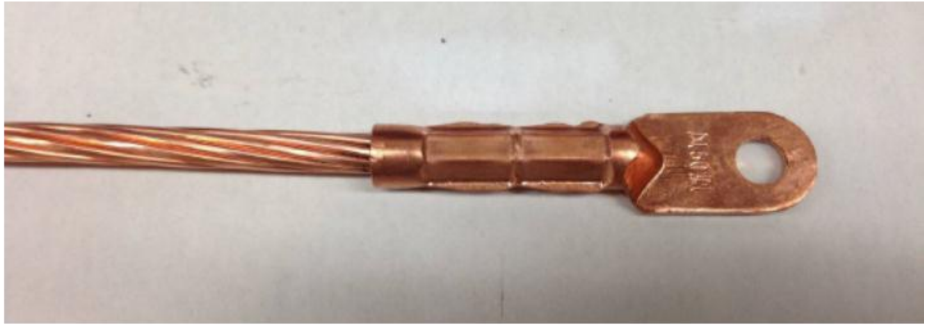
Cu Copper Alliance

Evaluation of Aluminum and Copper Mechanical and Compression Connectors



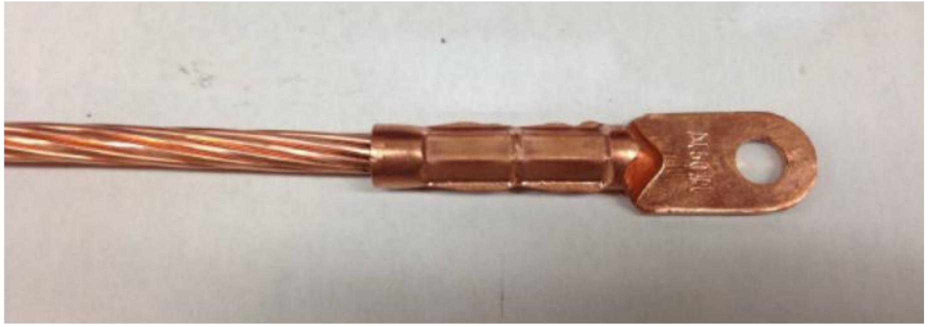
Outline

- **Purpose and Test Method**
- **Overview of Results**
- **Mechanical and Compression Connectors**
  - Samples
  - Connector Preparation
  - Test Method
  - Test Setup
  - Test Parameters
  - Evaluation of Results
  - Conclusion

Connectors

An electrical connector is an electro-mechanical device for joining electrical circuits as an interface using a mechanical assembly.

Power connectors are devices that allows an electrical current to pass through it for the exclusive purpose of providing power to a device.



Purpose

Evaluate electrical connectability of copper and 8000 series aluminum wires for low voltage electrical power distribution applications.

Testing Facility

Powertech Labs Inc.
12388 – 88th Avenue
Surrey, British Columbia
Canada

Test Method

IEC 61238-1: 2003 (Part 1: Test Methods and Requirements)

Compression and Mechanical Connectors for Power Cables for Rated Voltages up to 30kV

Class A Connectors: intended for electricity distribution or industrial networks in which they can be subjected to short-circuits of relatively high intensity and duration

Accelerated ageing by current cycling:

- heat cycle and short-circuit tests
- 1500 current cycles

Test Method

When a design of connector meets the requirements of this standard, then it is expected that in service:

a) The resistance of the connection will remain stable

b) The temperature of the connector will be of the same order or less than that of the conductor

c) The mechanical strength will be fit for the purpose

d) If the intended use demands it, application of short-circuits currents will not affect a) and b}

Summary – Mechanical Connectors

	Dual (AL/CU) Rated Mechanical Connector	CU Rated Mechanical Connector
Copper Wire	• Performed relatively poor • 1/3 of the samples failed	• No sample have failed for those tighten at 125% of rated torque • All samples had a relatively stable resistance and temperature over the course of the test
Aluminum Wire	• Performed very poor • Very high failure rate even before the midpoint of the test • 90% of samples failed or showed elevated resistance and temperature levels at the end of the test	NA

Summary – Compression Connectors

Copper compression connector on copper wire	• All samples had a relatively stable resistance and temperature during the course of the test . • No sample showed a trend of significantly increasing resistance and/or temperature by the end of the test.
Aluminum compression connector on aluminum wire	• Over 50% of the samples showed a trend of significantly increasing resistance and/or temperature by the end of the test. • Among the three preparations, those samples that were wire brushed and applied with oxide inhibitor performed best.

MECHANICAL CONNECTORS

Samples

Cu

Wires and connectors were purchased from a local industrial supplier by Powertech Labs.

Connectors were standard single screw mechanical lugs that are available from standard electrical suppliers

- Copper or brass body for CU rated connector
- Aluminum body for AL/CU (dual) rated connector

Connection Preparation

Aluminum alloy wire samples were prepared as follows:

- With wire brushing and application of oxide inhibitor compound
- Application of oxide inhibitor compound only
- No wire brushing and application of oxide inhibitor compound

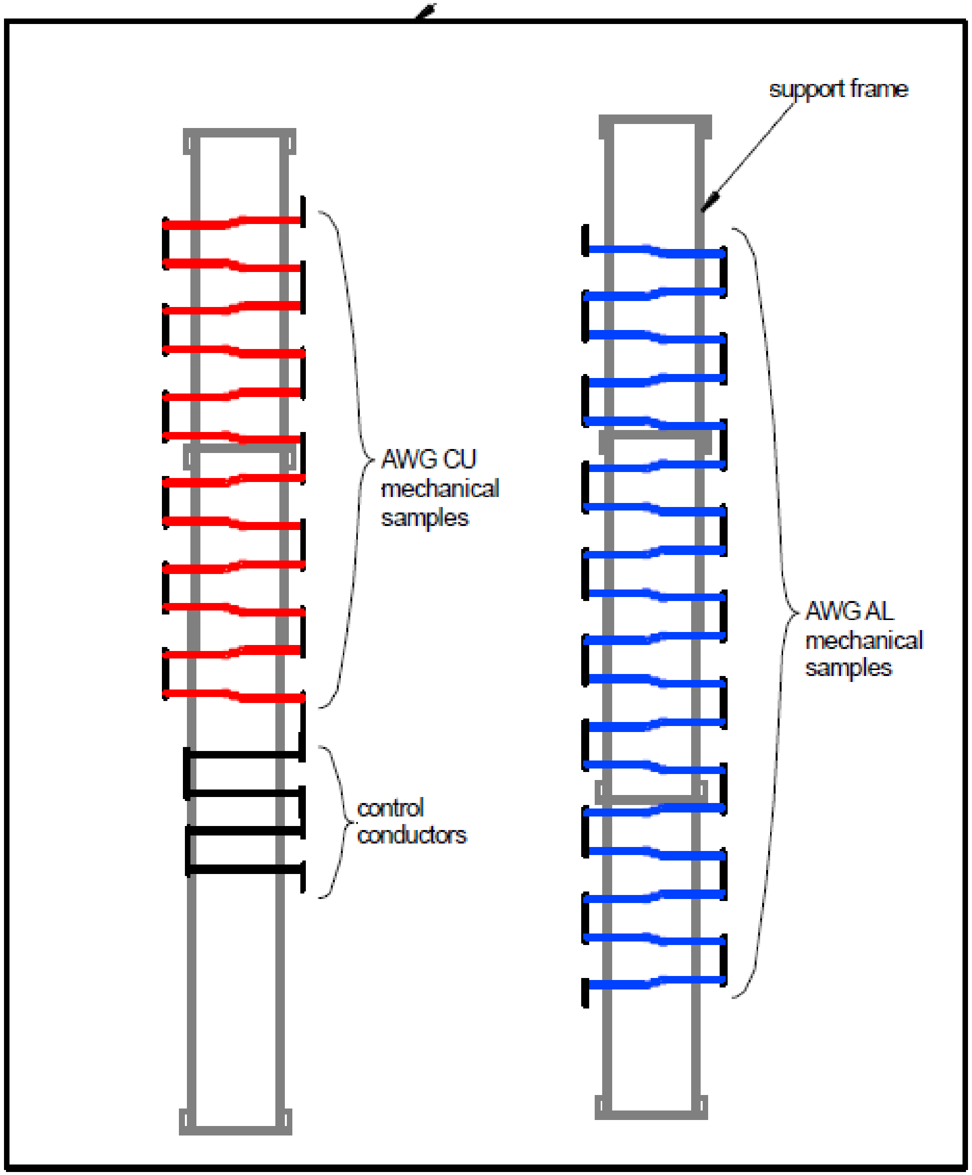
Copper wire samples were not wire brushed or treated with oxide inhibitor compound.

Connection Preparation

Connectors were tightened as follows:

- 70% of rated torque
- 100% of rated torque
- 125% of rated torque

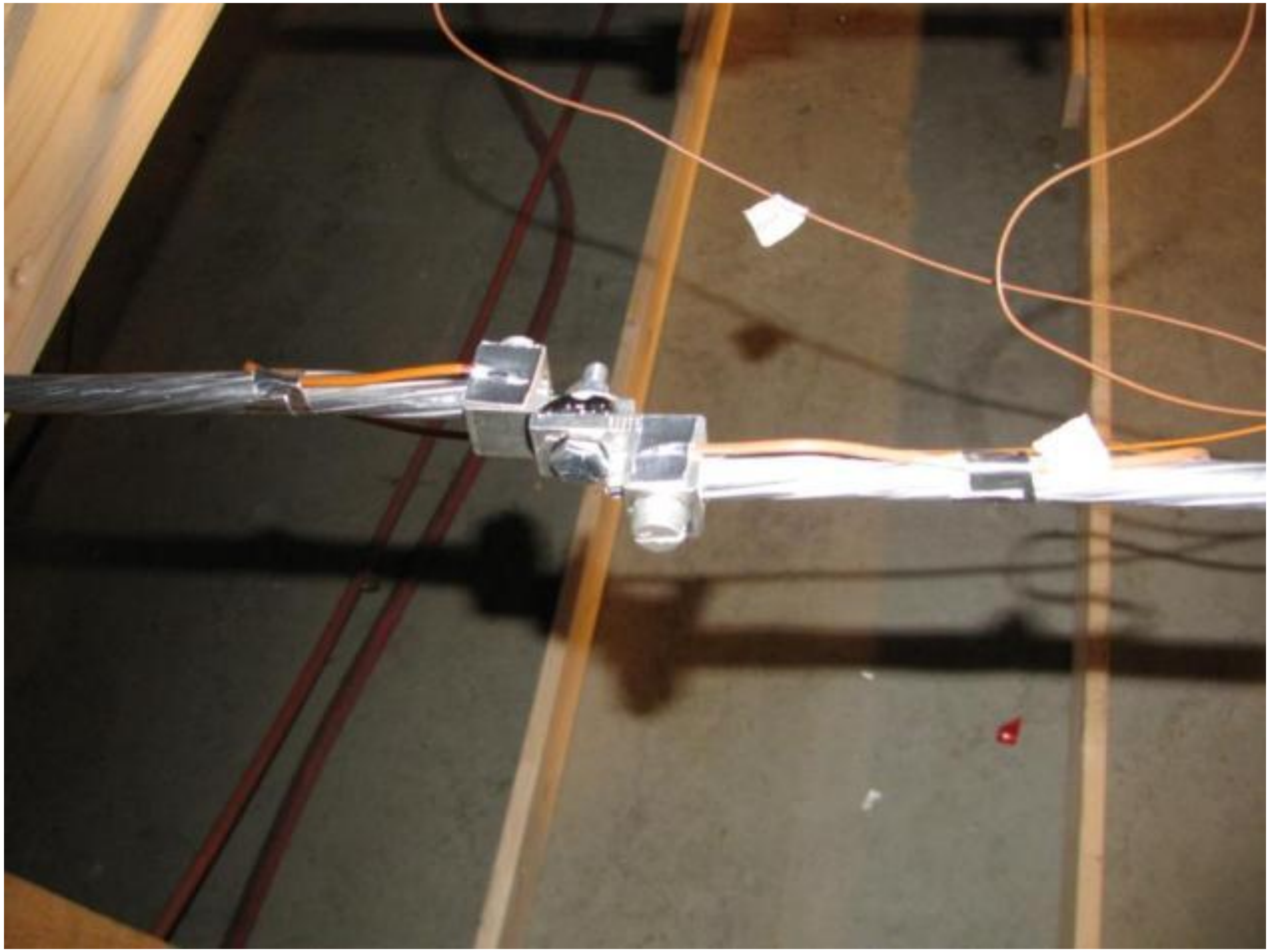
Test Loop Sample Layout



Test Setup

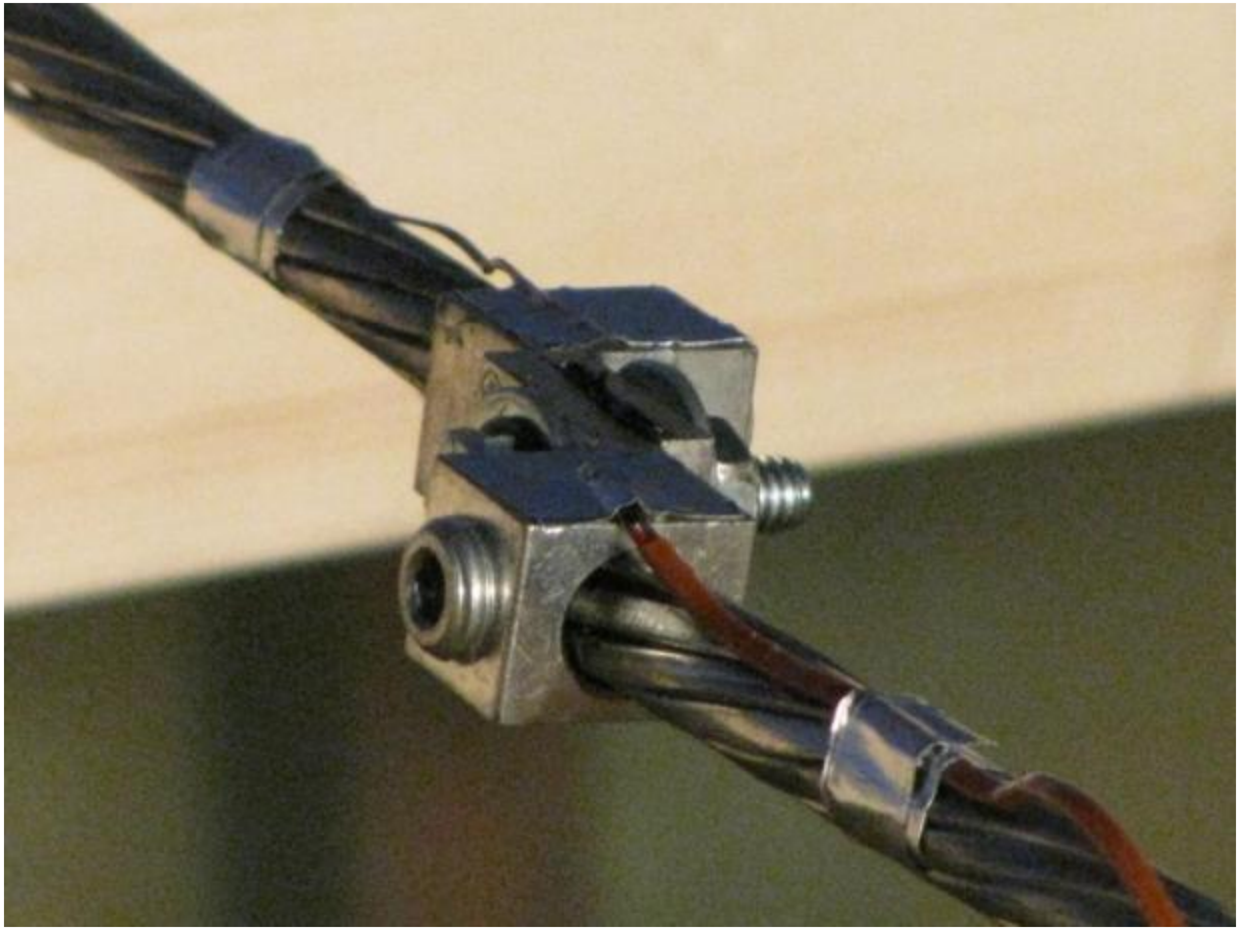
Close up of Test Set up

Close-up of Connection



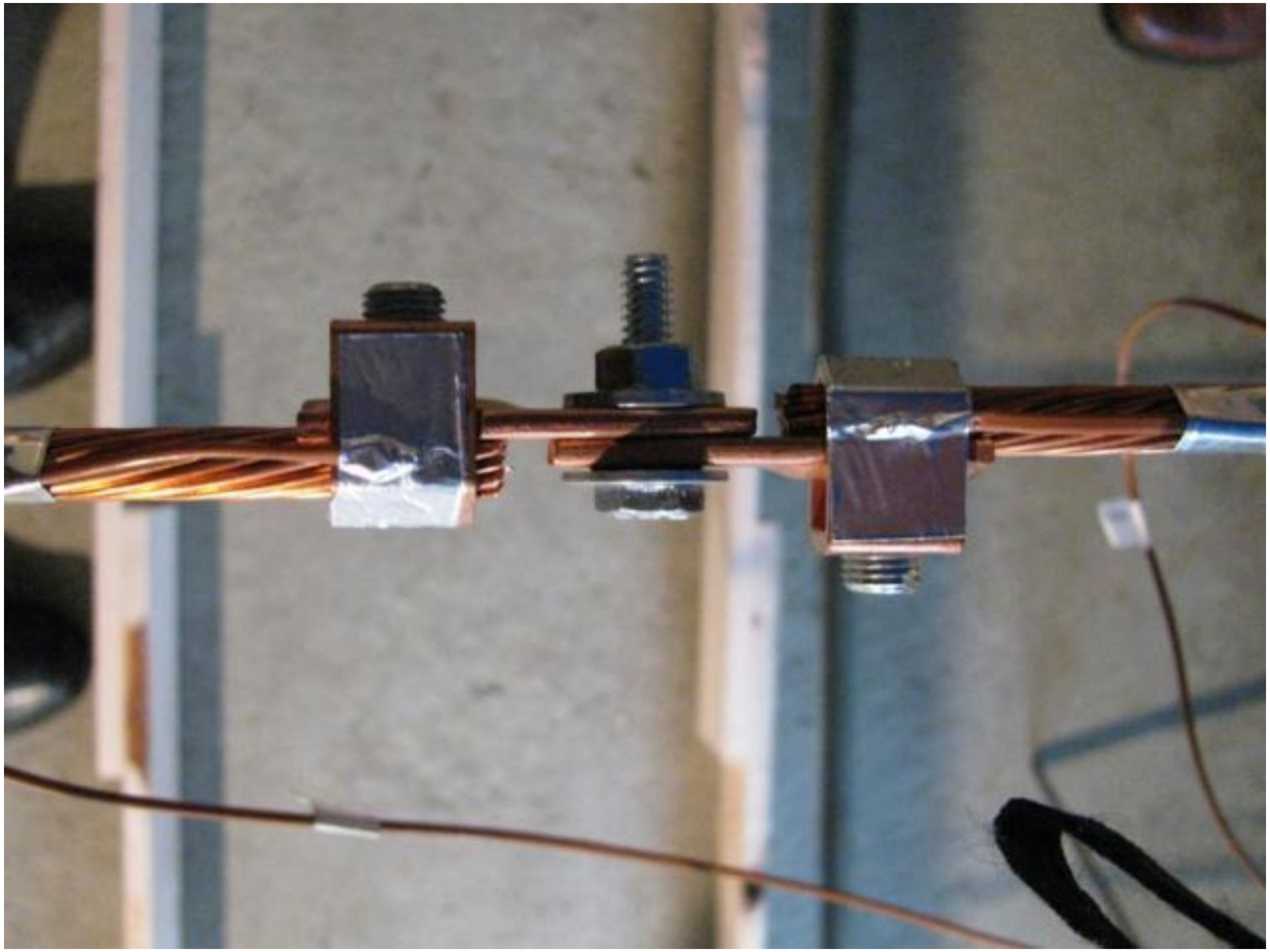
Close-up of Connection

Cu



Close-up of Connection

Cu



Summary of Samples

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

Test Parameters

Cu

Samples are in an enclosure with an ambient temperature of 25-30ºC and relative humidity of greater than 90%

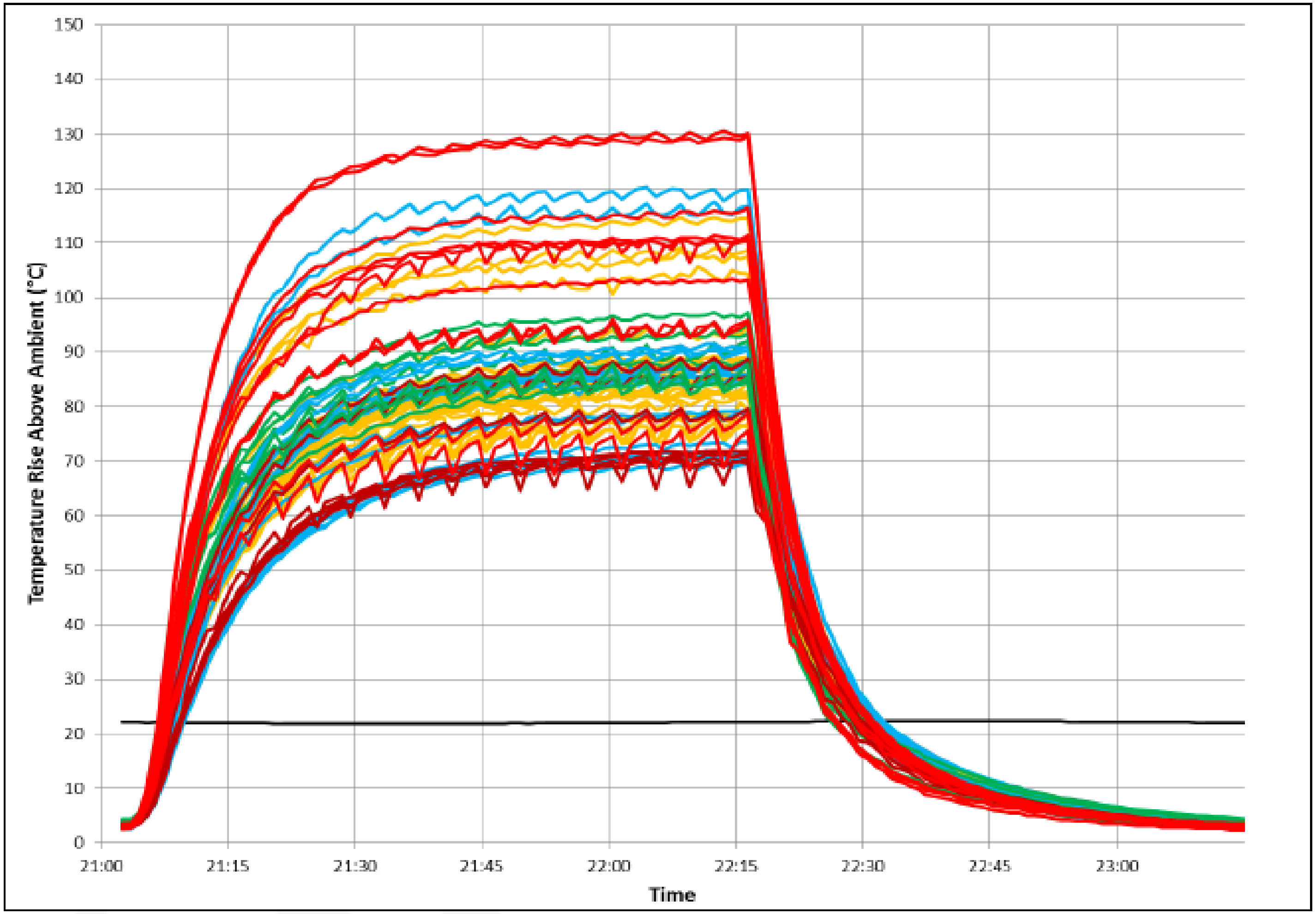
Samples were subjected to 1500 heating and cooling cycles, one (1) hour heating by high current and 1.25 hour of natural cooling with no current applied

Current of 280A was used to attain a temperature of 100-105ºC at the control cable.

One short circuit current applied at the 200th current cycle (250ºC to 270ºC at control cable)

Connector DC resistance were measured every 100 cycles

Typical Heat Rise



Typical heating/cooling cycle.

Ways to Evaluate Results

Resistance Ratio

- Resistance factor ratio ≤ 2.0

Heat rise

- Maximum connector temperature ≤ θ_{ref}

  Note: θ_{ref} = maximum temperature of the control cable

Connector Resistance Ratio

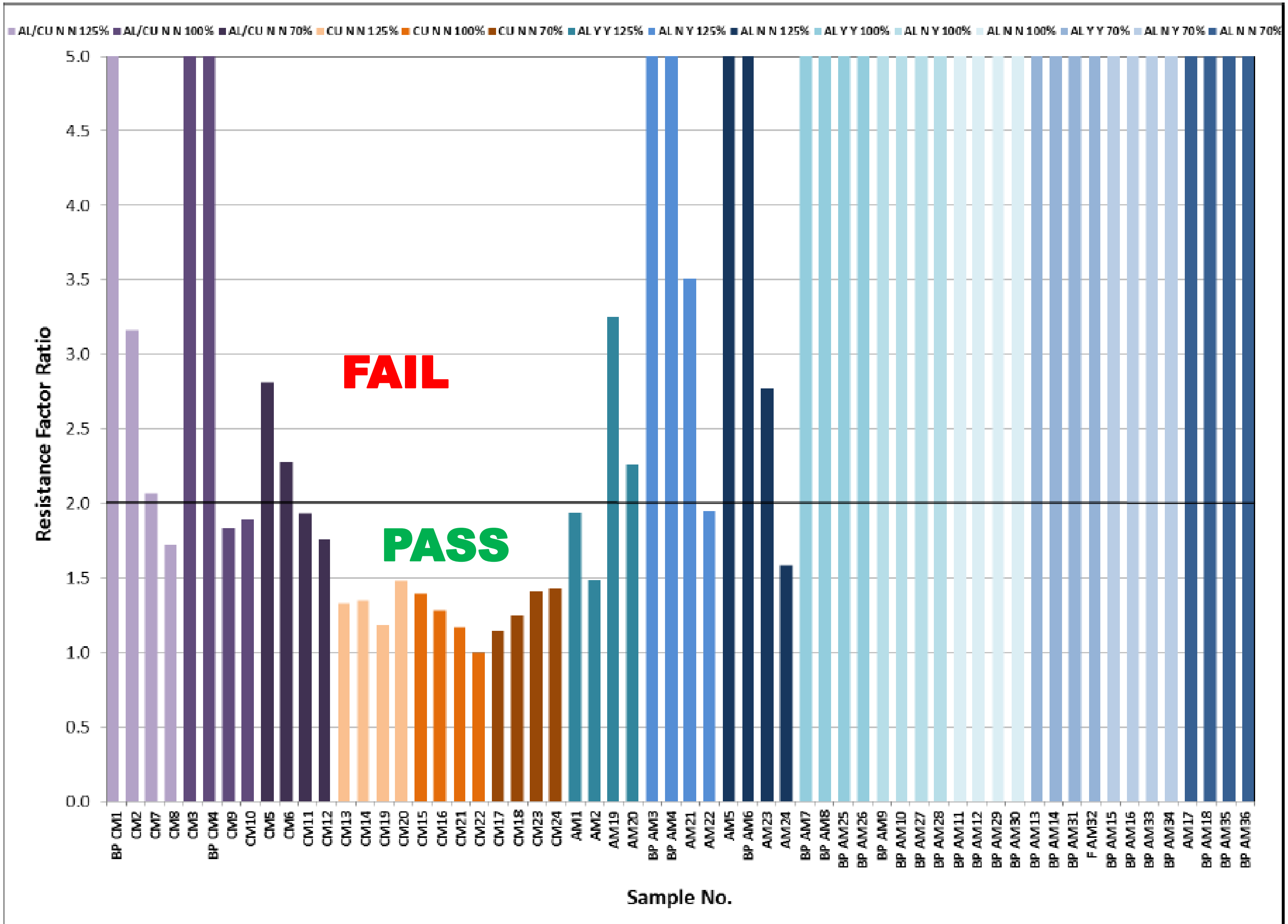


Figure 43. IEC resistance factor ratio for each sample, with the maximum IEC limit indicated by a line at 2.0. Samples are grouped by type and preparation. Solid bars indicate samples that failed and were removed from the test.

Temp Rise Above Control

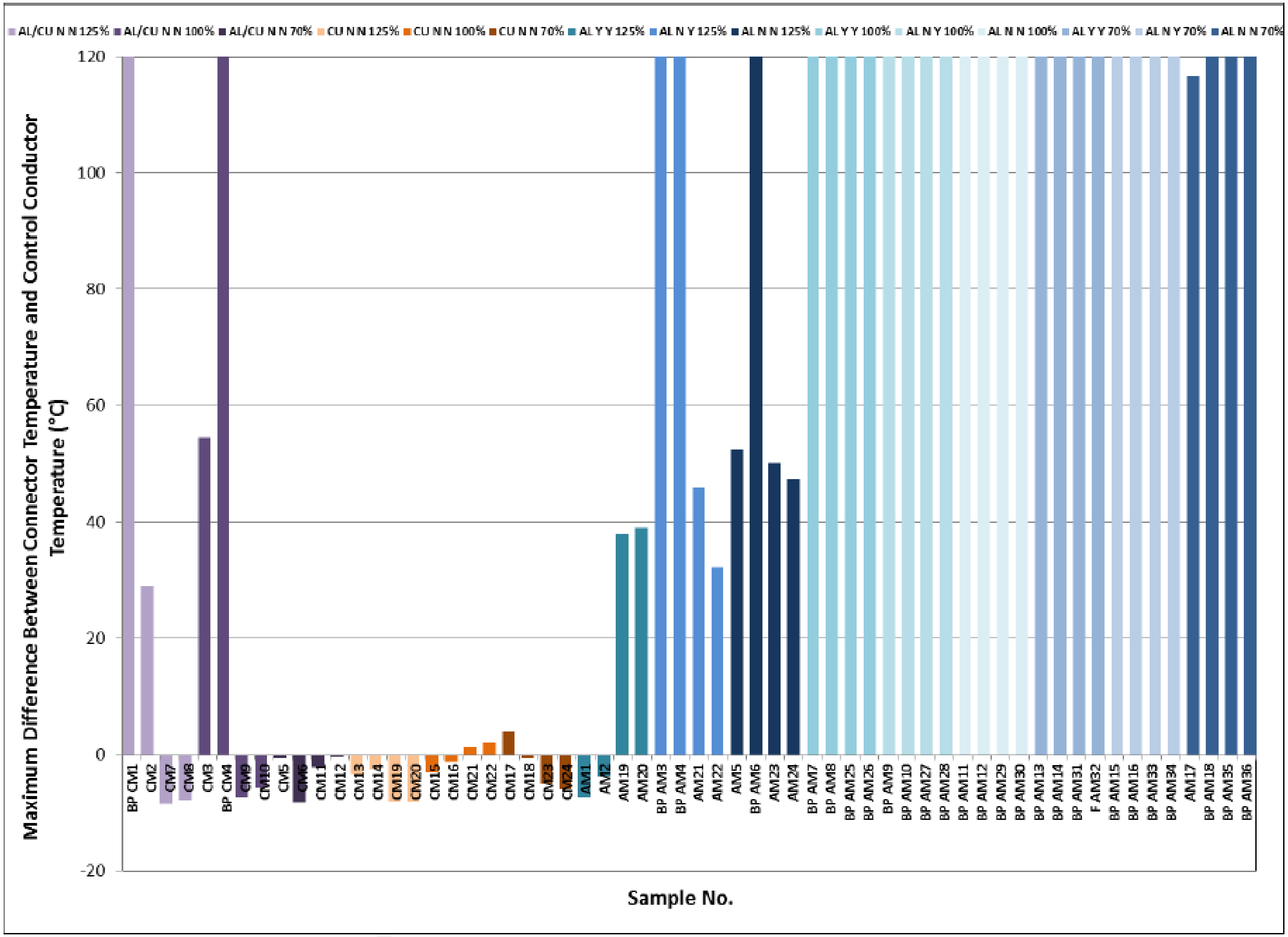


Figure 44. Difference between connector temperature and control conductor for each sample. Samples are grouped by typ and preparation. Solid bars indicate samples that failed and were removed from the test.

Summary of IEC Analysis

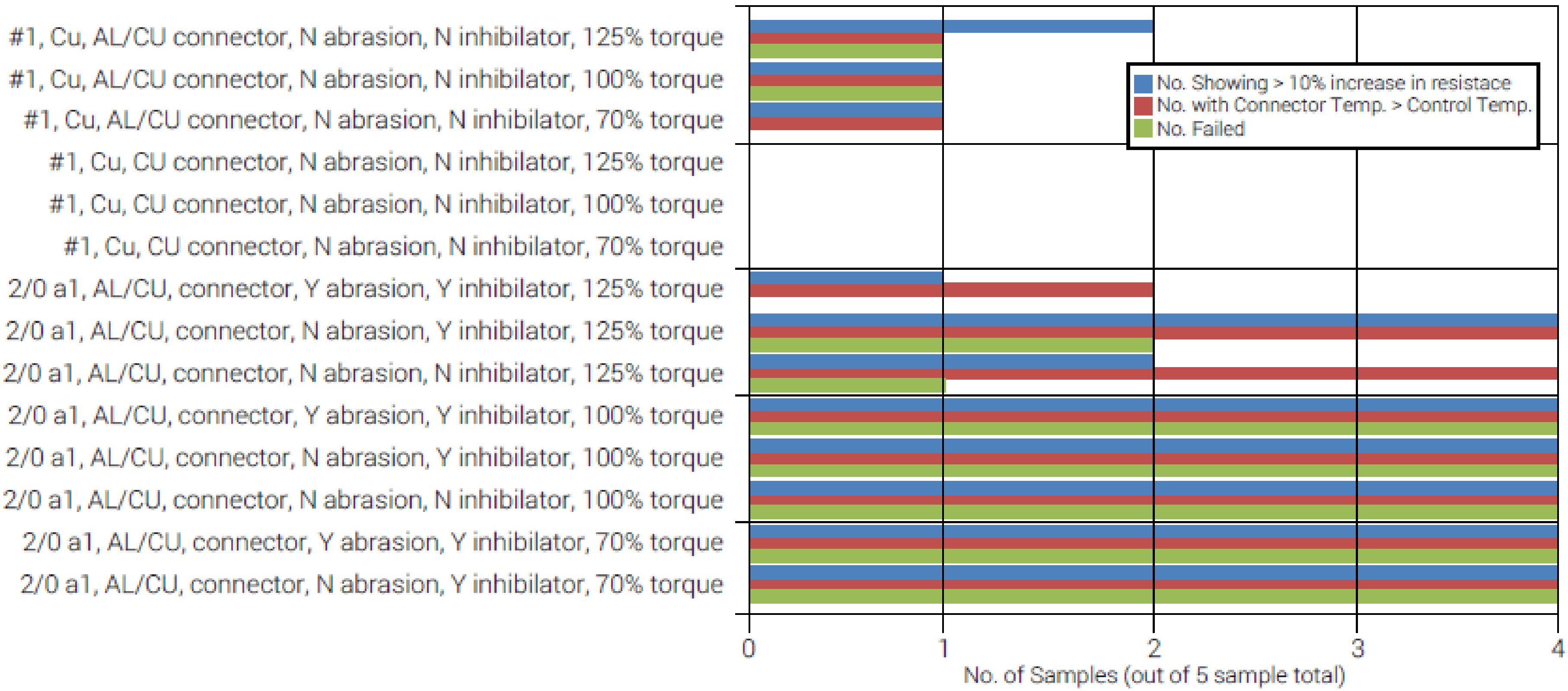
Cu

Conductor	Connector Rating	Abrasion	Inhibitor	Torque	Results of IEC Analysis (see Note (1) below)			
					Resistance Factor Ratio		Maximum Temperature Difference (sample-control)	
					No. Pass	No. Fail	No. Pass	No. Fail
#1 Cu	AL/CU	N	N	125%	1	3	2	2
#1 Cu	AL/CU	N	N	100%	2	2	2	2
#1 Cu	AL/CU	N	N	70%	2	2	4	0
#1 Cu	CU	N	N	125%	4	0	4	0
#1 Cu	CU	N	N	100%	4	0	2	2(2)
#1 Cu	CU	N	N	70%	4	0	3	1(2)
2/0 Al	AL/CU	Y	Y	125%	2	2	2	2
2/0 Al	AL/CU	N	Y	125%	1	3	0	4
2/0 Al	AL/CU	N	N	125%	1	3	0	4
2/0 Al	AL/CU	Y	Y	100%	0	4	0	4
2/0 Al	AL/CU	N	Y	100%	0	4	0	4
2/0 Al	AL/CU	N	N	100%	0	4	0	4
2/0 Al	AL/CU	Y	Y	70%	0	4	0	4
2/0 Al	AL/CU	N	Y	70%	0	4	0	4
2/0 Al	AL/CU	N	N	70%	0	4	0	4

Note 1
Any resistance factor ratio > 2.0 or maximum connector temperature that exceeds the control cable temperature at any time during the test is considered a failure by IEC.

Note 2
Copper connectors on copper wire, with 100% and 70% applied rated torque, exceeded the control cable temperature by a small amount in the middle of the test but dropped below the control cable temperature by the end of the test.

Summary of Results

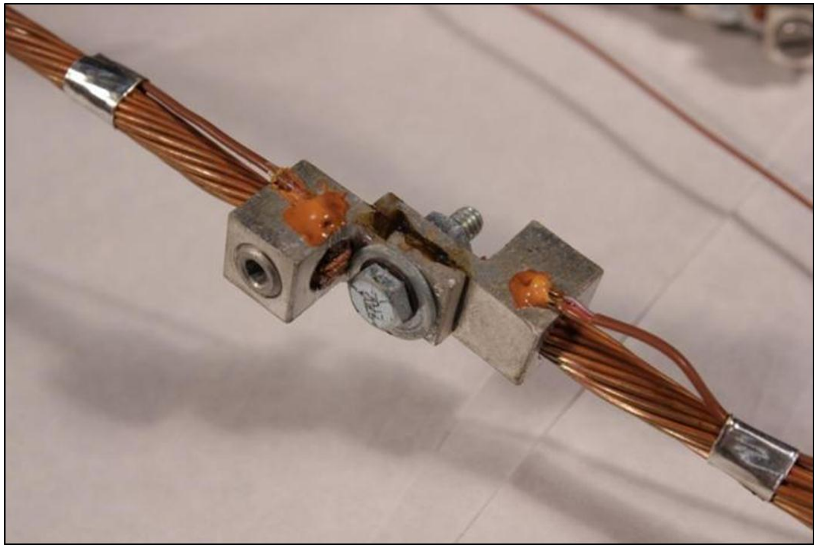


Conclusions

Cu

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.**

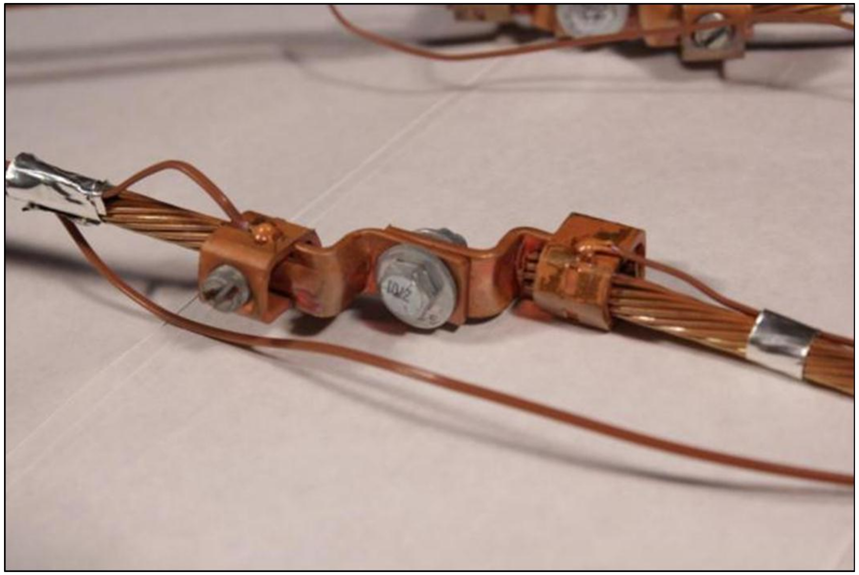


Conclusions

Cu

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.**

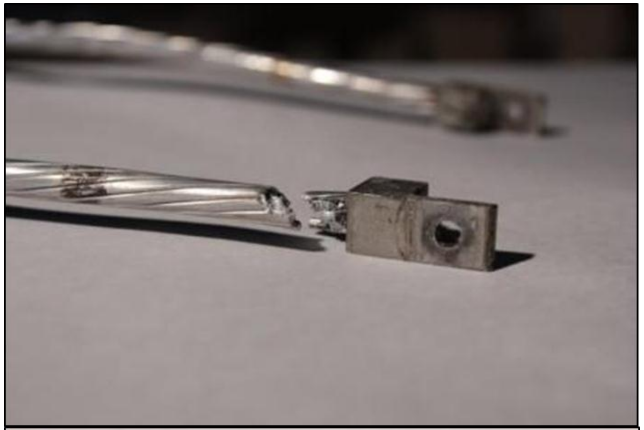


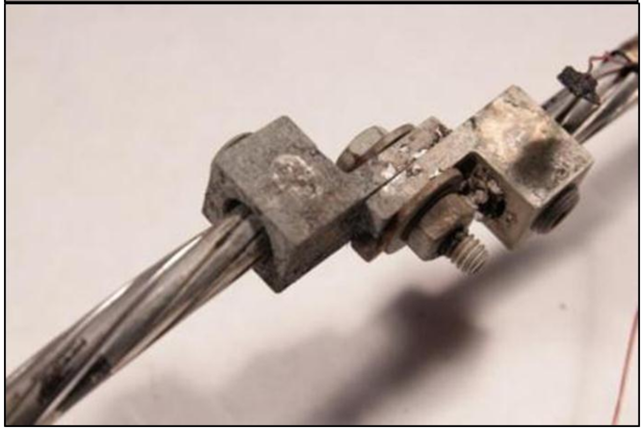
Conclusions

Cu

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 to 100% of rated torque failed, regardless of preparation.**





Overall Conclusions

Cu

	Dual (AL/CU) Rated Mechanical Connector	CU Rated Mechanical Connector
Copper Wire	• Performed relatively poor • 1/3 of the samples failed	• No sample have failed for those tighten at 125% of rated torque • All samples had a relatively stable resistance and temperature over the course of the test
Aluminum Wire	• Performed very poor • Very high failure rate even before the midpoint of the test • 90% of samples failed or showed elevated resistance and temperature levels at the end of the test	NA

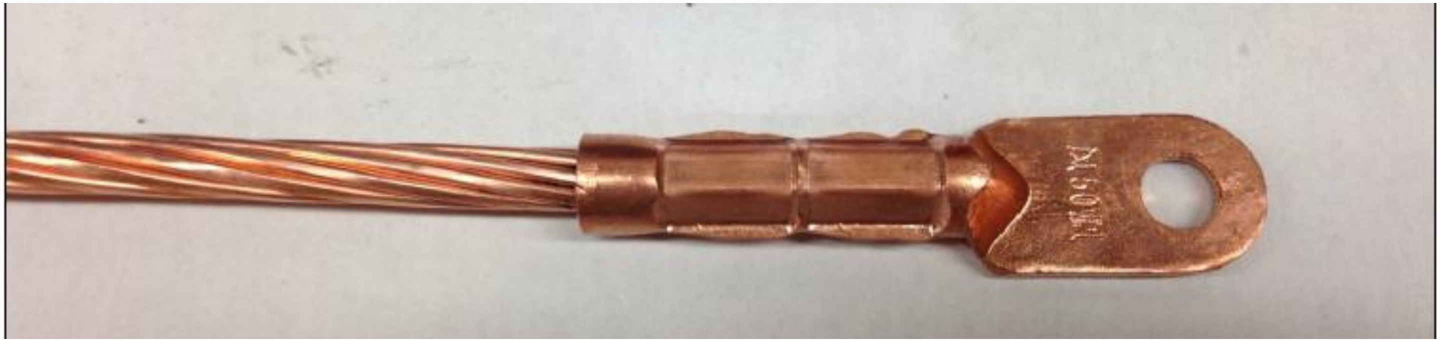
COMPRESSION CONNECTORS

Samples

Wires and connectors were provided by International Copper Association Ltd. (ICA) which were purchased from Chinese suppliers

Connectors were standard metric compression lugs with:

- Copper body for CU rated connector
- Aluminum body for AL/CU (dual) rated connector



Connection Preparation

Cu

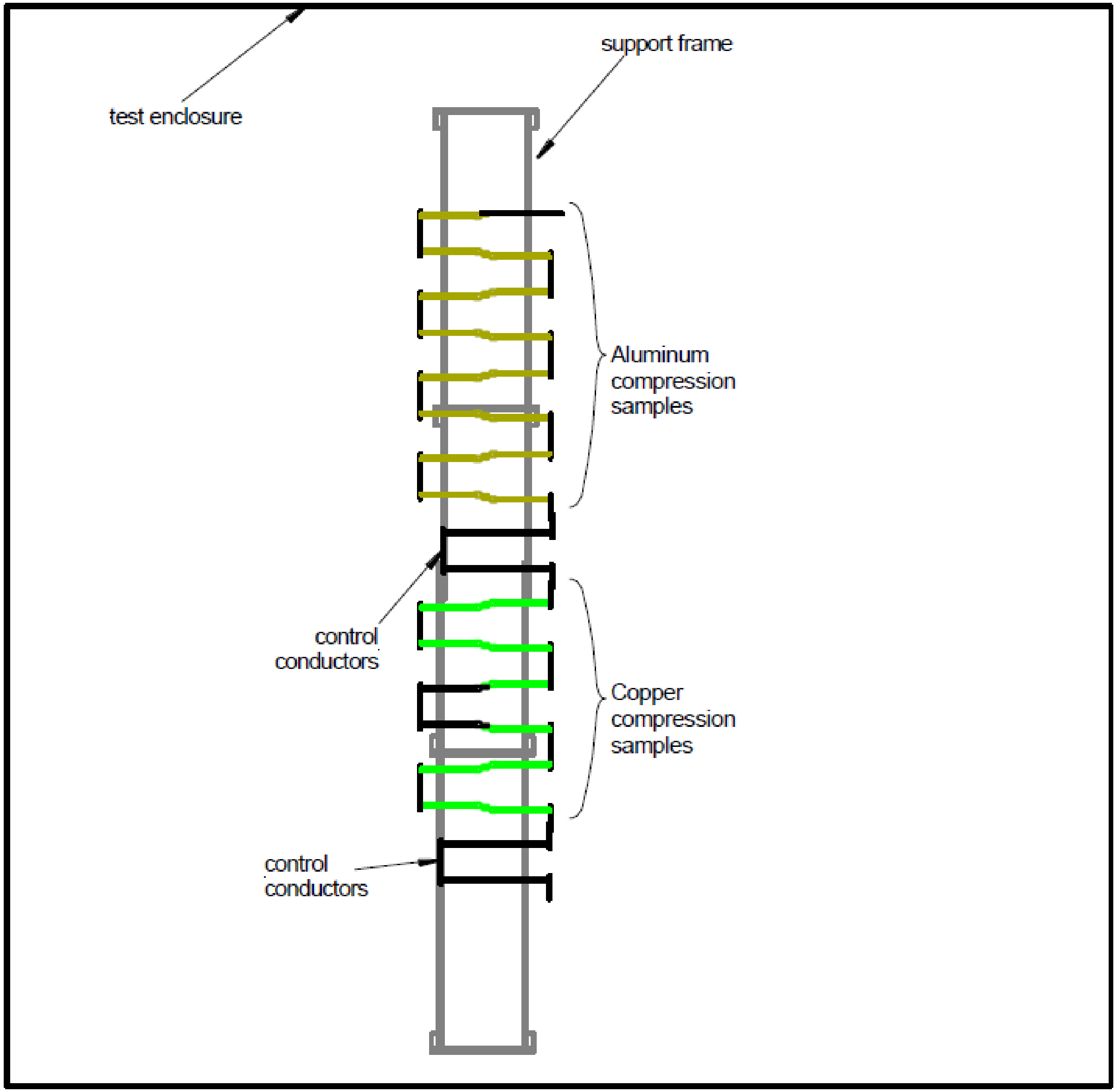
Aluminum alloy wire samples were prepared as follows:

- With wire brushing and application of oxide inhibitor compound
- Application of oxide inhibitor compound only
- No wire brushing and application of oxide inhibitor compound

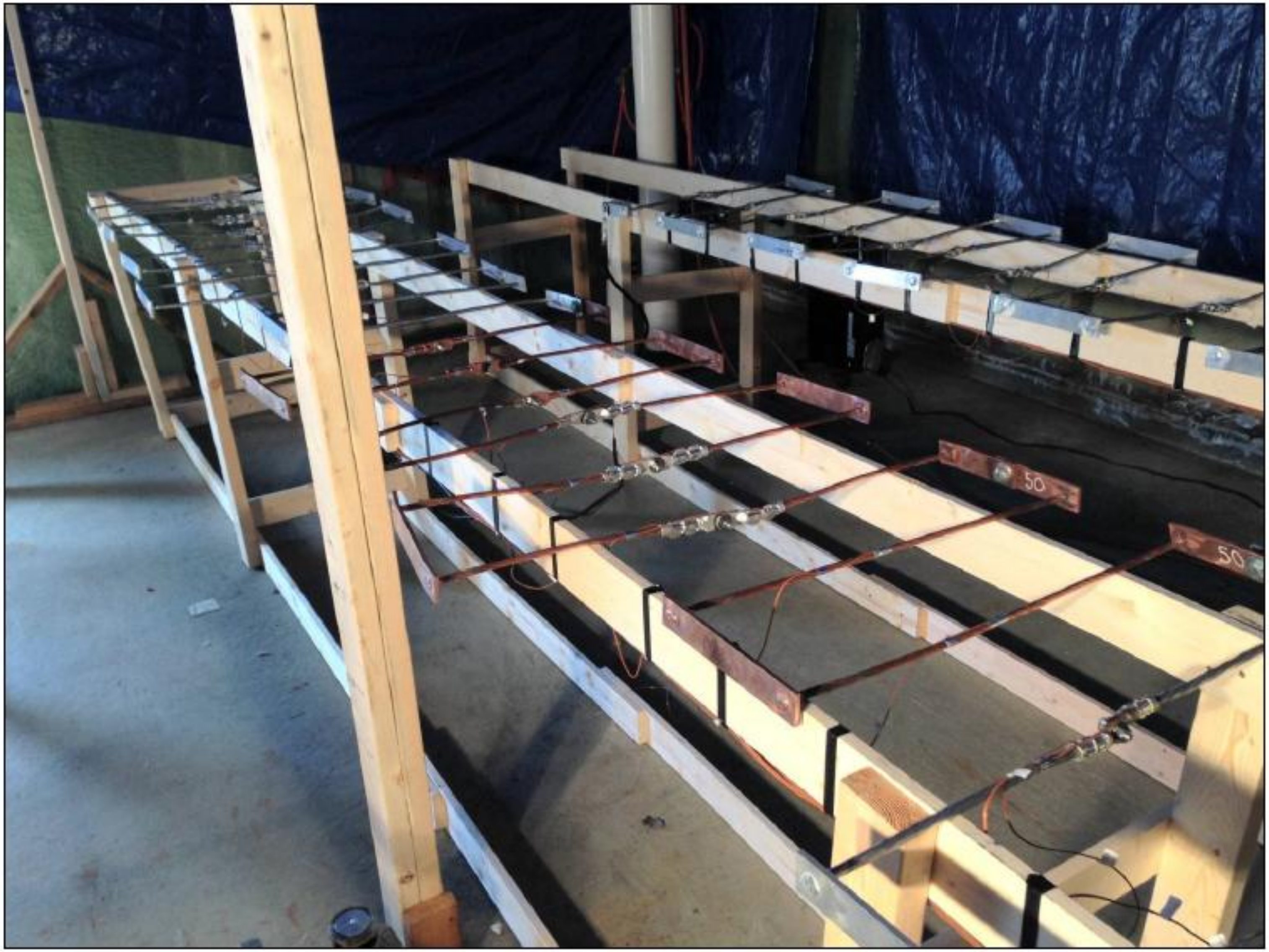
Copper wire samples were not wire brushed or treated with oxide inhibitor compound.

The appropriate die was used to compress the barrel of the connector

Test Loop Sample Layout



Test Setup



Summary of Samples

Cu

Type	Conductor	Connector Rating	Abrasion	Inhibitor	Total No. Units
Control	50 mm² Cu	---	---	---	2
Control	70 mm² Al	---	---	---	2
Metric compression	50 mm² Cu	CU	N	N	5
Metric compression	70 mm² Al	AL	Y	Y	5
Metric compression	70 mm² Al	AL	N	Y	5
Metric compression	70 mm² Al	AL	N	N	5

Test Parameters

Samples are in an enclosure with an ambient temperature of 25-30ºC and relative humidity of greater than 90%

Samples were subjected to 1500 heating and cooling cycles, one (1) hour heating by high current and 1.25 hour of natural cooling with no current applied

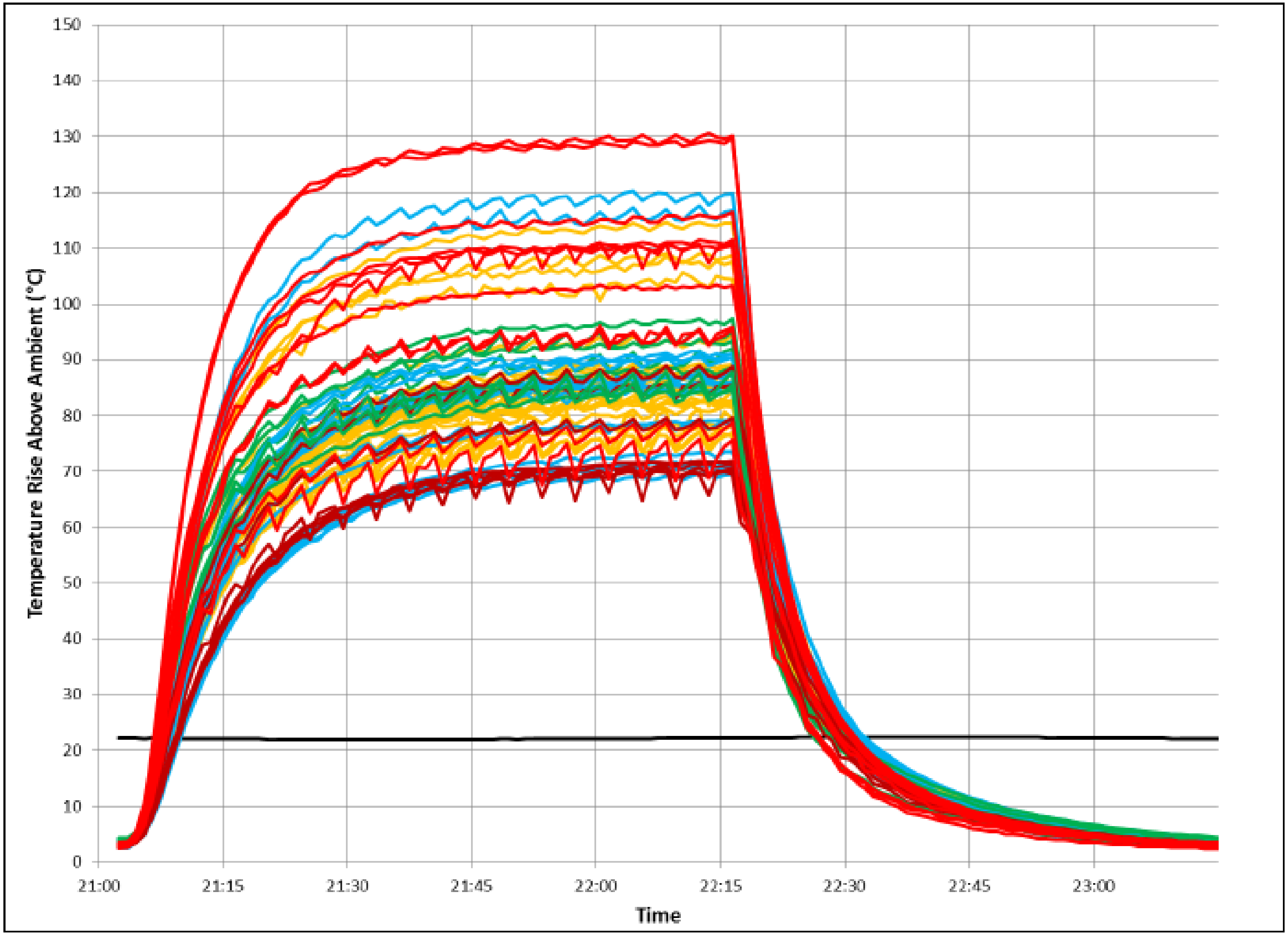
Current of 280A was used to attain a temperature of 100-105ºC at the control cable.

One short circuit current applied at the 200th current cycle (250ºC to 270ºC at control cable)

Connector DC resistance were measured every 100 cycles

Typical Heat Rise

Cu



Ways to Evaluate Results

Resistance Ratio

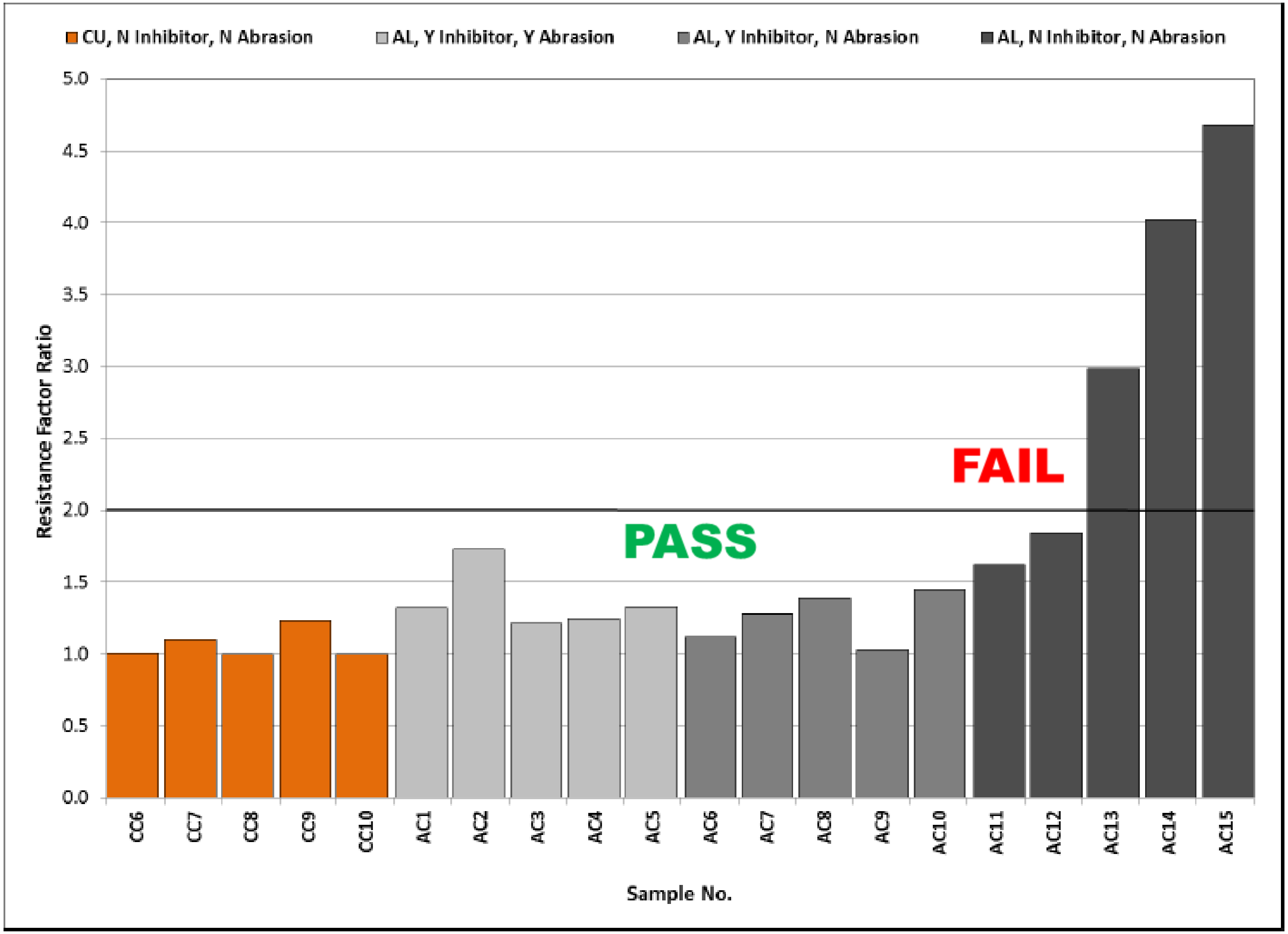
- Resistance factor ratio ≤ 2.0

Heat rise

- Maximum connector temperature $\leq \Theta_{ref}$

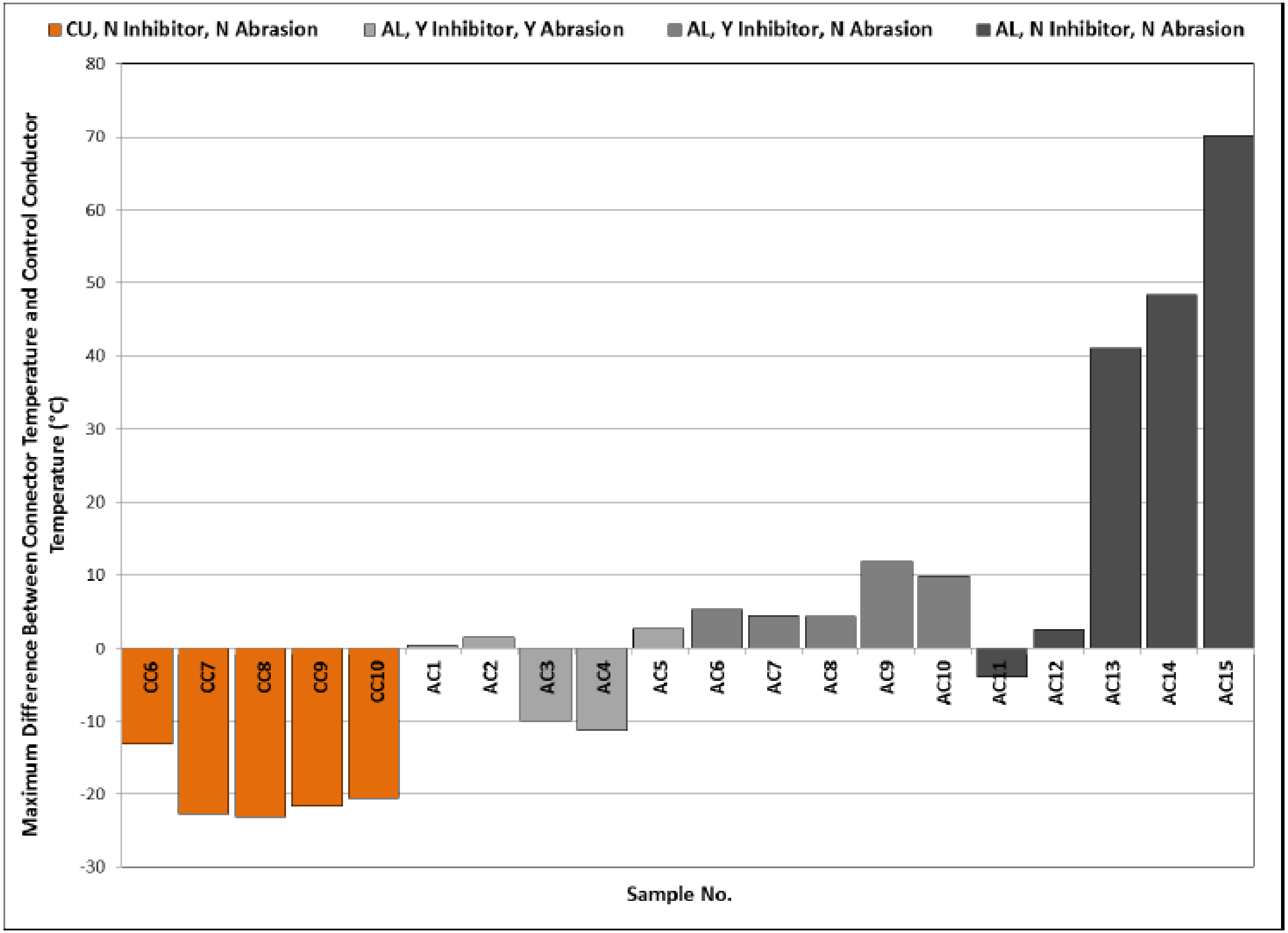
  Note: Θ_{ref} = maximum temperature of the control cable

Connector Resistance Ratio



IEC maximum 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.

Temp Rise Above Control



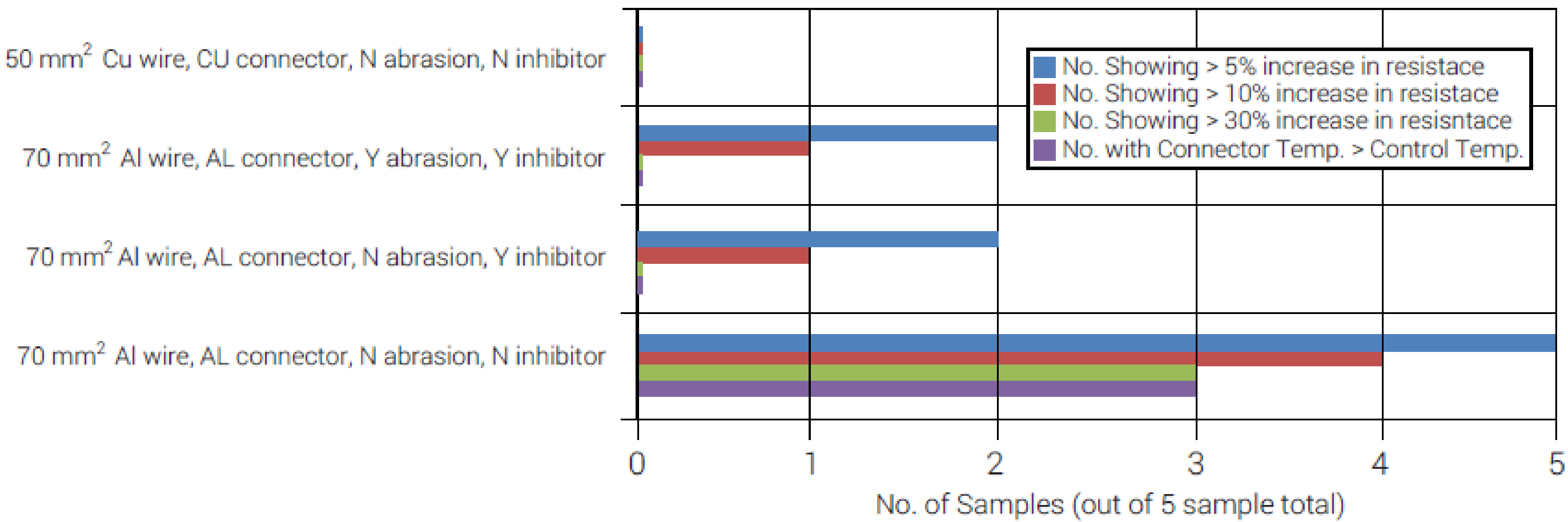
IEC maximum difference between connector temperature and control conductor for each sample. Samples are grouped by type and preparation.

Summary of IEC Analysis

Conductor	Connector Rating	Abrasion	Inhibitor	Results of IEC Analysis (see Note (1) below)			
				Resistance Factor Ratio		Maximum Temperature Difference (sample-control)	
				No. Pass	No. Fail	No. Pass	No. Fail
50 mm² Cu	CU	N	N	5	0	5	0
70 mm² Al	AL	Y	Y	5	0	2	3
70 mm² Al	AL	N	Y	5	0	0	5
70 mm² Al	AL	N	N	2	3	1	4

Note 1
Any resistance factor ratio > 2.0 or maximum connector temperature that exceeds the control cable temperature at any time during the test is considered a failure by IEC.

Summary of Results



Conclusions

	Resistance Factor Ratio	Max. Connector Temperature
Copper Connector on Copper Wire	Pass	Pass
Aluminum connector on Aluminum Wire, with wire brushing and oxide inhibitor	Pass	Fail
Aluminum connector on Aluminum Wire, with oxide inhibitor only	Pass	Fail
Aluminum connector on Aluminum Wire, without wire brushing and oxide inhibitor	Fail	Fail

Overall Conclusions

Cu

Copper compression connector on copper wire	• All samples had a relatively stable resistance and temperature during the course of the test . • No sample showed a trend of significantly increasing resistance and/or temperature by the end of the test.
Aluminum compression connector on aluminum wire	• Over 50% of the samples showed a trend of significantly increasing resistance and/or temperature by the end of the test. • Among the three preparations, those samples that were wire brushed and applied with oxide inhibitor performed best.


Thank You!