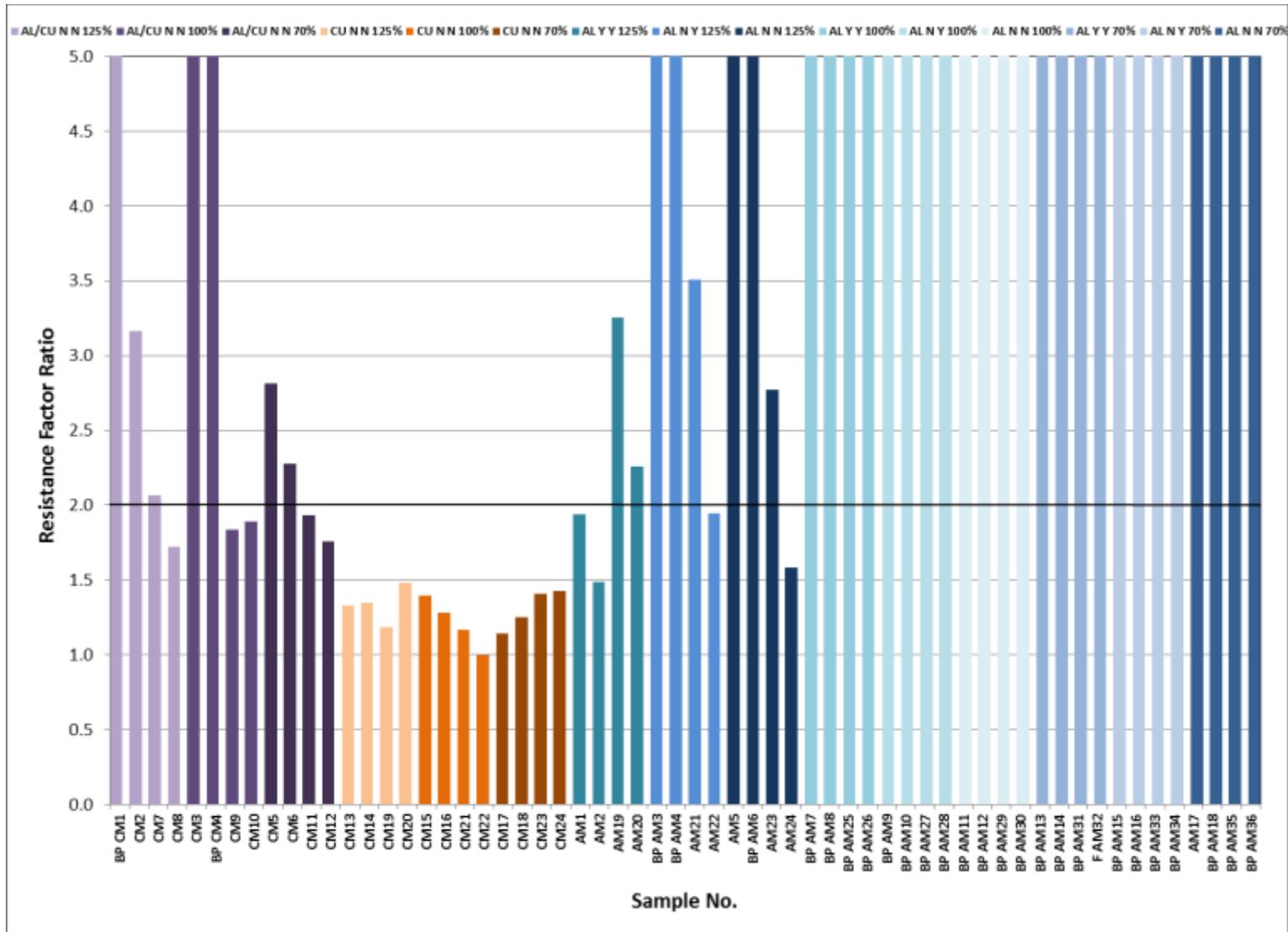


Figure 2. IEC resistance factor ratio for each sample, with the maximum IEC limit indicated by a line at 2.0. Samples are grouped by type and preparation. Solid bars off scale indicate samples that failed and were removed from the test. Color scale at top of the figure indicates conductor type, preparation and torque. Samples labelled “C” are copper while samples labelled “A” are aluminum.

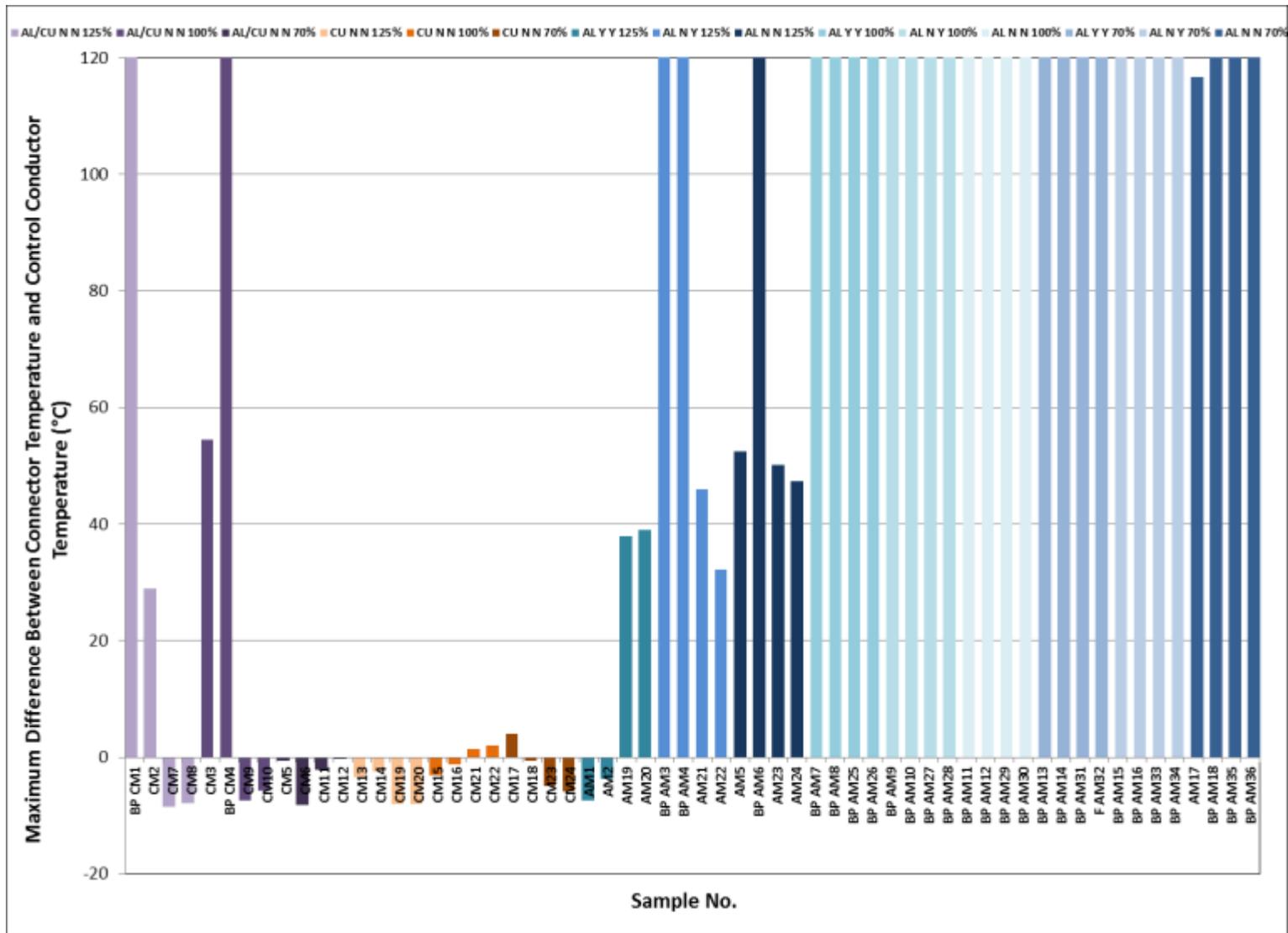


Figure 3. IEC maximum difference between connector temperature and control conductor for each sample. Samples are grouped by type and preparation. Solid off scale bars indicate samples that failed and were removed from the test.

In **Figure 2**, test samples that come in below the horizontal black line (resistance factor of 2.0) are considered to have passed. The further below the line, the better. Above the line is a failure. In **Figure 3**, test samples that are very near or below the temperature of the control conductor (shown as 0) are considered as passing. In both tests, copper conductors with copper connectors outperform aluminum alloy conductor and connector combinations by meaningful margins. Here are the general results for the three basic combinations of conductors and connectors following 1,500 cycles of testing:

- **Mechanical copper (CU) connectors on #1 AWG copper wire:**
All samples had a relatively stable resistance and temperature over the course of the test, and none showed a trend of significantly increasing resistance and temperature by the end of the test. No samples failed.
- **Mechanical dual-rated (AL/CU) connectors on #1 AWG copper wire:**
A third of the samples failed or showed a trend of significantly increasing resistance and temperature by the end of the test. There was no definite correlation between performance and the torque level applied to the connectors at the start of the test.
- **Mechanical dual-rated (AL/CU) connectors on #2/0 AWG aluminum wire:**
More than 90% of the samples failed or showed a trend of significantly increasing resistance and temperature by the end of the test. The best performance was achieved by the samples that had been prepared with the conductor wire brushed (abraded), oxide inhibitor applied, and a torque level of 125% of the rated torque.

What can we conclude?

- **Copper mechanical connectors on copper wire** perform the best and have the most stable resistance and temperature readings.
- **Aluminum (dual rated) mechanical connectors on copper wire** perform relatively poorly, with one-third of the samples failing or showing elevated resistance and temperature levels by the end of the test.

Aluminum (dual rated) mechanical connectors on aluminum wire perform very poorly, and have a very high failure rate, even before reaching the midpoint of the test. More than 90% of the samples either fail or show elevated resistance and temperature levels by the end of the test. There is no clear correlation between conductor preparation method, torque level, and failure, except that the connectors that had been torqued to 125% of the manufacturers rated torque level seemed to perform slightly better than the others.

In summary, the study demonstrates conclusively that copper conductors with copper connectors are the most reliable and dependable for electrical power distribution. Complete details of the study are available online at http://www.copper.org/publications/pub_list/pdf/A6163-ConnectabilityTesting.pdf.

Related studies available online: **Connecting with Copper Is Connecting with Trust**, http://www.copper.org/publications/pub_list/pdf/a6123.pdf; **Comparative Corrosion and Current Burst Testing of Copper and Aluminum Electrical Power Connectors**, <http://www.copper.org/applications/electrical/building/pdf/A6108.pdf>.

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