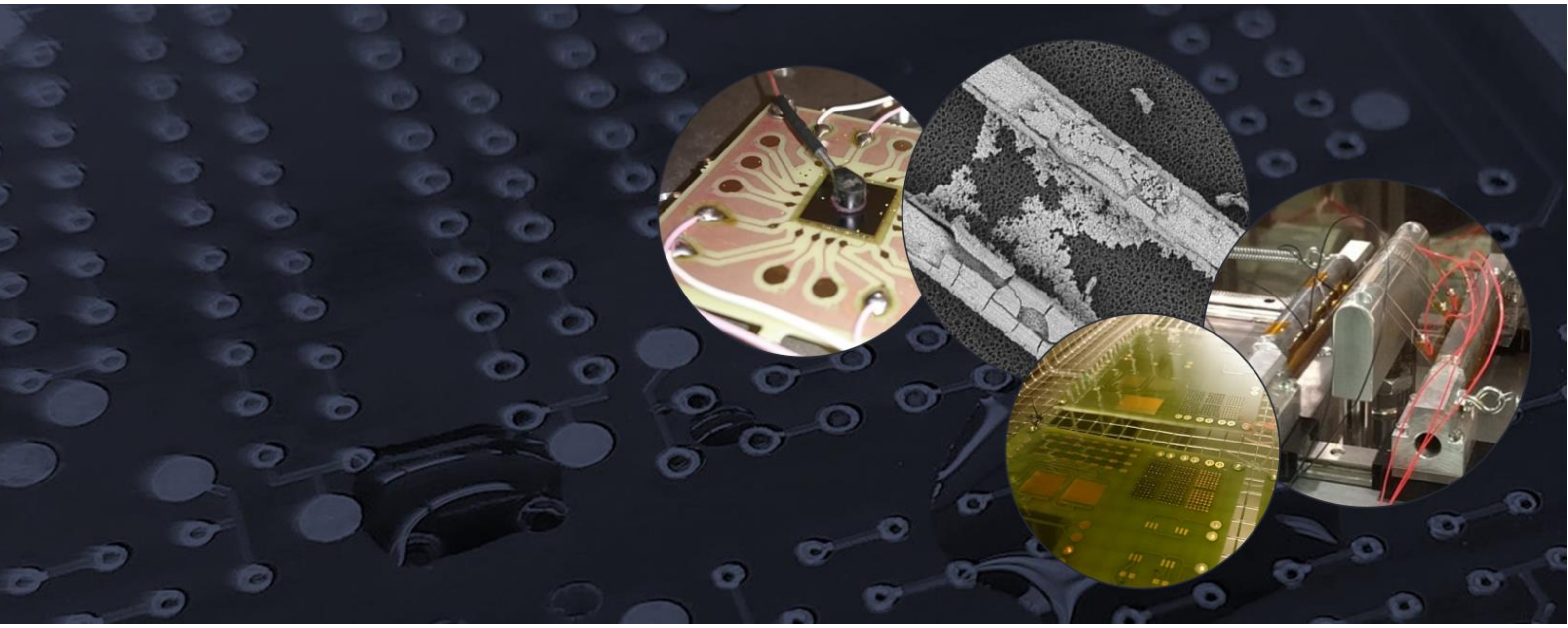
CORROSION CUBE - RISK ASSESSMENT REPORT

2.6.2021

Reference: Laboratory cabinet with exposure to corrosive elements



Corrosion cube - Risk assessment report

Laura Frisk, Trelic Oy **2.6.2021**

Customer: -
Contact Person: -
Reference: Laboratory cabinet with exposure to corrosive elements

System installation date: 29.4.2021
System removal date: 26.5.2021
Environment: Laboratory cabinet with exposure to some corrosive elements

1 Summary

This report gives results for corrosion rate analysis from Trelic Oy's Corrosion Cube – corrosion risk assessment system. The analysis has been conducted by Janne Kiilunen, Juha Pippola and Laura Frisk from Trelic Oy.

The corrosion risk analysis consisted of

- Corrosion analysis of 2 copper (Cu) and 2 silver (Ag) corrosion coupons.
- Temperature and relative humidity measurement during the exposure.

The exposure to the environmental conditions occurred 29.4.2021 - 26.5.2021. The measurement was conducted within laboratory cabinet with an exposure to corrosive elements.

The corrosion rate was analysed from the Cu and Ag coupons using weighing measurements and coulometric reduction.

- Moderate corrosion was seen with both Cu and Ag coupons.
- Copper (average 20Å/day) had clearly greater corrosion rate than silver (average 6Å/day).
- Copper sulphide and silver chloride were seen which indicates exposure to sulphur and chlorine containing impurities.
- The average temperature during exposure was 22°C and relative humidity 35%. The time of wetness level for the measured environment was τ_1 i.e. the environment was dry without exposure to high levels of humidity. The relative humidity was above 40% for 36% of the measured time. No exposure to high temperature (above 40°C) occurred.

The classification of the measured environment according to the corrosion standards is given in the table below.

Analysis and material	*ISO 9223:2012*	*ISO 11844-1:2020*	*ISA S71.04-2013*
Cu – Coulometric reduction	C2, Low	IC4, High	G2, Moderate
Ag – Coulometric reduction		IC3, Medium	G2, Moderate

Further information of the study:

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Contents

2 Corrosion coupons and analysis methods

Two copper (Cu) and two silver (Ag) coupons were used to monitor the environment for corrosive gases. Coupons were made of 99.5% pure oxygen free copper (CW008A) and 99.95% pure silver.

Coupons were mechanically cleaned and grinded prior testing.

Each coupon was weighed using a precision scale before and after testing. The results were used to calculate corrosion rates.

After weighing the coupons were analysed using coulometric reduction. The coulometric reduction was conducted according to ASTM standard B825-02. 0.1M potassium chloride was used as an electrolyte. The used current values depended on the coupons and their corrosion levels.

In the reduction process different corrosion products give plateaus which are used to identify the corrosion products and calculate their amounts. In this analysis literature data has been used to identify the corrosion products related to various plateaus. The method described in ASTM international B825-02 standard was used to calculate the corrosion rates.

3 Corrosion analysis results

3.1 Visual appearance

Some corrosion was seen on coupons after the exposure (Figure 1.). The colour of the coupons had changed slightly, and some corrosion product could be seen. However, the amount of corrosion products seemed to be moderate.

Figure 1. Coupons after the exposure. Copper coupons on left and silver coupons on right.

3.2 Corrosion rate measurements using weighing

Average corrosion rates based on weighing analysis are given in Table 1. Mass gain measurement was used.

Table 1. Average corrosion rates for copper and silver coupons based on mass gain.

	Copper corrosion rate (Å/day)	Silver corrosion rate (Å/day)
Coupon 1	25	7
Coupon 2	20	9
Average	**23**	**8**

3.3 Corrosion rate measurements by coulometric reduction

In both copper reduction curves two plateaus were identified. According to the literature the plateaus were identified as Cu_2O and Cu_2S.

Silver reduction curve had only one plateau. According to the literature the plateau was identified as AgCl.

Table 2 gives the corrosion rates for the different corrosion products identified from the plateaus. The reduction curves are shown in Figure 2 and Figure 3.

Table 2. Corrosion rates for the different corrosion products.

Copper corrosion rate (Å/day)			Silver corrosion rate (Å/day)		
	Coupon 1	Coupon 2		Coupon 1	Coupon 2
Cu_2O	3.3	2.0	AgCl	3.6	3.9
CuS	0.0	0.0	Ag2S	0.0	0.0
Cu_2S	19.1	12.5			
Overall	**22.5**	**14.5**	**Overall**	**3.6**	**3.9**
Average	**18**		**Average**	**4**	

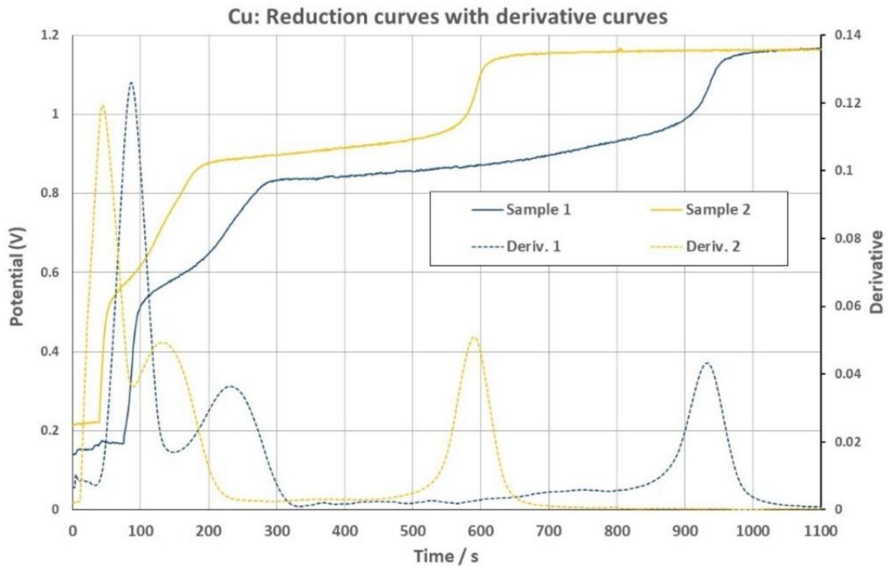

Figure 2. Reduction curves for copper coupons.

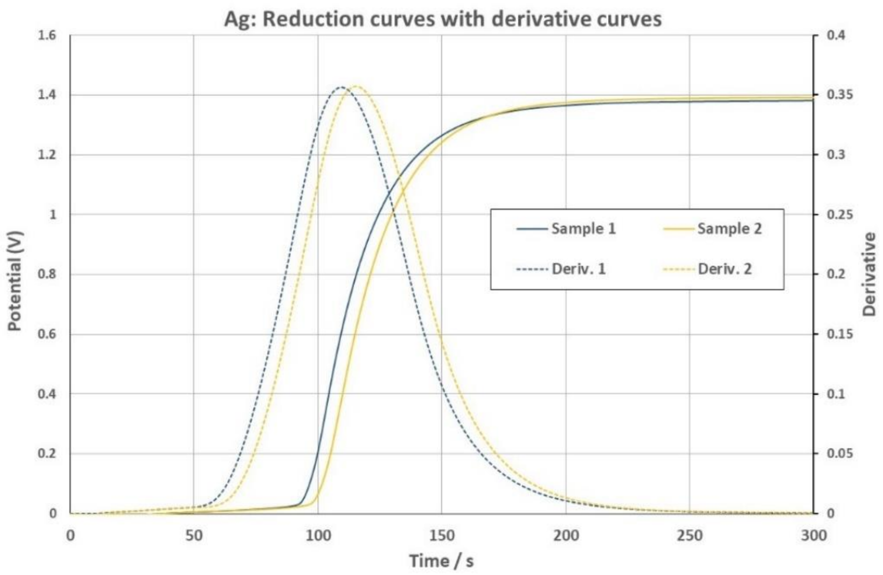

Figure 3. Reduction curves for silver coupons.

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3.4 Comparison of weighing and coulometric reduction analysis

Corrosion rates based on mass gain measurements and coulometric reduction are given in Table 3. In Figure 4 a comparison of the corrosion rates is shown.

The weighing measurement gave somewhat greater values than the coulometric reduction.

The corrosion rate of copper is clearly greater than that of silver.

Table 3. Average corrosion rates from weighing and reduction measurements.

	Copper corrosion rate (Å/day)	Silver corrosion rate (Å/day)
Weighing	23	8
Coulometric reduction	18	4
Average	**20**	**6**

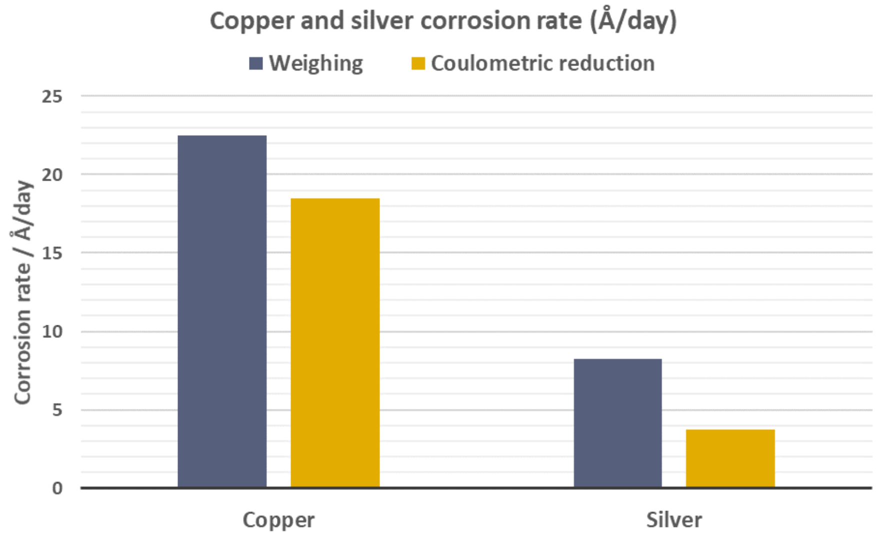

Figure 4. Comparison of corrosion rates in weighing analysis and coulometric reduction.

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4 Temperature and humidity conditions during exposure

The temperature and humidity were measured during the corrosion exposure. The measurement was conducted in every minute. The overall time of the measurement was approximately 27 days (648h).

The average temperature and humidity with the maximum and minimum values are given in Table 4. The measurement data is shown in Figure 5. In Figure 6 box plot giving the median and quartiles of the data is shown.

Table 4. Average temperature and relative humidity values during the exposure.

	Temperature (°C)	Relative humidity (%)
Average	**22.0**	**35.0**
Maximum value	24.2	53.2
Minimum value	20.6	18.8

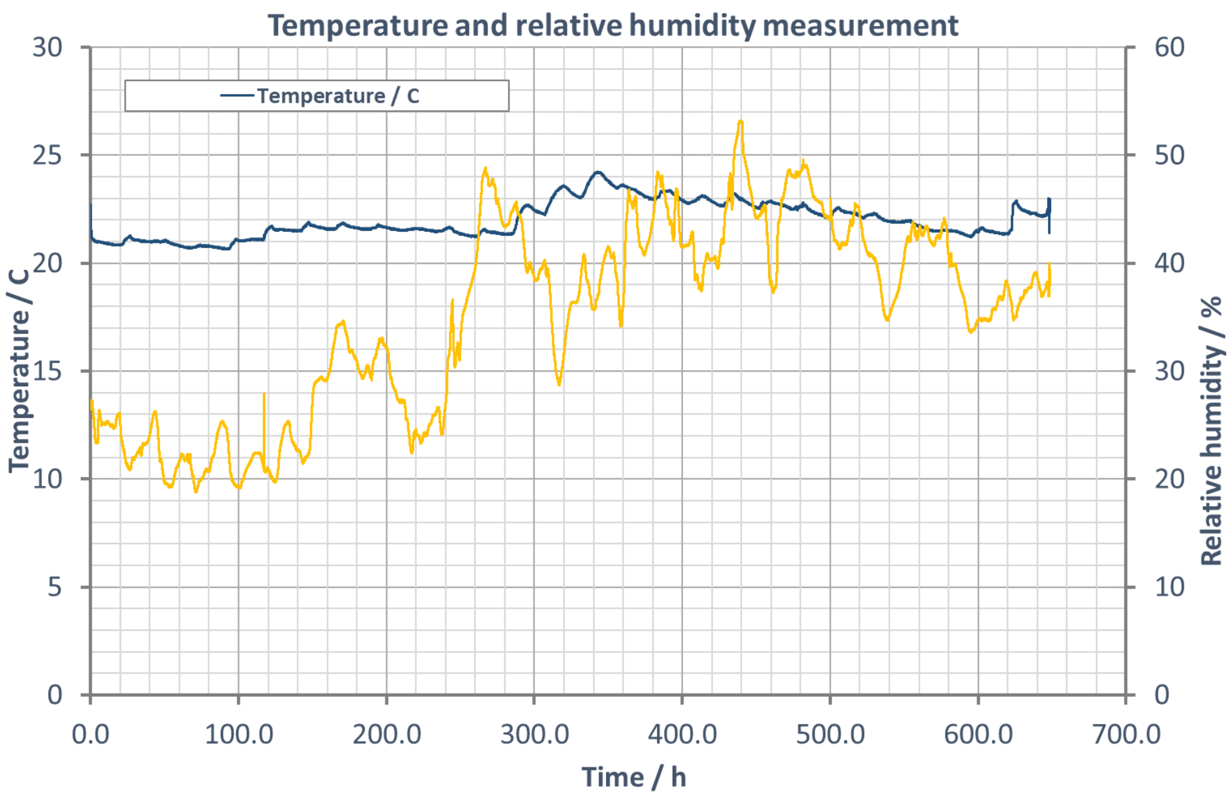

Figure 5. Temperature and humidity measurement during the exposure.

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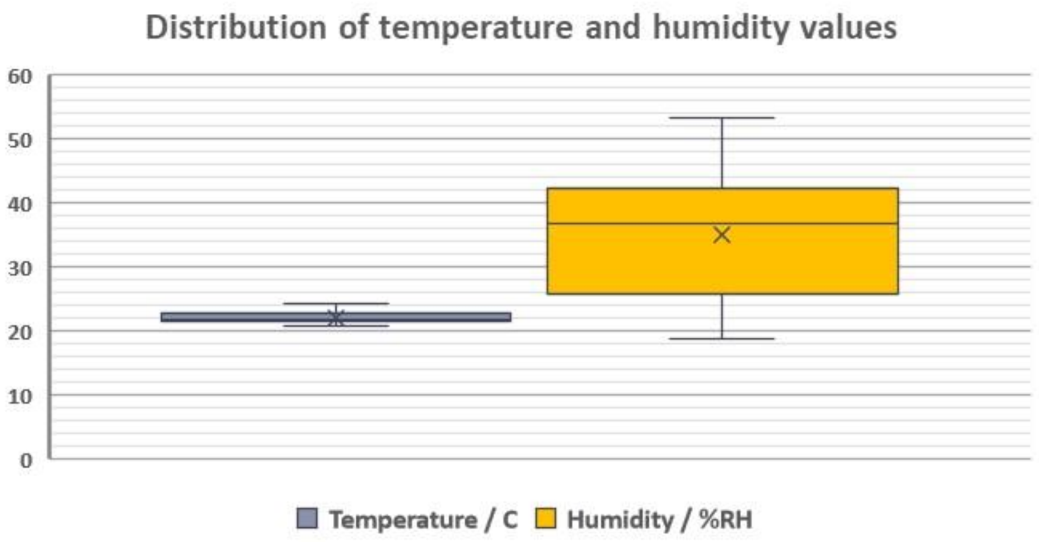

Figure 6. Distribution of temperature and humidity values.

4.1 Exposure to relative humidity above 40% and temperature above 40°C

Exposure to humidity and high temperatures are critical conditions for corrosion.

- When relatively humidity exceeds 40%, the corrosion starts to occur even in mild temperatures.*
- Above 40°C corrosion may occur with relative humidity values smaller than 40%.*

The occurrence of relative humidity above 40% and exposure to temperature above 40°C for the studied environment are shown in the table below.

Table 5. Exposure to relative temperature

	Percentage	Hours/year
Exposure to relative humidity above 40%	**35.9**	**3143.0**
Exposure to temperature above 40°C	0.0	0.0

* **Corrosion and climatic effects in electronics**, VTT publications 626, 2007

4.2 Time of wetness (TOW)

The time of wetness (τ, TOW, ISO 9223) was used to determine how humid the measured conditions were. TWO is defined as the time-period during which the relative humidity is in excess of 80%, when the temperature is above 0°C.

- **TOW level for the measured environment was τ_1.**
- The relative humidity did not exceed 80% during the measurement.
- τ_1 -level indicates that the studied environment was relatively dry, and corrosion was not greatly accelerated by humidity.

TOW is given in ***hours/year*** when relative humidity (RH) is greater than 80% and the temperature is above 0°C. The TOW levels determined by ISO 9223 are given in the table below.

Table 6. The TOW levels determined by ISO 9223.

Time of Wetness (h/a)	level	Example of occurrence
$\tau \leq 10$	τ_1	Internal microclimates with climatic control
$10 < \tau \leq 250$	τ_2	Internal microclimates without climatic control except for internal non-air-conditioned spaces in damp climates
$250 < \tau \leq 2\,500$	τ_3	Outdoor atmospheres in dry, cold climates and some zones of temperate climates; properly ventilated sheds in temperate climates
$2\,500 < \tau \leq 5\,500$	τ_4	Outdoor atmospheres in all climates (except for dry and cold climates); ventilated sheds in humid conditions; unventilated sheds in temperate climates
$5\,500 < \tau$	τ_5	Some zones of damp climates; unventilated sheds in humid conditions

High TOW levels are favourable for the formation of a surface layer of moisture on a metal. Formation of moisture film can affect corrosion mechanisms and significantly increase corrosion rates. TOW level does not consider impurities and other factors and it is important to notice these factors may greatly affect the effect of humidity on corrosion.

5 Summary and comparison to standardized environments

5.1 *Summary of the results*

- The corrosion rate of copper was on average 20Å/day and the corrosion rate of silver was on average 6Å/day.
- The corrosion rate of copper was clearly greater which indicates that the environment was especially harmful to copper.
- The copper corrosion products were copper oxide and copper sulphide, which indicates exposure to sulphur. Only silver chloride was seen with silver, which indicates exposure to chlorine.

5.2 *Comparison to standards*

The results of the analysis were compared to the corrosion classifications by

- *Instrument Society of America (ISA) Standard S71.04-2013 Environmental Conditions for Process Measurement and Control Systems: Airborne Contaminants (levels from G1 to GX)*
- *ISO 9223:2012 Corrosion of metals and alloys - Corrosivity of atmospheres - Classification, determination and estimation (levels from C1 to CX)*
- *ISO 11844-1:2020 Corrosion of metals and alloys. Classification of low corrosivity of indoor atmospheres (levels from C1 to CX)*

Table 7 gives the environmental classifications according to various standards for the studied environment. The descriptions of the highest classification levels for the studied environments are given in Table 8. In Figure 7 and Figure 8 comparison of the test conditions to the levels defined in various standards are shown.

Table 7. Classification of the measured conditions according to various standards.

Analysis and material	*ISO 9223:2012*	*ISO 11844-1:2020*	*ISA S71.04-2013*
Cu - Weighing	C2, Low	IC4, High	G2, Moderate
Cu - Coulometric reduction	C2, Low	IC4, High	G2, Moderate
Ag - Weighing		IC3, Medium	G2, Moderate
Ag - Coulometric reduction		IC3, Medium	G1, Mild

Table 8. The descriptions of the highest levels according to various standards.

Standard	*Severity level*	*Description*
ISO 9223:2012	C2, Low	Unheated spaces with varying temperature and relative humidity. Low frequency of condensation and low pollution, e.g. storage, sport halls Temperate zone, atmospheric environment with low pollution e.g. rural areas, small towns.
ISO 11844-1:2020	IC4, High	Heated spaces with fluctuations of humidity and temperature, elevated levels of pollution including specific pollutants, e.g. electrical service rooms in industrial plants. Unheated spaces with high relative humidity (> 70%), some risk of condensation, medium levels of pollution, possible effects of specific pollutants, e.g. churches in polluted areas, outdoor boxes for telecommunication in polluted areas.
ISA S71.04-2013	G2, Moderate	An environment in which the effects of corrosion are measurable and may be a factor in determining equipment reliability.

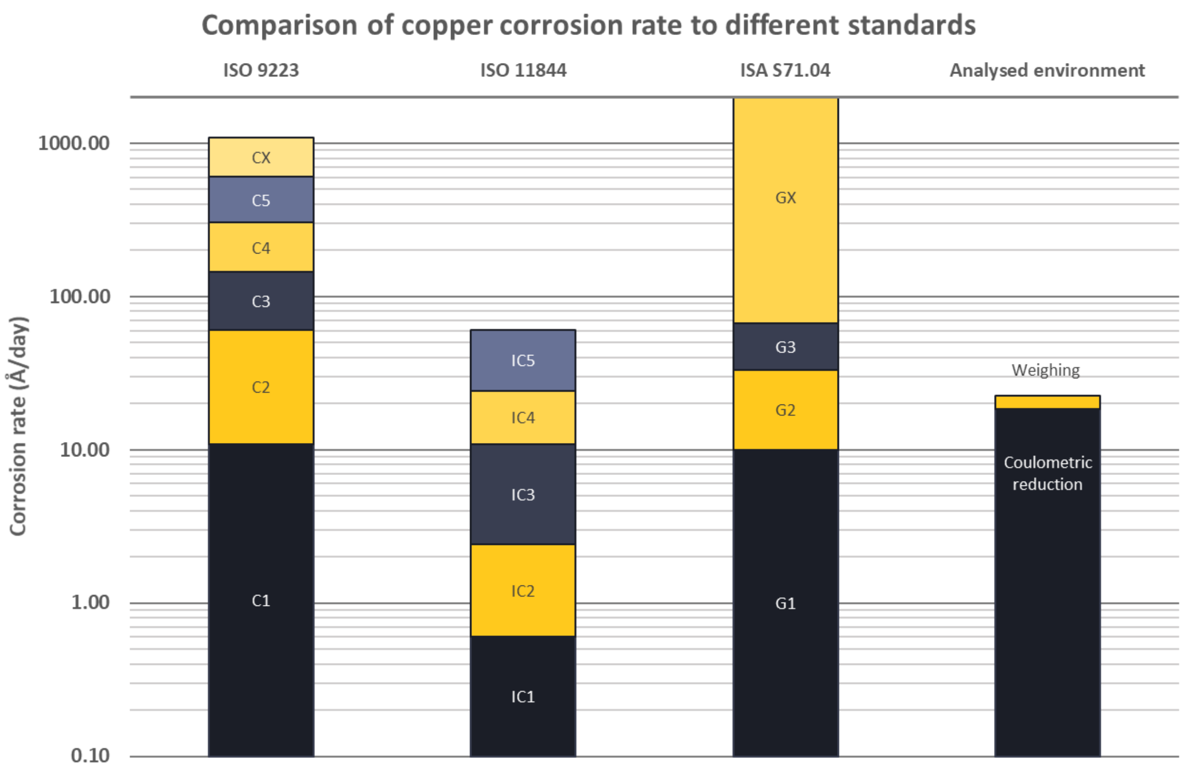

Figure 7. Comparison of copper corrosion rate to corrosion test standards.

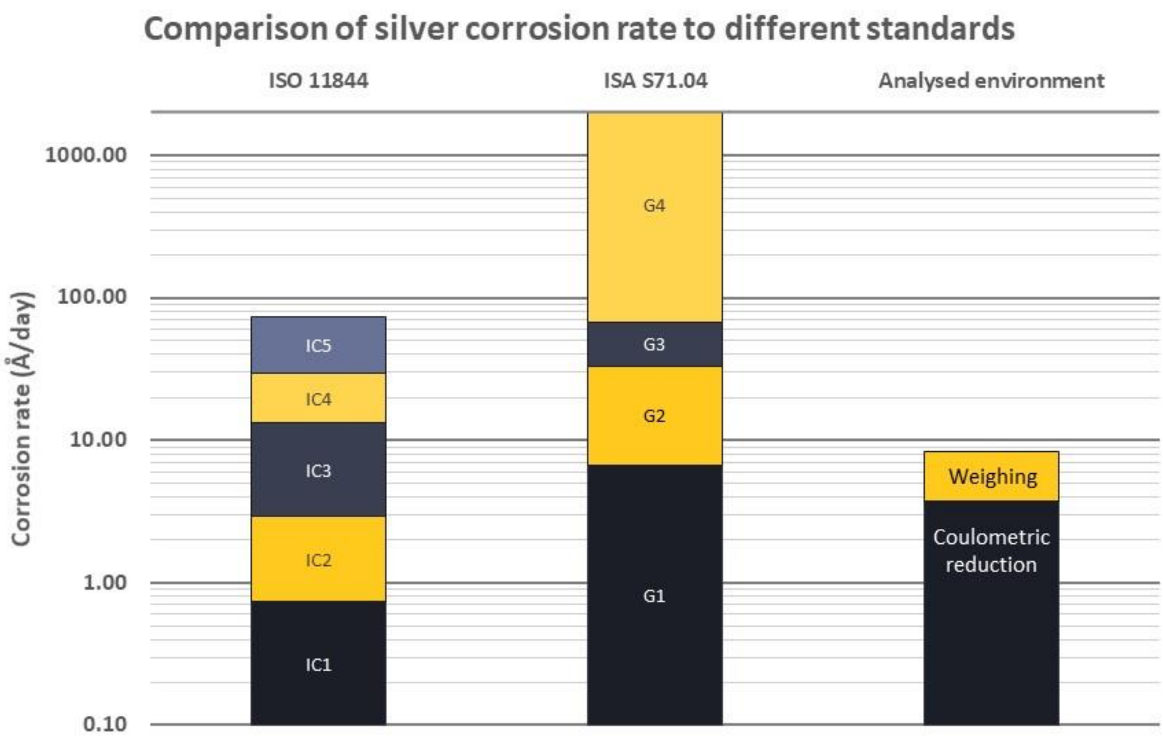

Figure 8. Comparison of silver corrosion rate to corrosion test standards.