Evaluation of Aluminum and Copper Connectors

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Purpose

- Evaluate aluminum 8000 series alloy and copper conductors and terminations
- Evaluate Chinese and North American product

Powertech Labs

Ground Rule

- All material was purchased on the open market from a local electrical distributor (manufacturer in the case of China.) There was no selection of any sample prior to testing.
- Powertech tested #1 AWG copper, 2/0 AWG Aluminum alloy for heat cycle test. Only North American tests are presented here.

Material Evaluation

- Chinese and N.A. Copper

Table 9. Principal trace elements found in the Copper wire (ppm by weight).

Element	North American			Chinese		
	#1 AWG	4/0 AWG	500 kcmil	50 mm²	120 mm²	240 mm²
Cu*	Major	Major	Major	Major	Major	Major
Ag	7.2	14	11	3.6	16	9.0
Fe	15	2.0	2.2	3.7	0.38	1.9
S	4.0	3.0	4.2	2.7	2.6	3.1
Sb	0.54	0.78	<0.3	0.50	3.0	1.8
Pb	1.7	0.67	0.28	1.1	0.64	1.6
Ni	0.39	1.3	0.20	0.31	0.47	0.57
As	0.53	0.51	0.32	0.27	0.86	0.54
Bi	0.67	0.17	0.11	0.16	0.45	0.48
Se	0.39	0.21	< 0.1	<0.1	< 0.1	< 0.1

*Major elements are outside the range of quantified measurement.

Material Evaluation

- Chinese and N.A. Aluminum Alloy

Table 10. Principal alloy and trace elements found in the Aluminum wire (ppm by weight).

Element	North American			Chinese		
	2/0 AWG	300 kcmil	750 kcmil	70 mm²	150 mm²	400 mm²
Al*	**Major**	**Major**	**Major**	**Major**	**Major**	**Major**
Fe	**5400**	**5660**	**6955**	**9250**	**7200**	**9585**
Cu	7.4	4.6	10	**1265**	**1820**	**1310**
Si	**485**	**490**	**510**	**760**	**995**	**590**
Zn	160	130	105	50	55	50
Ga	50	50	70	110	150	80
B	12	11	4.2	34	100	25
V	43	55	80	23	5.0	2.8
P	6.7	2.3	3.2	27	14	60
Ni	42	20	18	55	55	55
Ca	0.35	0.21	0.56	0.16	0.46	45
Mn	40	35	23	36	14	24
Ti	36	38	26	10	27	25
Pb	5.0	2.9	3.4	11	23	14
Mg	6.7	3.0	3.0	8.5	20	9.7
Cr	4.2	4.5	3.8	15	4.2	14
Sn	<0.3	< 0.3	0.65	0.36	5.2	1.6
Co	2.6	2.2	1.3	2.8	3.4	4.1
Zr	2.8	2.4	3.6	1.4	1.9	1.5
Ce	1.6	0.50	0.42	3.6	0.37	0.52
La	1.8	0.88	1.2	3.3	1.4	1.4
U	0.42	0.43	0.49	1.2	0.41	0.63

*Major elements are outside the range of quantified measurement.

Connectability Tests

- Preparation:

Aluminum alloy sample were prepared as follows:

With and without wire brushing

With and without oxide inhibitor

Copper samples were not brushed or treated with inhibitor

Connectability Tests

- Torque:

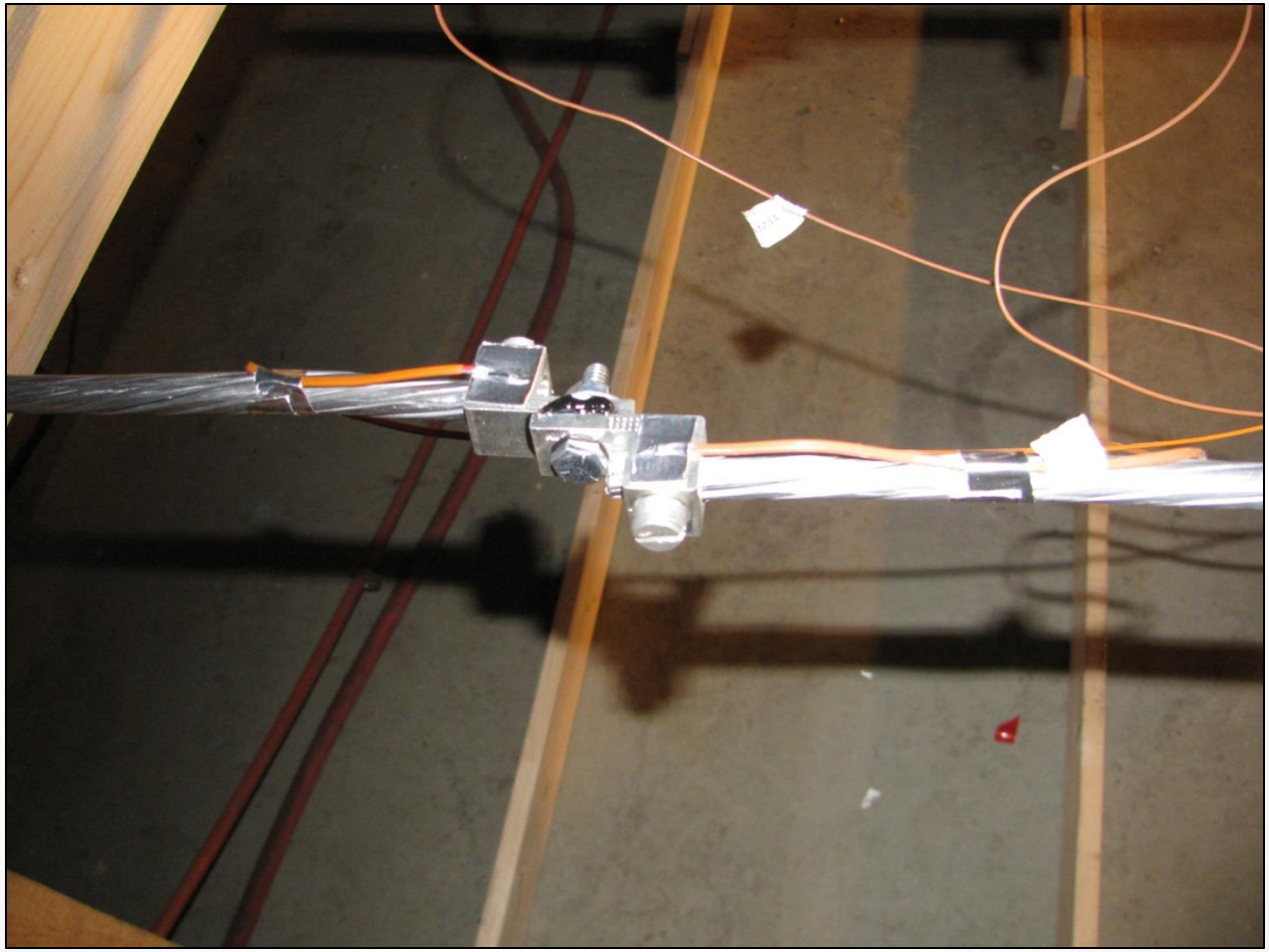
All samples, aluminum alloy and copper, were tested at 70% rated torque, 100% rated torque and 125% rated torque.

Test Methods

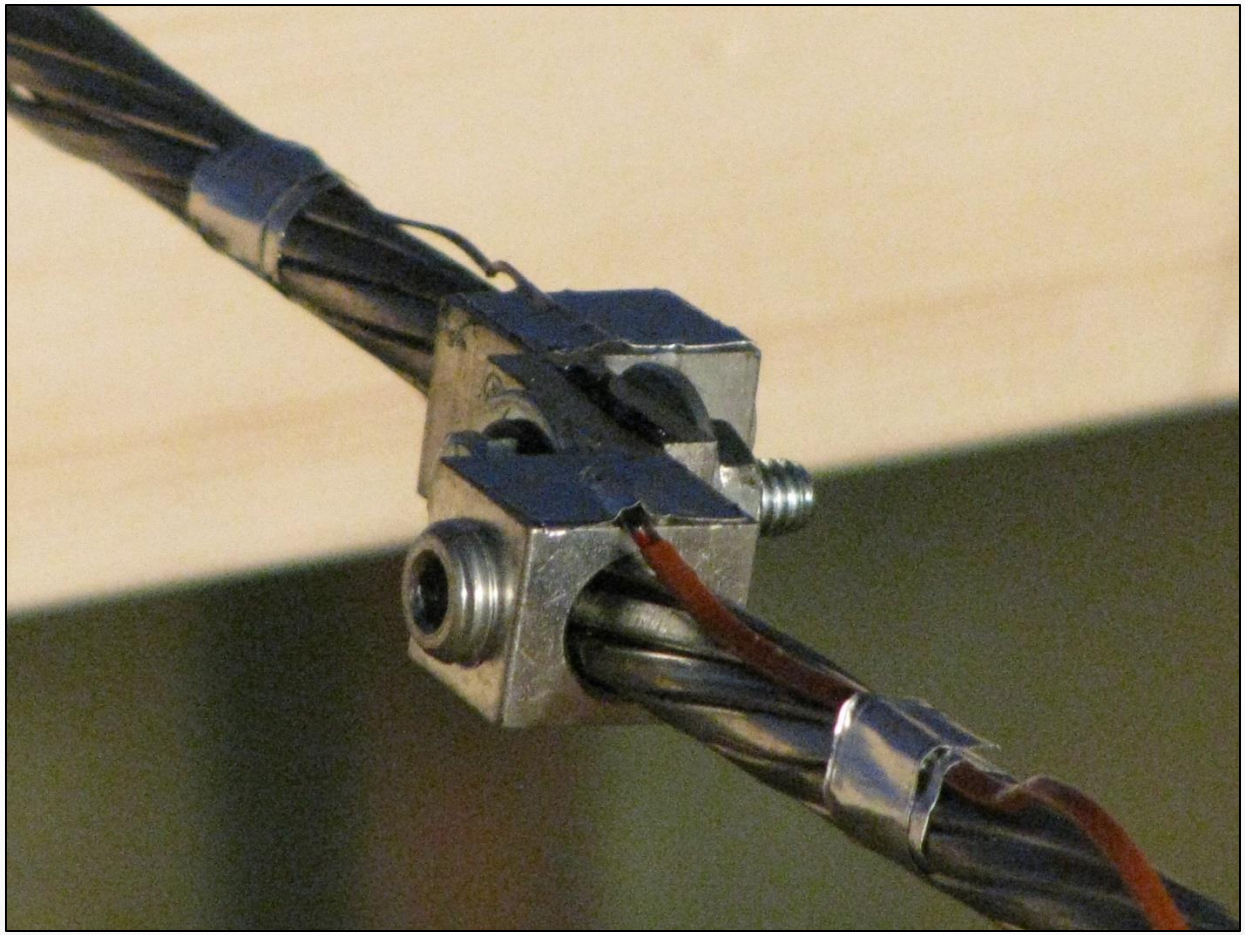
- IEC 61238-1 was used for testing
- More stringent than standard UL test used in North America

Samples Were in Series

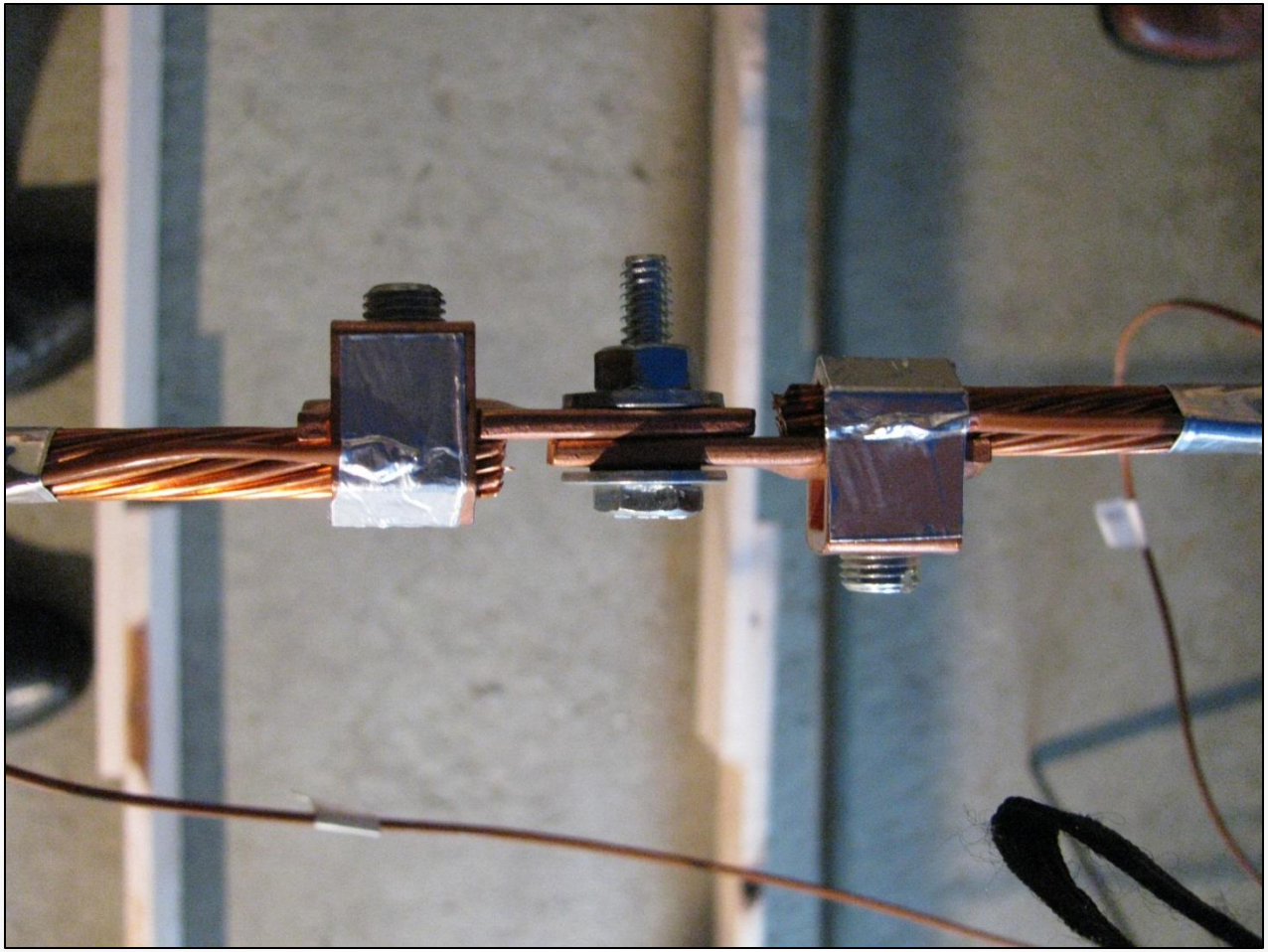
Close-up of Connector



Close-up of Connector



Close-up of Connector



Samples Set Up for Test

Summary of Samples

Table 3. Sample preparation used for the current cycle tests.

Type	Conductor	Connector Rating	Abrasion	Inhibitor	Torque	Total No. Units
Control	#1 Cu	---	---	---	---	2
Control	2/0 Al	---	---	---	---	2
Mechanical	#1 Cu	AL/CU	N	N	125%	4
Mechanical	#1 Cu	AL/CU	N	N	100%	4
Mechanical	#1 Cu	AL/CU	N	N	70%	4
Mechanical	#1 Cu	CU	N	N	125%	4
Mechanical	#1 Cu	CU	N	N	100%	4
Mechanical	#1 Cu	CU	N	N	70%	4
Mechanical	2/0 Al	AL/CU	Y	Y	125%	4
Mechanical	2/0 Al	AL/CU	N	Y	125%	4
Mechanical	2/0 Al	AL/CU	N	N	125%	4
Mechanical	2/0 Al	AL/CU	Y	Y	100%	4
Mechanical	2/0 Al	AL/CU	N	Y	100%	4
Mechanical	2/0 Al	AL/CU	N	N	100%	4
Mechanical	2/0 Al	AL/CU	Y	Y	70%	4
Mechanical	2/0 Al	AL/CU	N	Y	70%	4
Mechanical	2/0 Al	AL/CU	N	N	70%	4

Typical Heat Rise

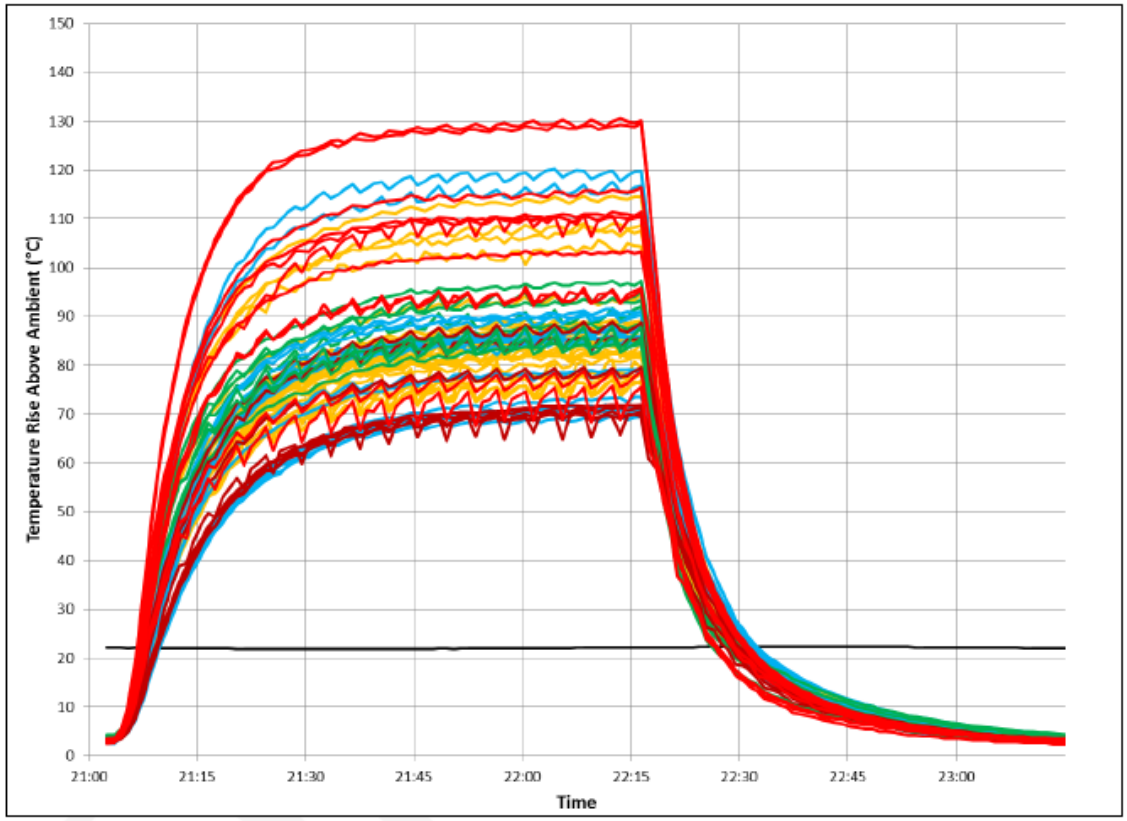


Figure 6. Typical heating/cooling cycle.

Different Ways to Evaluate Results

- Resistance Ratio
- Heat rise

Resistance Ratio of Connector

- FAIL
- PASS

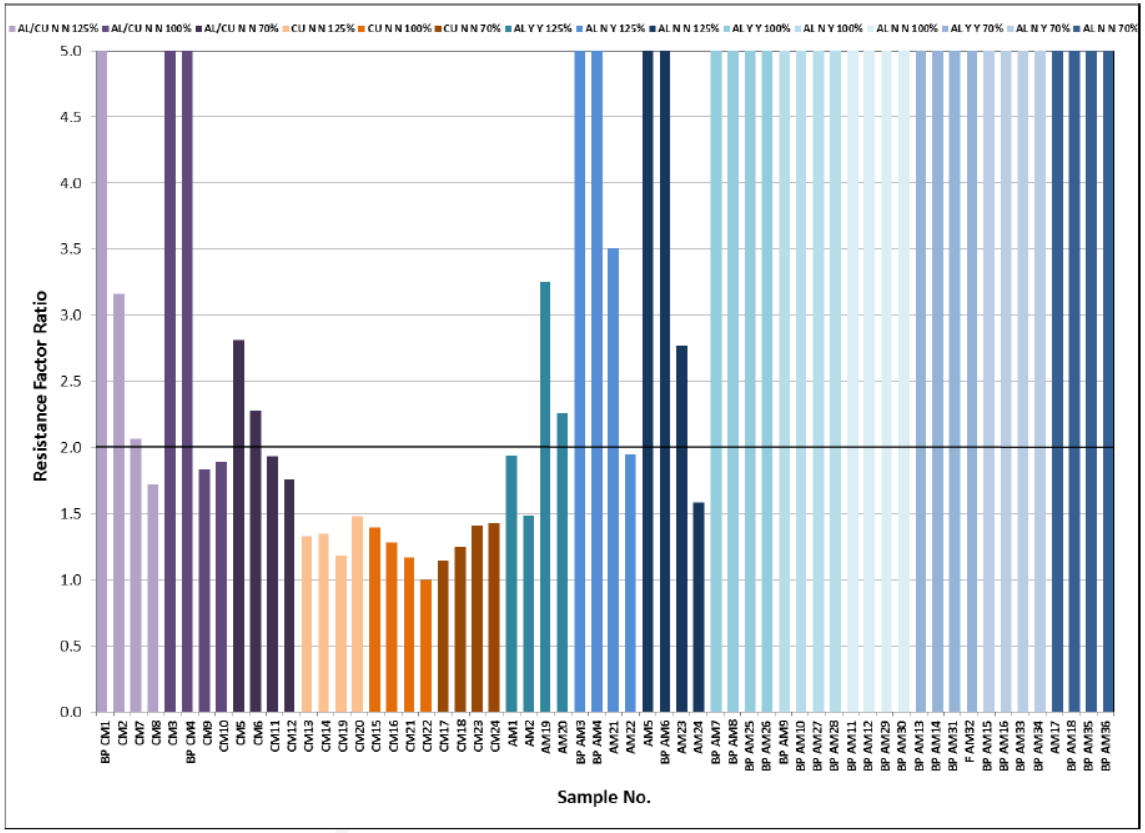


Figure 43. IEC resistance factor ratio for each sample, with the maximum IEC limit indicated by a line at 2.0. Samples are grouped by type and preparation. Solid bars indicate samples that failed and were removed from the test.

Temperature Rise Above Control

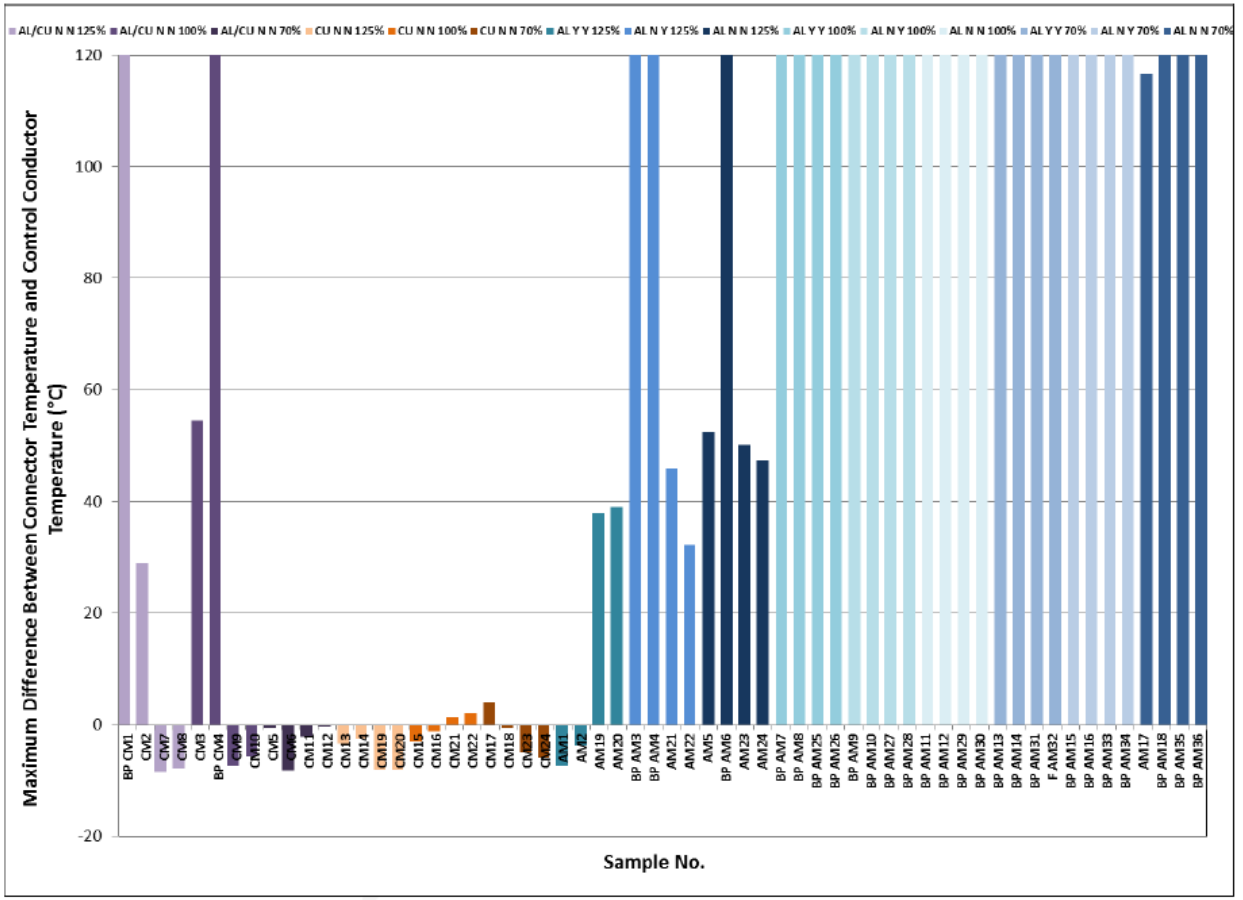
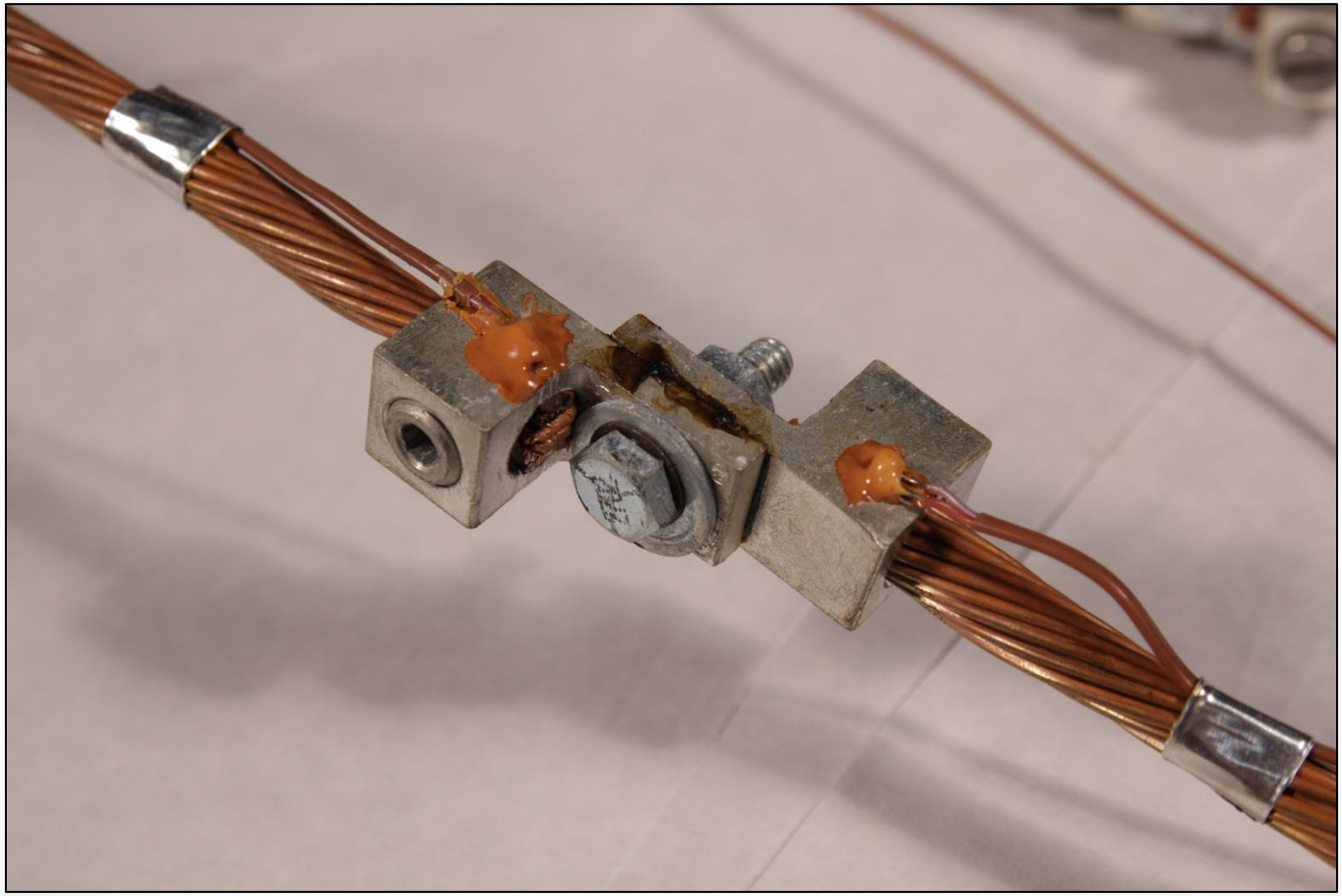


Figure 44. Difference between connector temperature and control conductor for each sample. Samples are grouped by typ and preparation. Solid bars indicate samples that failed and were removed from the test.

Conclusions

- **Mechanical dual-rated (AL/CU) connectors on #1 AWG copper wire**: 33% 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.

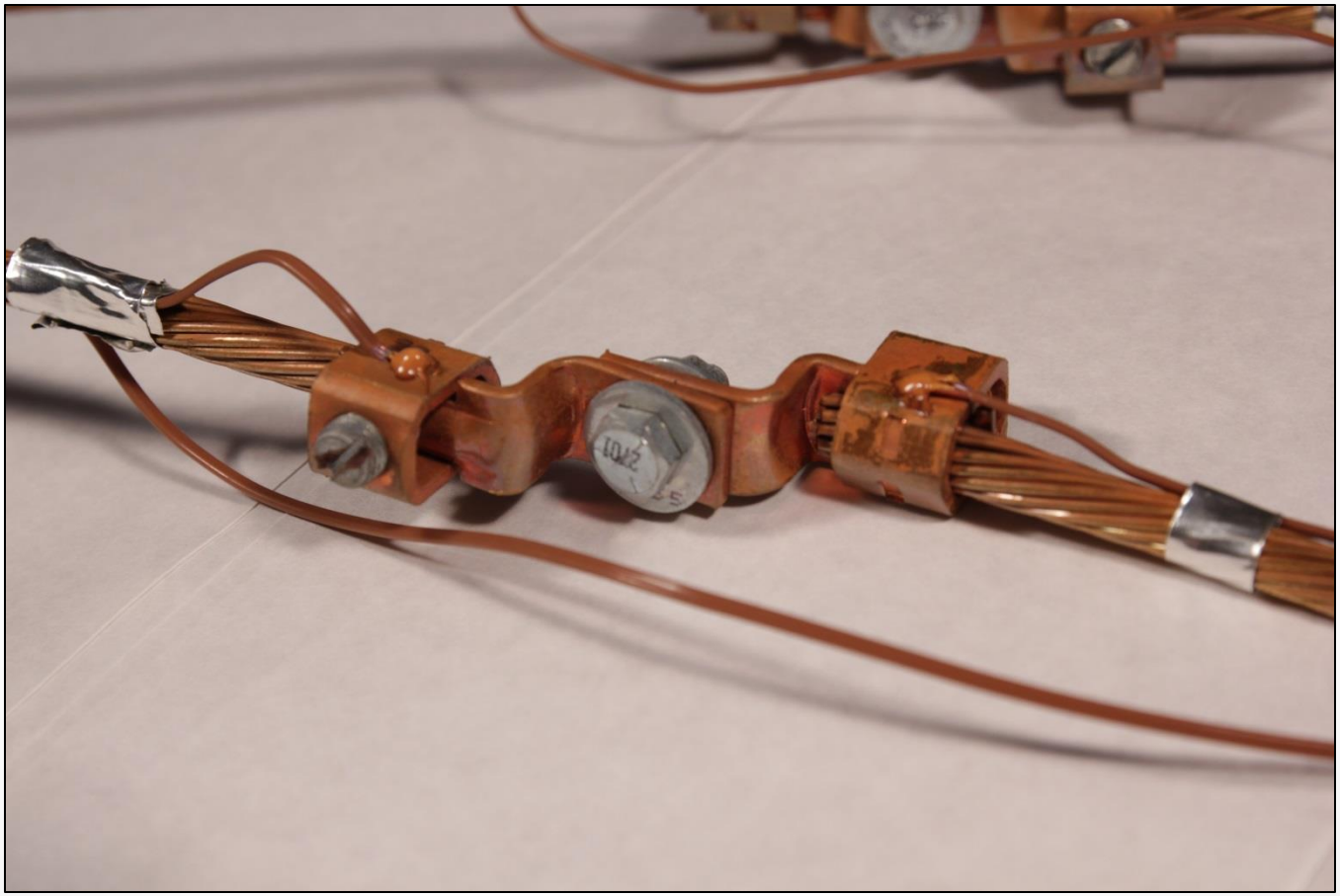
Copper on Dual-rated



Conclusions

- **Mechanical copper (CU) connectors on #1 AWG copper wire**: All samples had a relatively stable resistance and temperature over the course of the test. No samples failed, and none showed a trend of significantly increasing resistance and temperature by the end of the test.

Conclusions

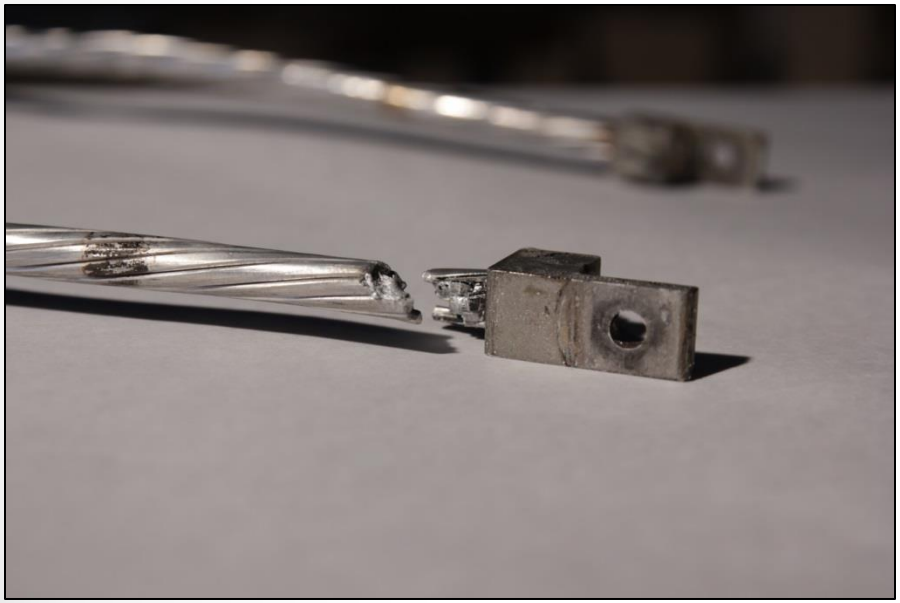


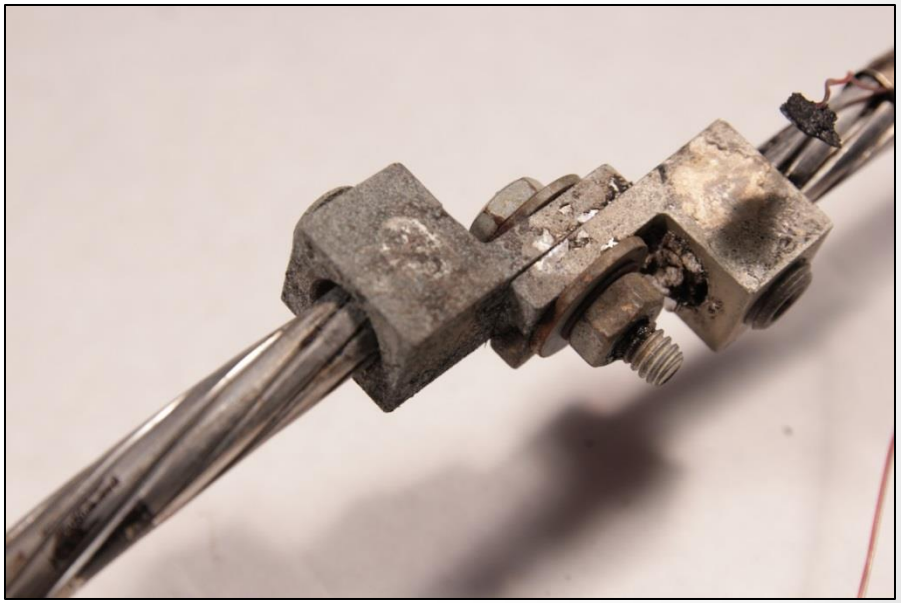
Conclusions

- **Mechanical dual-rated (AL/CU) connectors on #2/0 AWG aluminum wire**: 94% of the samples failed or showed a trend of significantly increasing resistance and temperature by the end of the test.

- **100% of the aluminum samples tightened to100% of rated torque failed, regardless of preparation.**

Conclusions





Overall

- The **aluminum (dual-rated) mechanical connectors on copper wire** performed relatively poorly during the test, with 1/3 of the samples failing or showing elevated resistance and temperature levels by the end of the test.

- The **aluminum (dual rated) mechanical connectors on aluminum wire** performed very poorly during the test, and had a very high failure rate even before the mid-point of the test. Over 90% of the samples had either failed or showed elevated resistance and temperature levels by the end of the test. There was no clear correlation between conductor preparation method, torque level, and failure.

Thank you for your attention

Questions?

Complete Report is available at:
http://www.copper.org/BW

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