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Influence of Surface Finish on Copper Corrosion in Propylene Glycol-Based Direct-to-Chip Coolants for Data Centers

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DYNALENE INC., WHITEHALL, PA USA

*SPEAKER

DATACENTER COOLING

Figure 1 showing Data Center energy consumption [1,2]

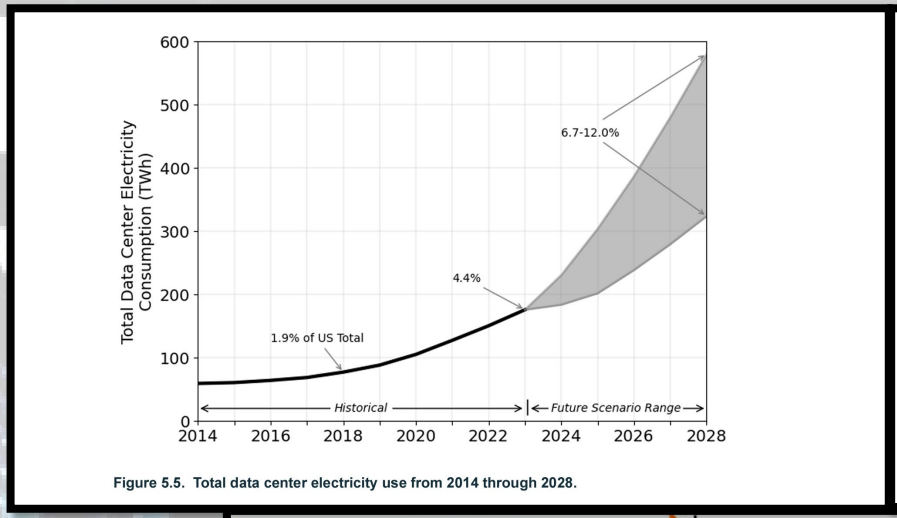


Figure 5.5. Total data center electricity use from 2014 through 2028.

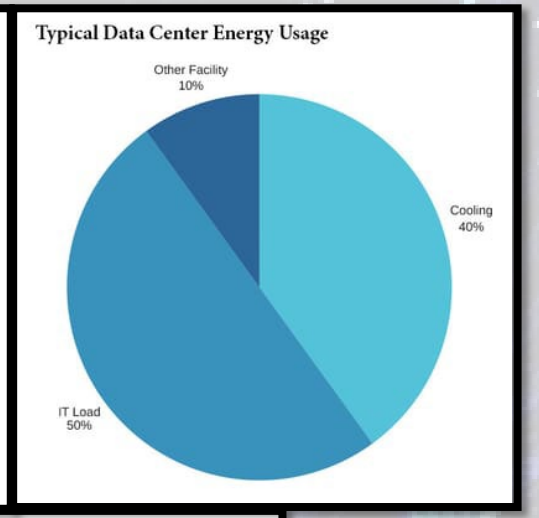


Figure 2: Pie chart showing Data Center thermal management energy use [3]

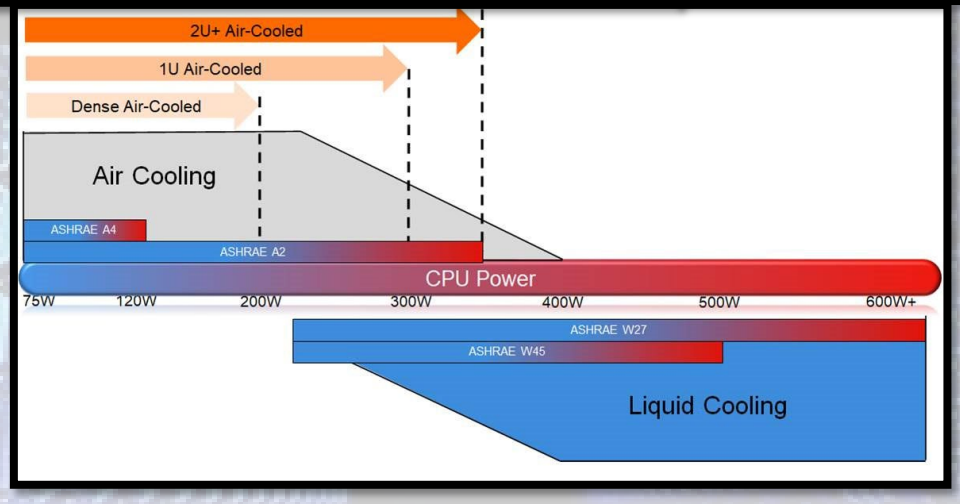


Figure 3: Liquid cooling is necessary due to heat generated from increased power consumption [4]

1. *M. C. Offutt and L. Zhu, Data Centers and Their Energy Consumption: Frequently Asked Questions, Congressional Research Service (CRS), Rep. R48646, Aug. 2025.* https://www.congress.gov/crs-product/R48646
2. https://www.datacenterdynamics.com/en/news/doe-data-centers-consumed-44-of-us-power-in-2023-could-hit-12-by-2028/
3. https://www.datacenterknowledge.com/energy-power-supply/optimizing-cooling-efficiency-in-modern-data-centers
4. *ASHRAE Technical Committee 9.9, Thermal Guidelines for Data Processing Environments, 5th ed. Atlanta, GA, USA: ASHRAE, 2021* https://www.ashrae.org/technical-resources/bookstore/datacom-series

DIRECT-TO-CHIP (DTC) LIQUID COOLING

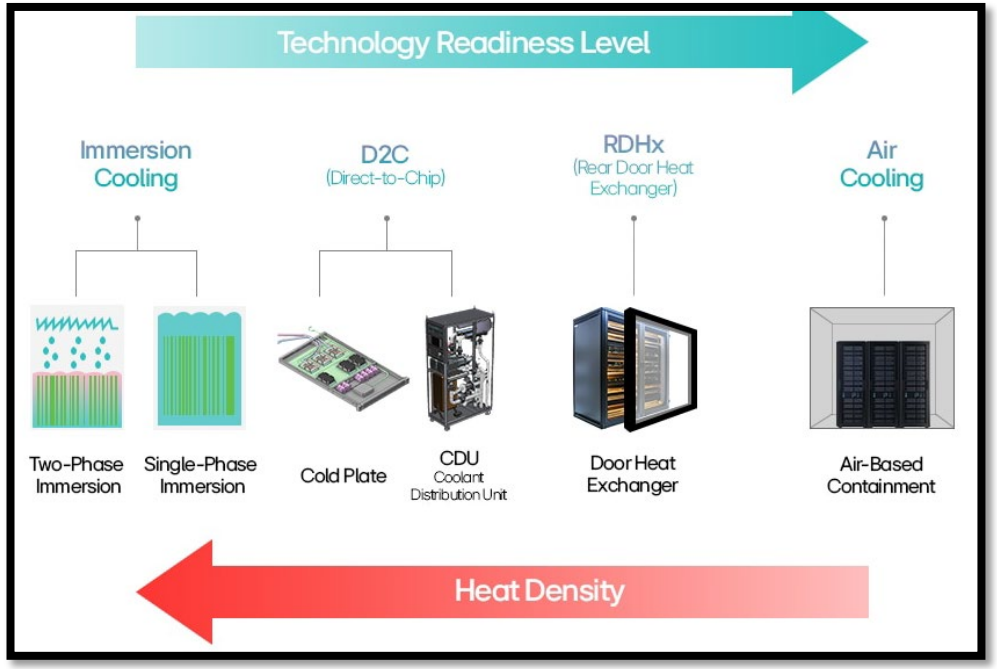


Figure 4: Different types of cooling methods [5]

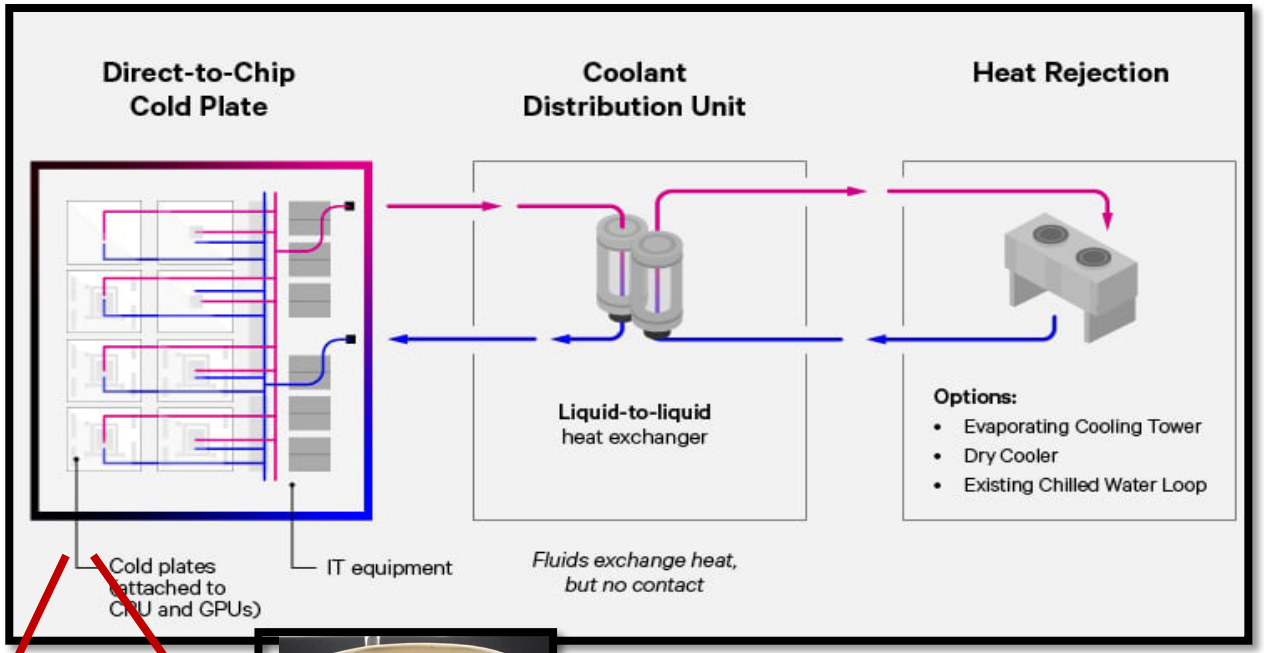


Figure 5: Direct to chip liquid cooling [6]

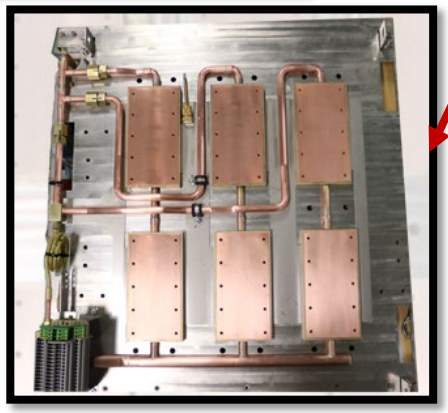


Figure 6: Copper Cold plate [7]



Figure 7: Representative Inhibited Propylene Glycol (PG)-Water 25% DTC Coolant

5. https://www.lg.com/global/business/insights/hvac/blog/data-center-cooling-air-vs-liquid-which-way-to-the-future/
6. https://www.vertiv.com/en-us/about/news-and-insights/articles/educational-articles/understanding-direct-to-chip-cooling-in-hpc-infrastructure-a-deep-dive-into-liquid-cooling/
7. https://www.1-act.com/resources/blog/data-center-cooling-systems/?srsltid=AfmBOoqFdILRB7iTzFuJrWd5dtCi1oIfE96U8iSXS_1klPD5Oo1fTivV

BACKGROUND

Copper Corrosion and Inhibition in Water based Coolants

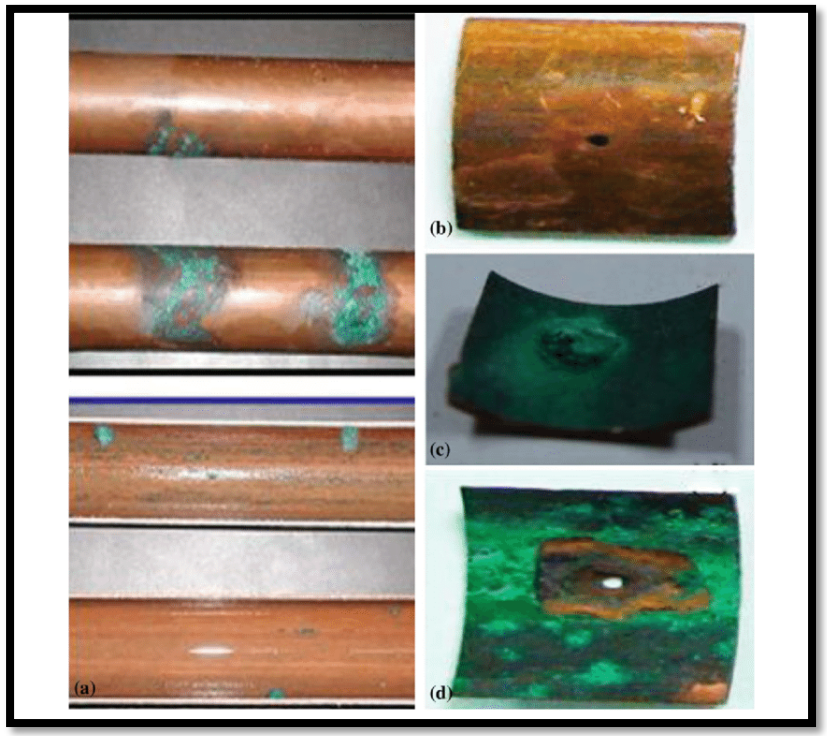


Figure 7: Copper corrosion in water pipes [8]

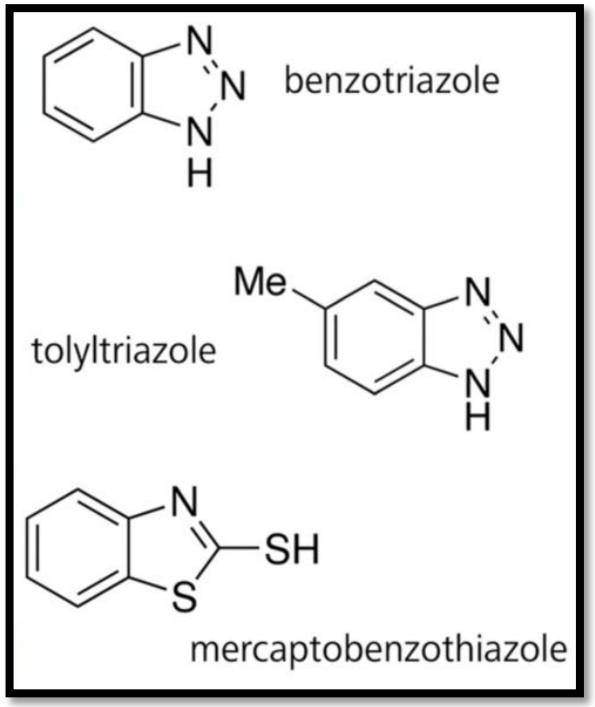


Figure 8: Copper corrosion inhibitors in water/glycol [9]

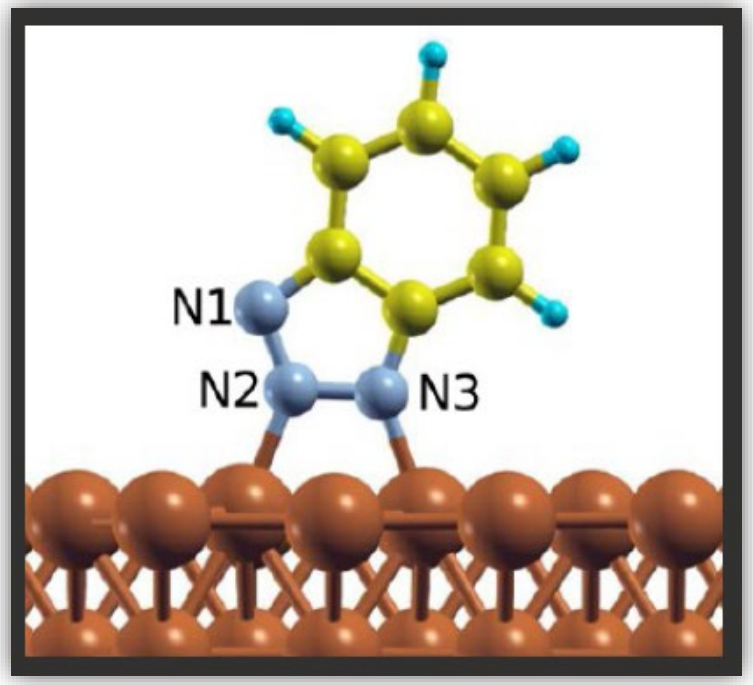
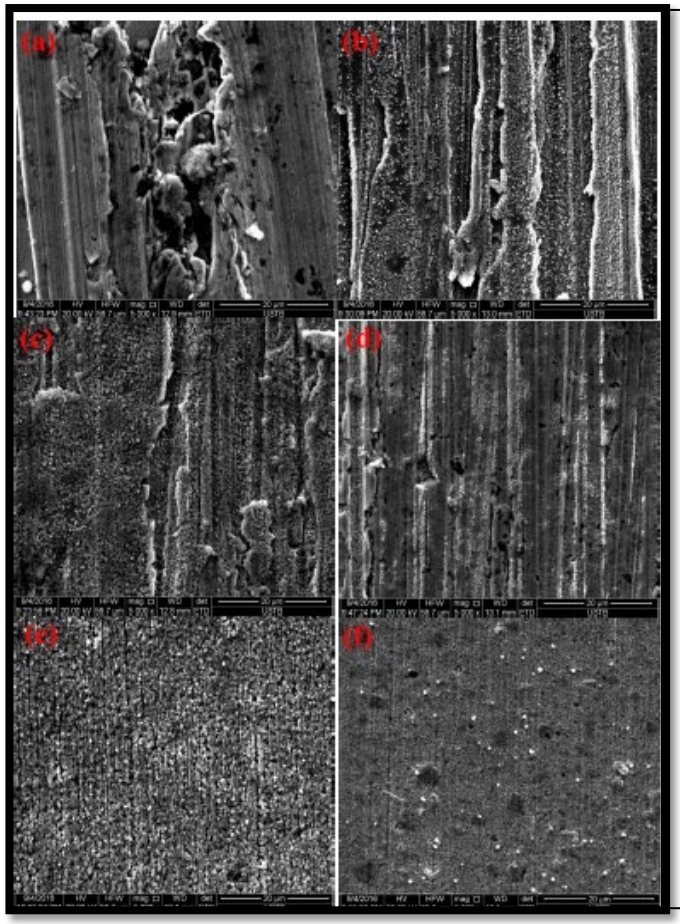


Figure 9: Copper azole (BTA) inhibition schematic [10]

8. Jia, Zhijun & Du, Cuiwei & Zhang, Dongdong & li, Xiaogang. (2010). Analysis of Copper Pitting Failure in Drinking Water Distribution System. Journal of Failure Analysis and Prevention. 2011. 152-157. 10.1007/s11668-010-9415-y.
9. https://www.metrohm.com/en_us/applications/application-notes/prozess-applikationen-anpan/an-pan-1045.html
10. Peljhan, S., Koller, J., & Kokalj, A. (2013). The Effect of Surface Geometry of Copper on Adsorption of Benzotriazole and Cl. Part I. The Journal of Physical Chemistry C, 118(2), 933-943. https://doi.org/10.1021/jp409717e.

BACKGROUND

Surface Roughness and Corrosion



Observations [11]

- In absence of inhibitor surfaces with higher roughness showed higher corrosion current and dissolution.
- The corrosion product uniformly covered smoother surfaces and prevented further corrosion.

Figure 10: Groundwater corrosion effect on copper surfaces with different roughness [11]

Observations [12]

- Increase of surface roughness can cause formation of localized corrosion cells.
- Rougher surface with larger surface area promoted higher corrosion current.

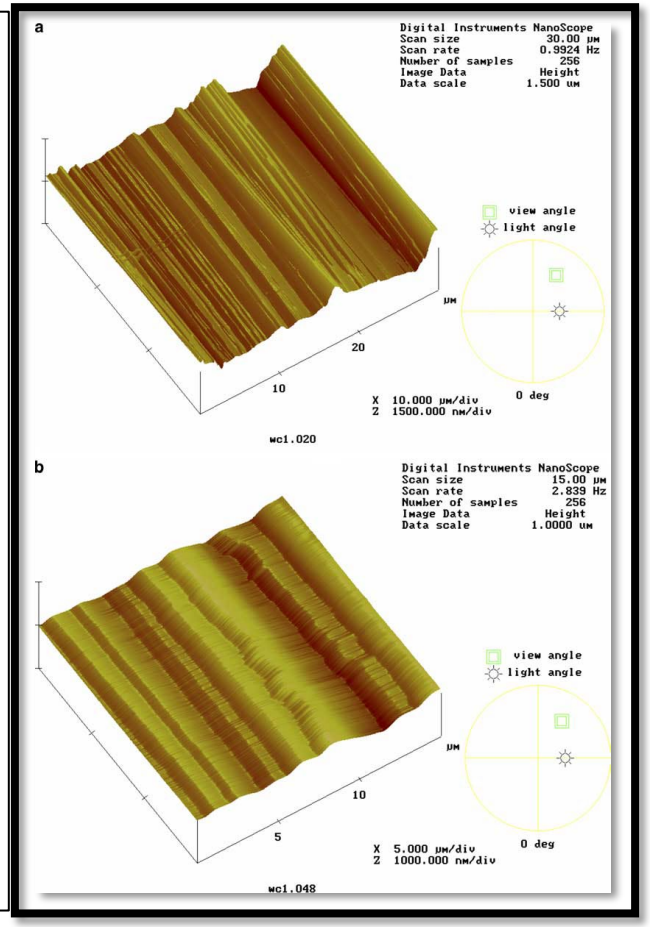


Figure 11: AFM images of before and after corrosion [12]

11. Hu, Minglei. (2020). Effect of Surface Roughness on Copper Corrosion in Simulated Beishan Groundwater, China. International Journal of Electrochemical Science. 15. 2961-2972. 10.20964/2020.04.05.

12. Li, W., & Li, D. Y. (2006). [Title summarized to avoid repetition]. Acta Materialia, 54(2), 445–452. https://doi.org/10.1016/j.actamat.2005.09.017

OBJECTIVE

- Understand how corrosion rate varies with different surface roughness of copper in electrochemical test
- Investigate effect of surface roughness and corrosion inhibition under immersion and heat rejecting conditions
- Examine the inhibitor film morphology formed under different conditions

EXPERIMENTAL

Tests performed:

- Coolant preparation with 25% glycol, benzotriazole (BTA) and phosphate inhibitor *(as per OCP*)*
- Copper (CDA 110) surface roughening/polishing: 60 grit, 240 grit, 600 grit, 1500 grit and ~8,000 grit
- Immersion test in the oven at 50°C for 1 week and 60°C for 3 weeks with different copper surface roughness
- Modified ASTM D4340 with copper discs for 1 week at 65°C

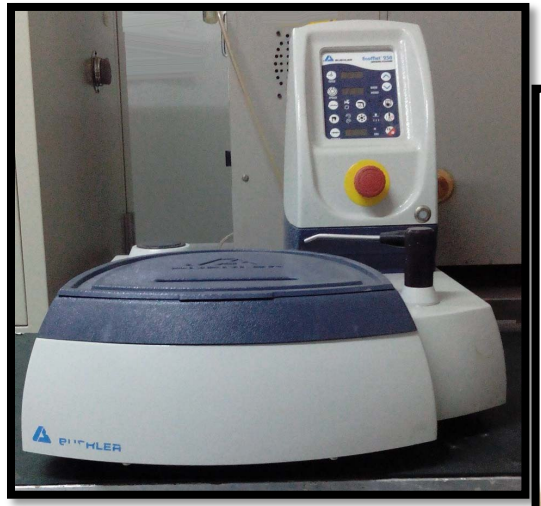
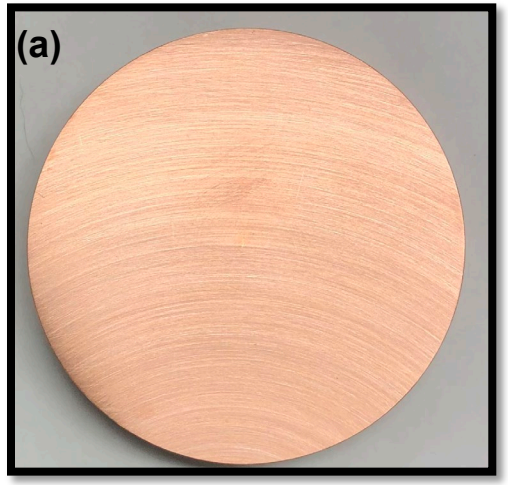


Figure 12: Buehler Ecomet 250 variable speed polisher



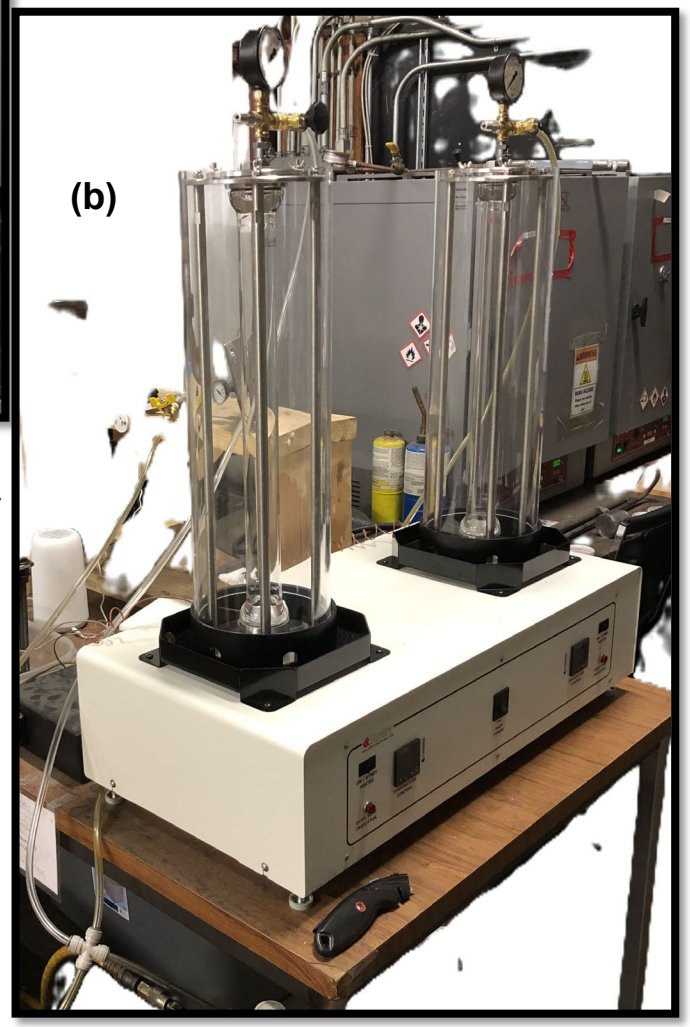




Figure 13: (a) Copper disc polished for (b) ASTM D4340 set-up with a close-up in (c)

**Open Compute Project*

EXPERIMENTAL

Corrosion test and analysis performed:

- Roughness measurement using Mitutoyo Surftest SJ-220 Portable Surface Roughness Tester
- Electrochemical test using Gamry Potentiostat
- Tescan Vega Scanning Electron Microscopy (SEM) and Quantax Energy Dispersive Spectroscopy (EDS) for inhibitor layer morphology and concentration



Figure 14: Surface roughness testing in progress

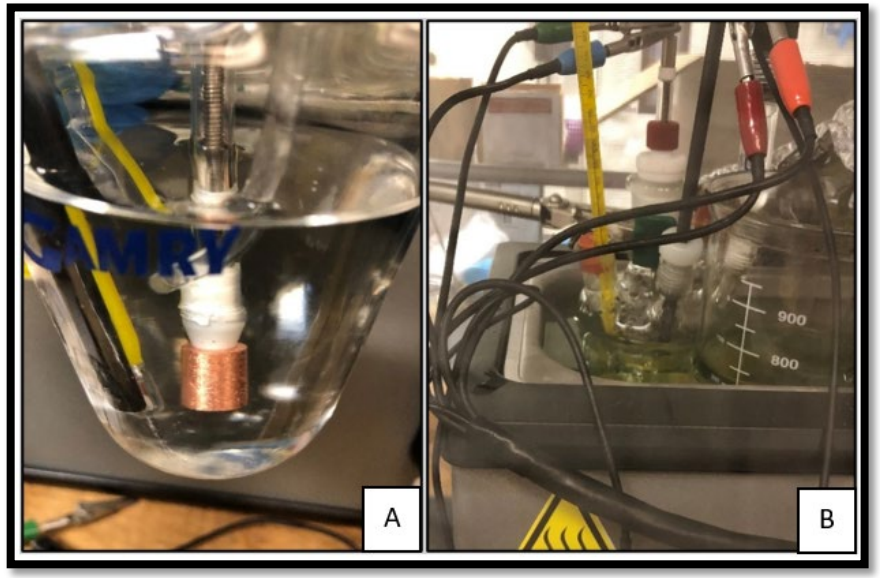


Figure 15: Gamry setup for electrochemical test

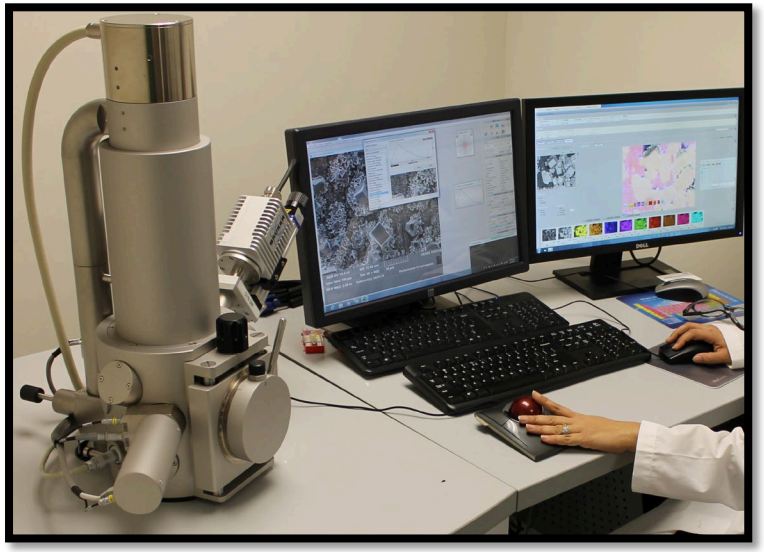


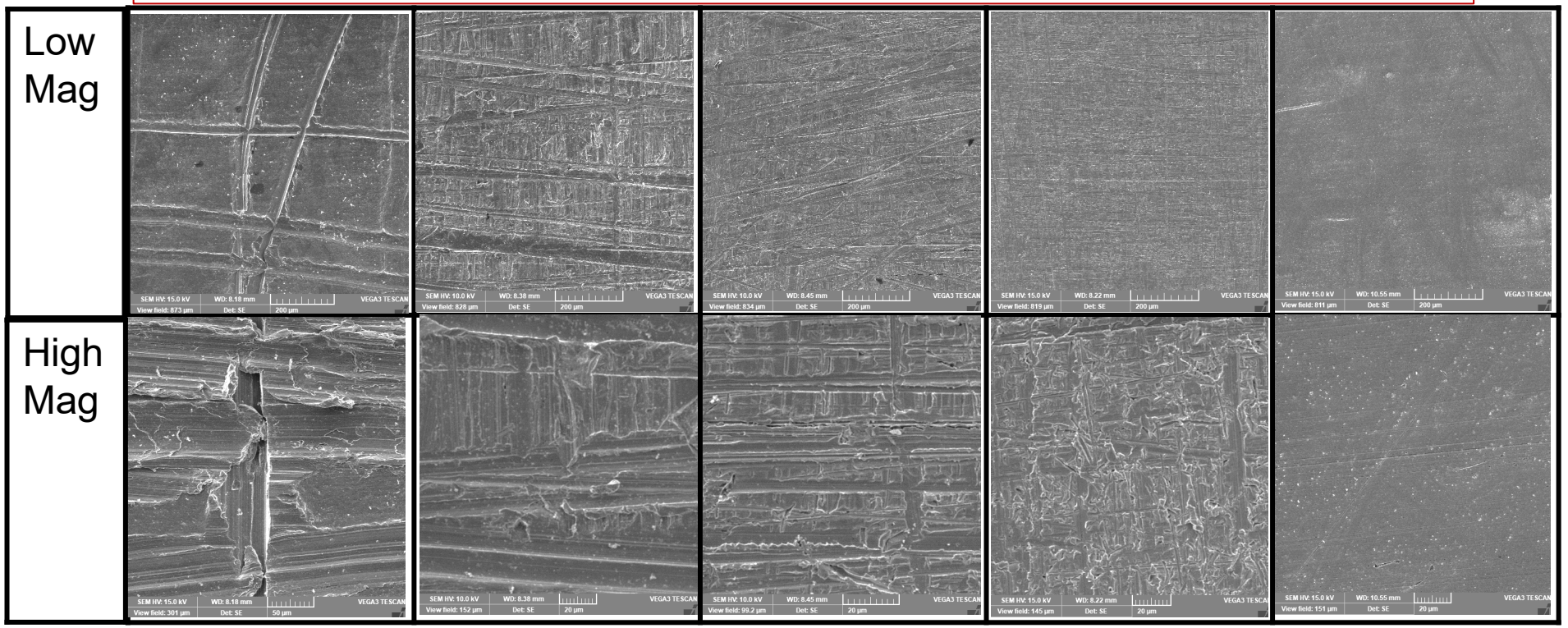
Figure 16: SEM-EDS for microscopy and elemental analysis

RESULTS

Table 1: Surface Roughness of the Copper

Grit	RA_1	RA_2	RA_3	RA_4	RA_5	RA_{AVG}
Mirror	0.029	0.024	0.028	0.025	0.024	0.026
P1500	0.204	0.199	0.230	0.242	0.223	0.220
P600	0.134	0.135	0.125	0.156	0.139	0.138
P240	0.573	0.521	0.628	0.635	0.596	0.591
P60	2.308	2.821	2.846	2.327	2.467	2.554

Figure 17: SEM of Different Surface Roughness on the Copper Coupons



RESULTS

Inhibitor Passivation of Copper Coupons under Immersion Condition (100h at 50°C)

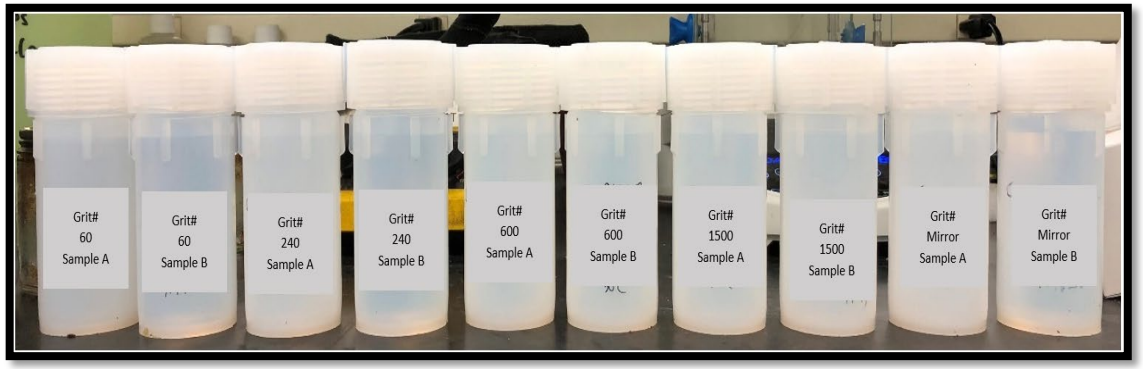


Figure 18: Immersion of Flat Copper Coupons in PG25%

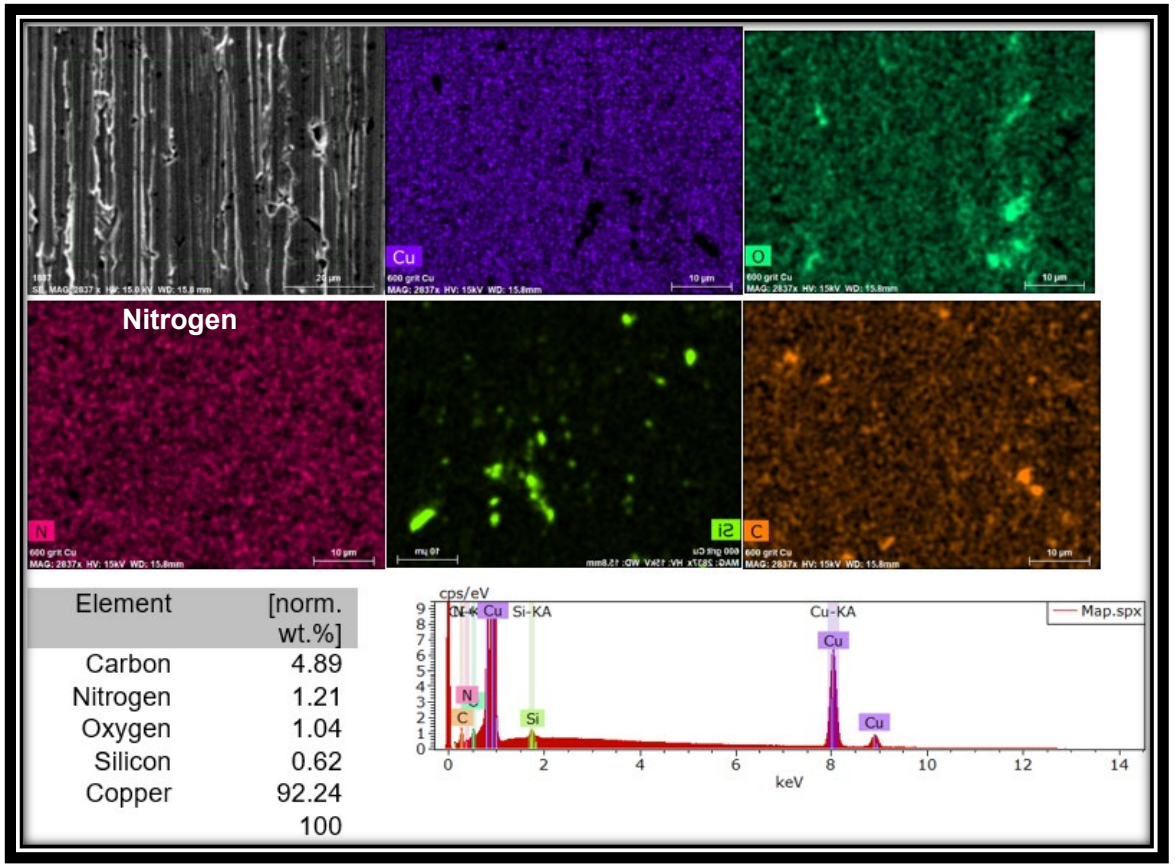


Figure 19: Elemental map and distribution on the copper surface polished with 600-grit

RESULTS

Immersion of Flat Copper Coupons in PG25% (500h at 60°C)

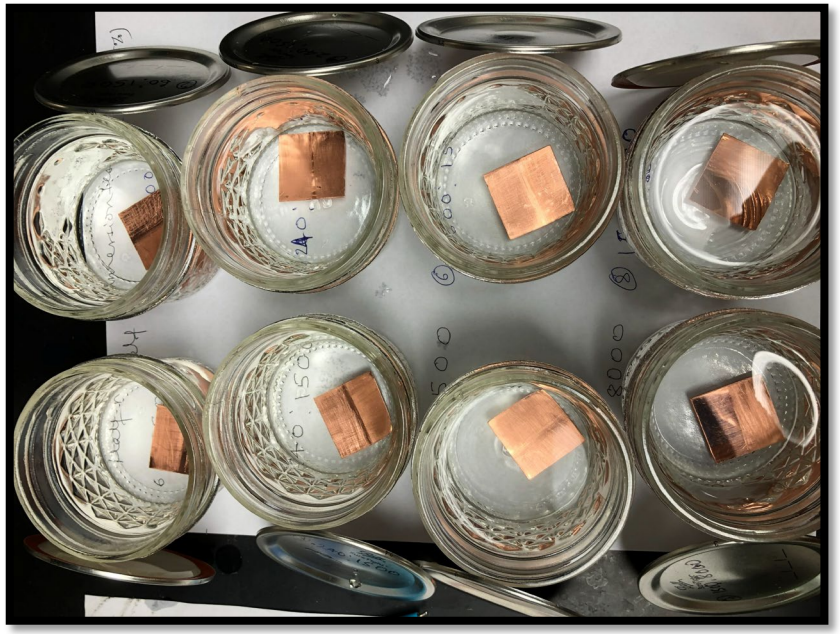


Figure 20: Coupons were polished half and half with two different roughness per coupon to understand variation of azole inhibition

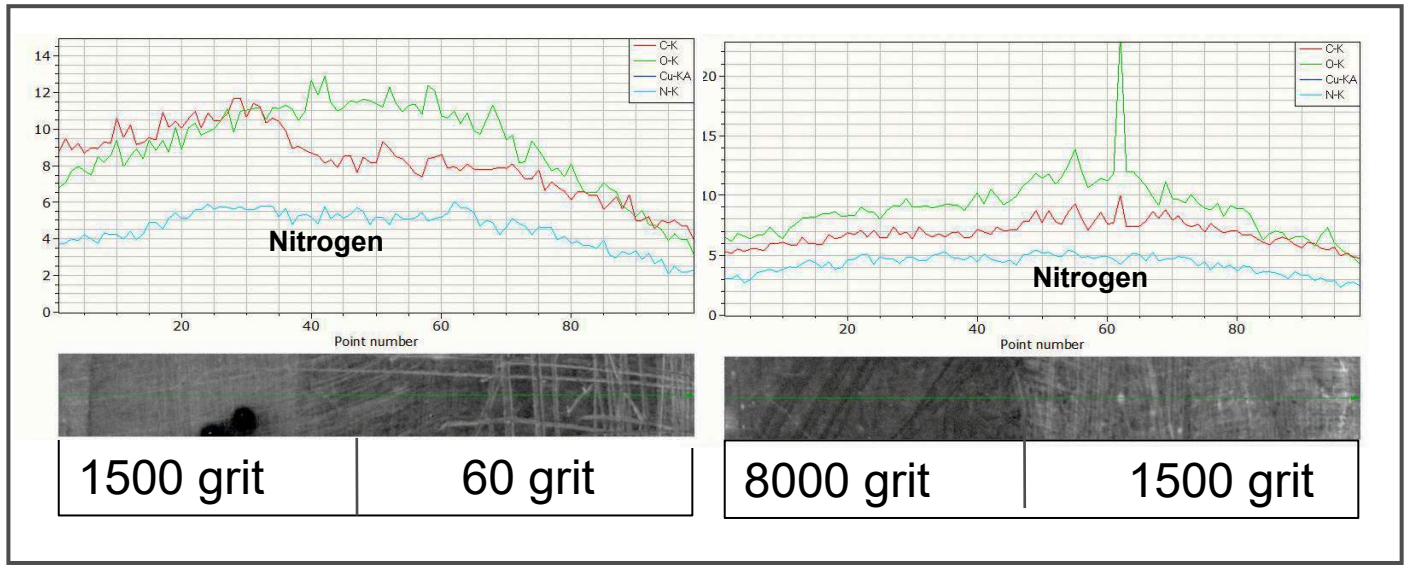


Figure 21: Line scan across two different surface finishes on the immersed copper coupons did not detect difference in nitrogen levels.

RESULTS

Electrochemical Corrosion Test of Copper in PG25% at 50°C

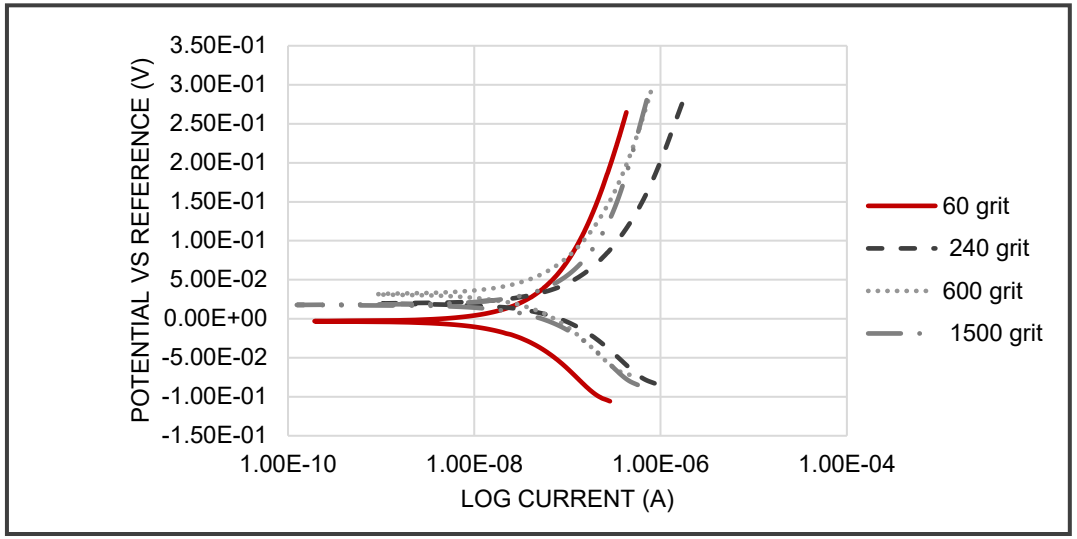


Figure 22: Polarization curves for BTA-inhibited copper polished to different grits

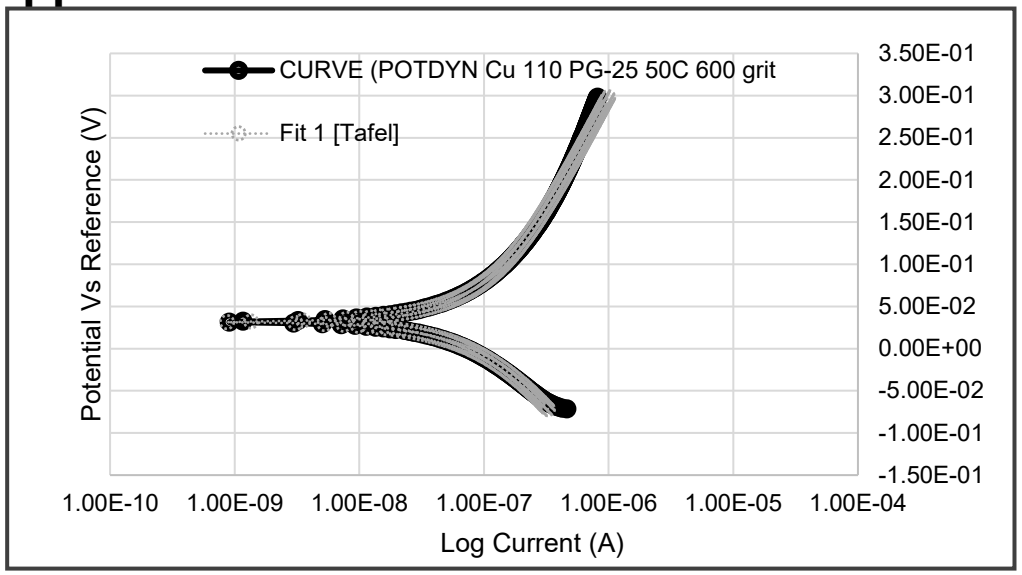


Figure 23: Tafel fit to the polarization curve for BTA-inhibited copper

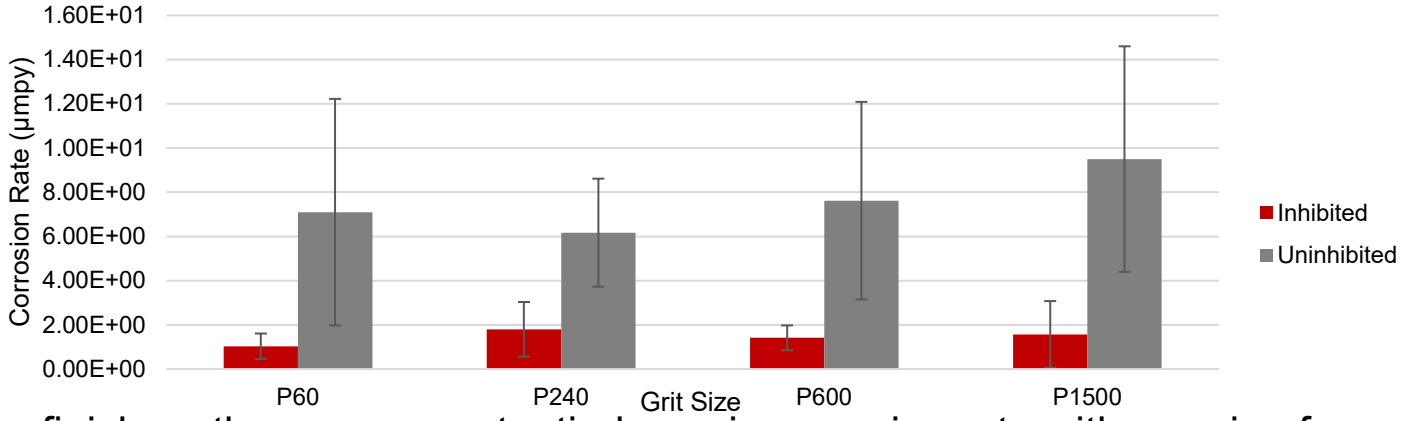


Figure 24: Effect of surface finish on the average potentiodynamic corrosion rate with margin of error (95% confidence level)

RESULTS

Modified ASTM D4340 Test

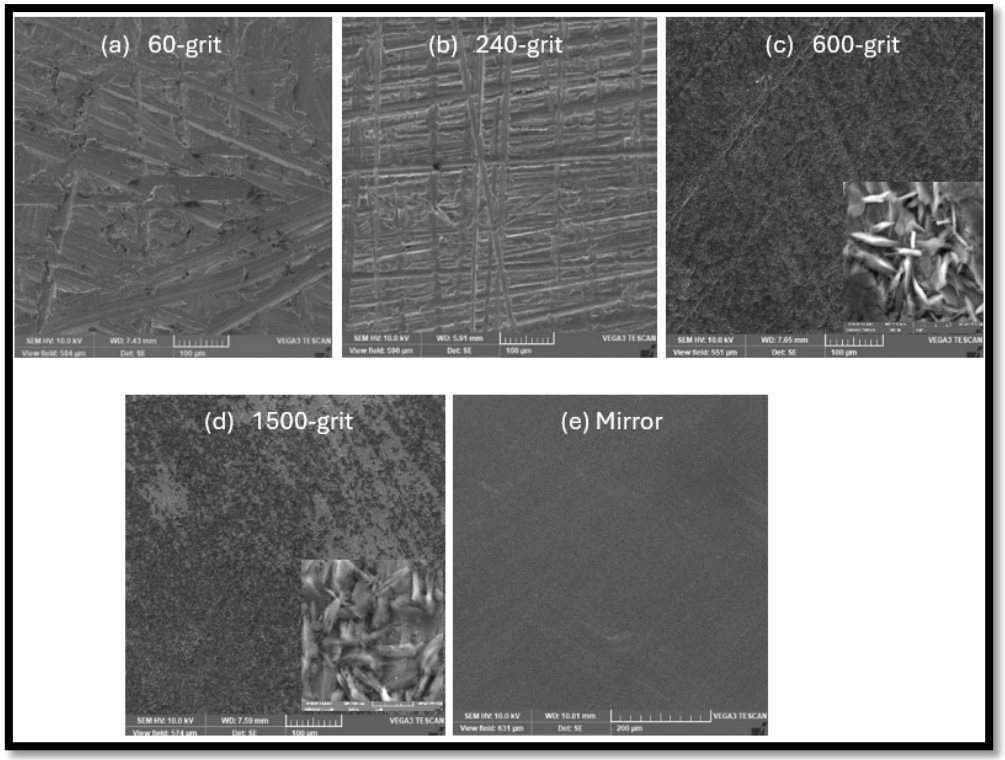


Figure 25: SEM of post-test copper surfaces showed lamellar passivation layer on the surface

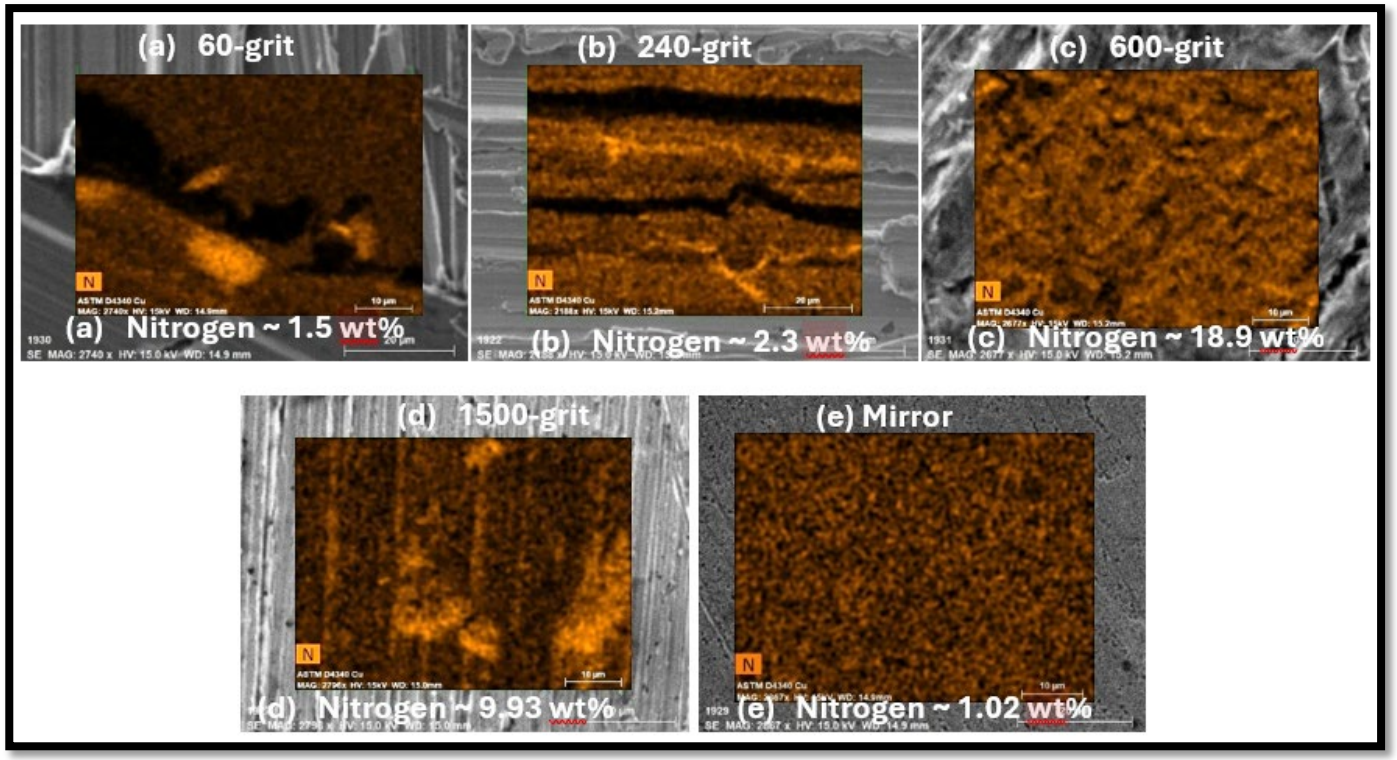


Figure 26: The Nitrogen elemental maps are overlayed on the SEM images illustrating that BTA (N) coverage varied depending on the surface finish.

RESULTS

Tabel 2: Concentration of Nitrogen in the EDS indicating approximate amount of BTA present on the copper surface

Surface Roughness	Immersed copper surface (%) (100h@50°C)	Immersed copper surface (%) (500h@60°C)	Heat rejecting copper surface (%) (168h@65°C)
60	1.10	1.40	1.50
240	1.00	1.80	2.30
600	1.21	1.18	18.90
1500	1.48	1.47	9.93
8000	1.20	0.96	1.02

ONGOING AND FUTURE WORK

Effect of Impurity on Copper Surface



Figure 27: Understanding effect of impurities such chloride and sulfate on copper corrosion in uninhibited PG 25% coolant

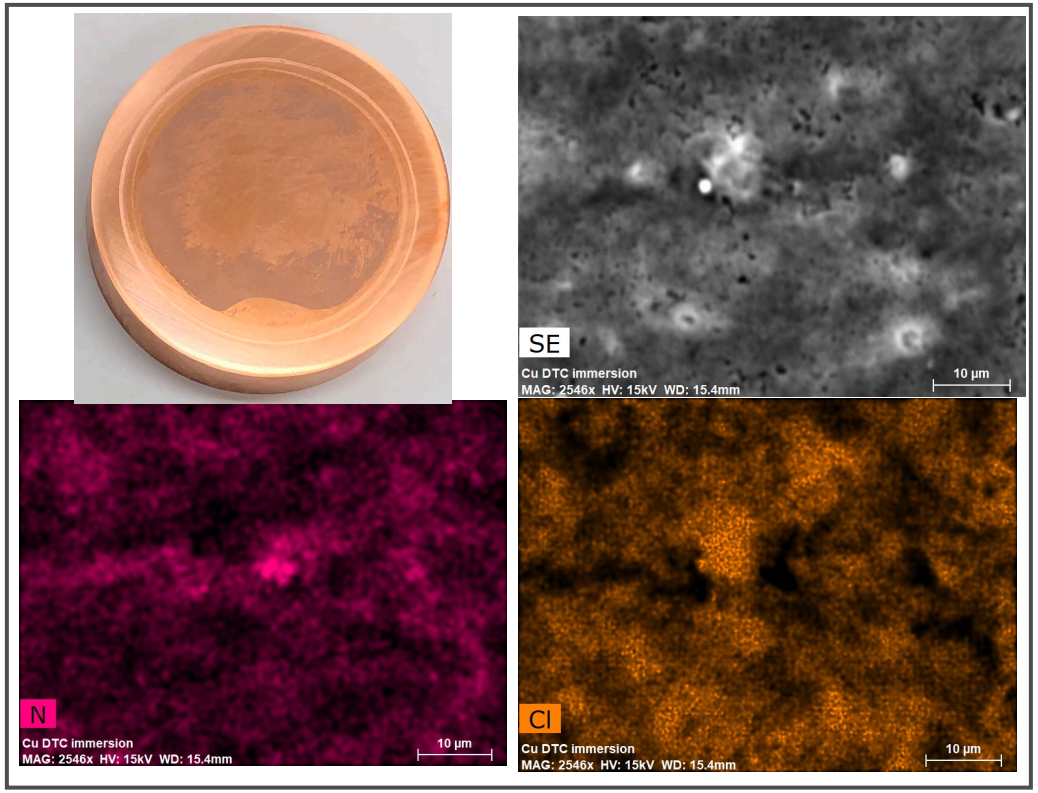


Figure 28: Copper disc from modified ASTM D4340 at 1500-grit polish showed the presence of chloride interfered with nitrogen coverage

SUMMARY AND CONCLUSIONS

I. Electrochemical potentiodynamic studies showed that the inhibited coolant significantly improved corrosion resistance of the copper surfaces compared to the uninhibited coolant.

II. Potentiodynamic studies demonstrated a spread in that corrosion data, which can be contributed to the difficulty of polishing cylindrical coupon and not uniform passivation of the copper surface.

III. Heat rejecting copper plates showed formation of lamellar passivating layers on the copper surface rich in nitrogen between 600-1500 grit.

IV. High surface roughness of copper cold plates poses uncertainty with inhibitor coverage and smoother surface finish greater than 1500-grit does not provide enough adhesion points for the inhibitor to passivate.

V. Presence of contaminants poses challenges to the passivation of copper cold plate surfaces

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