Chrys Shea
Jim Kenny
Jean Rasmussen
Cookson Electronics
Jersey City, NJ, USA

Girish Wable
Quyen Chu
Jabil
St. Petersburg, Florida, USA

Keith Sweatman
Nihon Superior
Osaka, Japan

Dr. Kazuhiro Nogita
University of Queensland
Australia

Shiang Teng
San Jose State University
San Jose, Ca, USA

THE INFLUENCE OF THE PWB FABRICATION/ELECTRODEPOSITION PROCESS ON COPPER EROSION DURING WAVE SOLDERING

Copper Thieves!

Copper Thefts Are Costing Us

Authorities say copper, such as at this scrap-metal yard in Gibsonton, is hard to trace to a source, making it attractive to scavengers.

ROBERT BURKE / Tribune

By KEITH MORELLI The Tampa Tribune

Published: Jul 12, 2007

TAMPA - Copper, the not-so-rare precious metal that as pennies slips forever between couch cushions, is a hot commodity on the

Et Tu, Brute

Copper theiving is inherent to the lead-free soldering process

- Copper from PCB dissolves in lead free solders at a faster rate than tin lead solders
  - Occurs in reflow, wave, PTH rework and hand soldering
  - Pronounced effect in PTH rework
- 3 Ms
  - Industry has identified that the combination’s of current methods, machines and materials are inadequate
- Further investigation is necessary to:
  - Optimize current methods including pad design
  - Innovate machine configurations
  - Analyze possibility to use multiple alloys for assembly and rework

Starting with Definitions…

- Copper dissolution
  - Dissolution IS NECESSARY to form intermetallic bonds, which give solder joints their strength
- Copper erosion
  - Excess dissolution, which removes too much copper, resulting in weak joints or poor bonding of the metal with the PWB
- When does dissolution become erosion?
  - No defined, quantitative metrics at this time

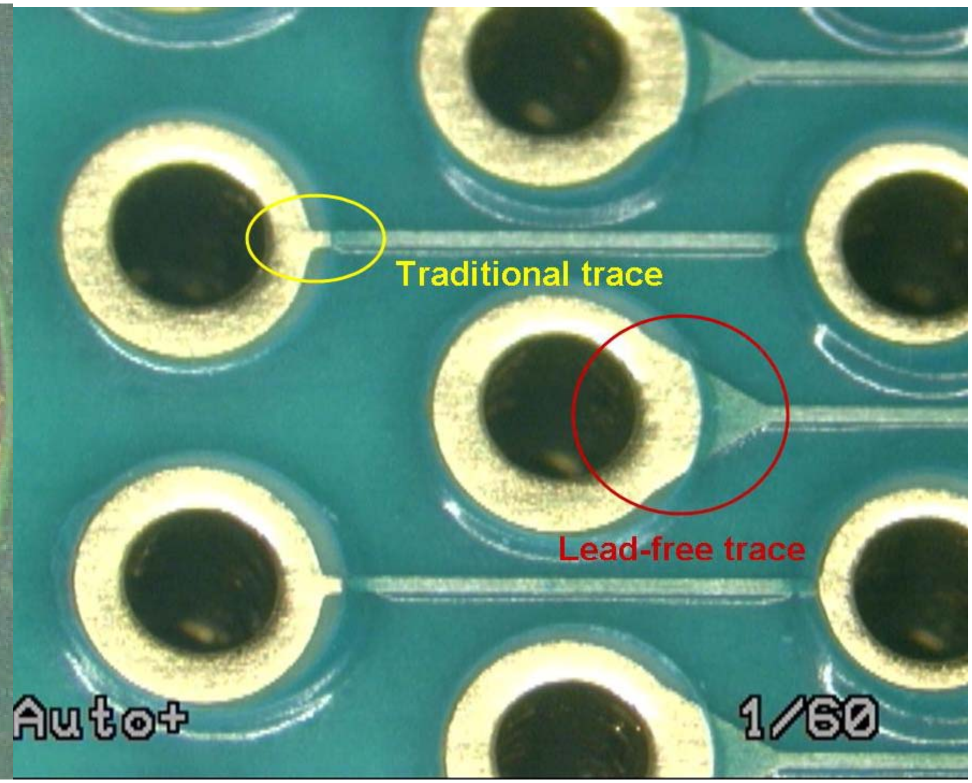
Copper Erosion - Knowns

- Different alloys erode Cu at different rates
- Erosion rates are time-temperature dependent
- Erosion rate increases with flow rate of molten solder
- Erosion occurs on exposed traces, annular rings, barrels, and knees
- Knees are most susceptible to erosion
- Based on studies published in 2006-2007

Copper Erosion - Unknowns

- The effect of the PWB on its own erosion rate
- Historically, studies have focused on the time-temp-alloy dependencies on a single test vehicle design from a single fabrication lot
- Anecdotal evidence that a PWB from one fabricator erodes faster than the same PWB from a different fabricator

Effects: Trace Erosion

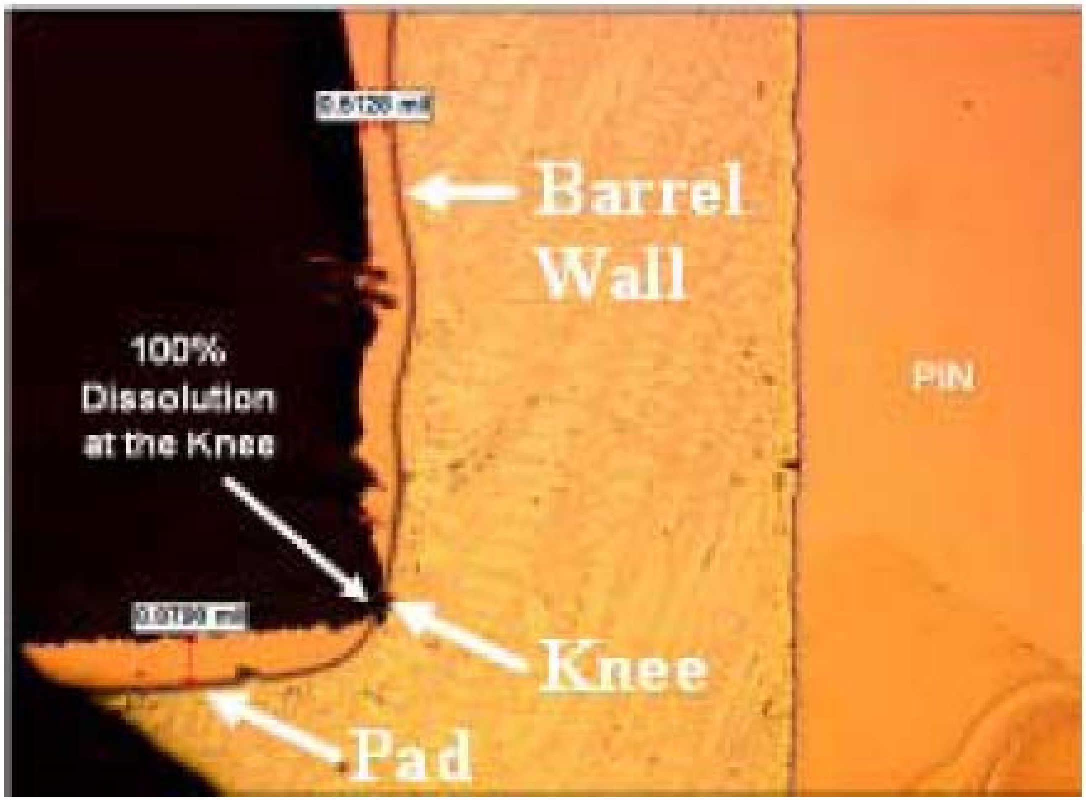


Dissolved Trace to Pad

Source: Yau-Jabil Internal Report, 2005

Source: Cookson Electronics Assembly Materials

Effects: Knee Erosion



Source: "A Study of Copper Dissolution in During PTH Rework Using a Thermally Massive Test Vehicle," Hamilton, C., et al, Proceedings of SMTA International, 2006

No known design guidelines to resolve or minimize issue

Experiment

- Determine where PWB fabrication fits into the erosion equation
- How does the “quality” of the electrodeposited copper influence its propensity to erode
  - Is it a function of grain structure?
- Electrodeposited copper “quality” is typically gauged by T&E tests
  - Higher elongations generally represent preferred, tighter grain structures

Experiment

- Assuming tighter grain structures are less likely to erode

and

- If tighter grain structures are reflected in higher elongation numbers

then…

- A correlation should exist between erodibility and elongation

Yes, "erodibility" is a real word!

Experiment

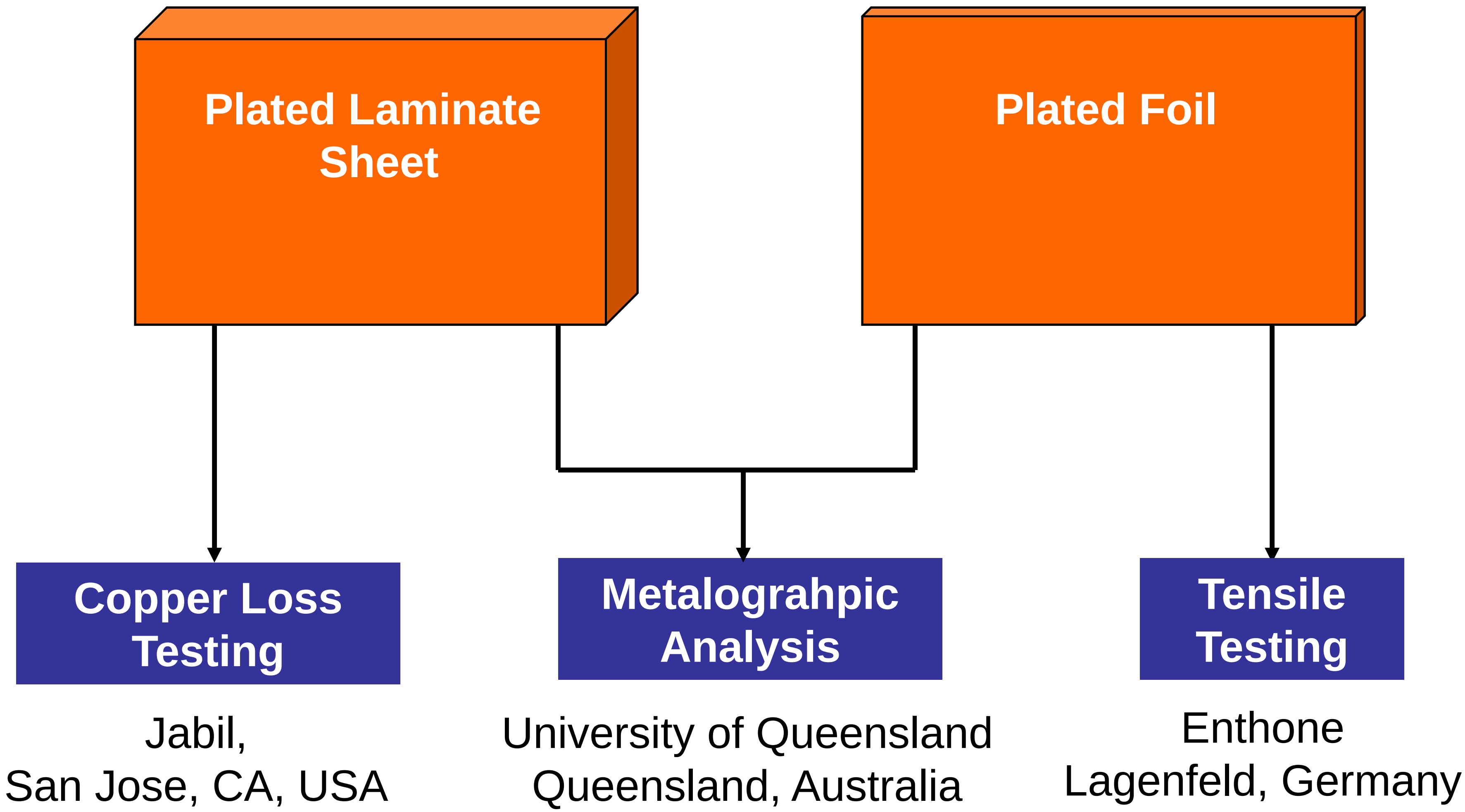
To investigate potential correlation between elongation and erodibility:

- Asked fabricators to plate up blank 18”x24” laminate (25 um) *and* provide specimens for tensile testing (50 um)
- Laminate to be cut into test sample coupons for wave solder
  - Treated with OSP process to ensure “equivalent” solderability among samples
  - Exposed to flowing solder for fixed times

Experiment

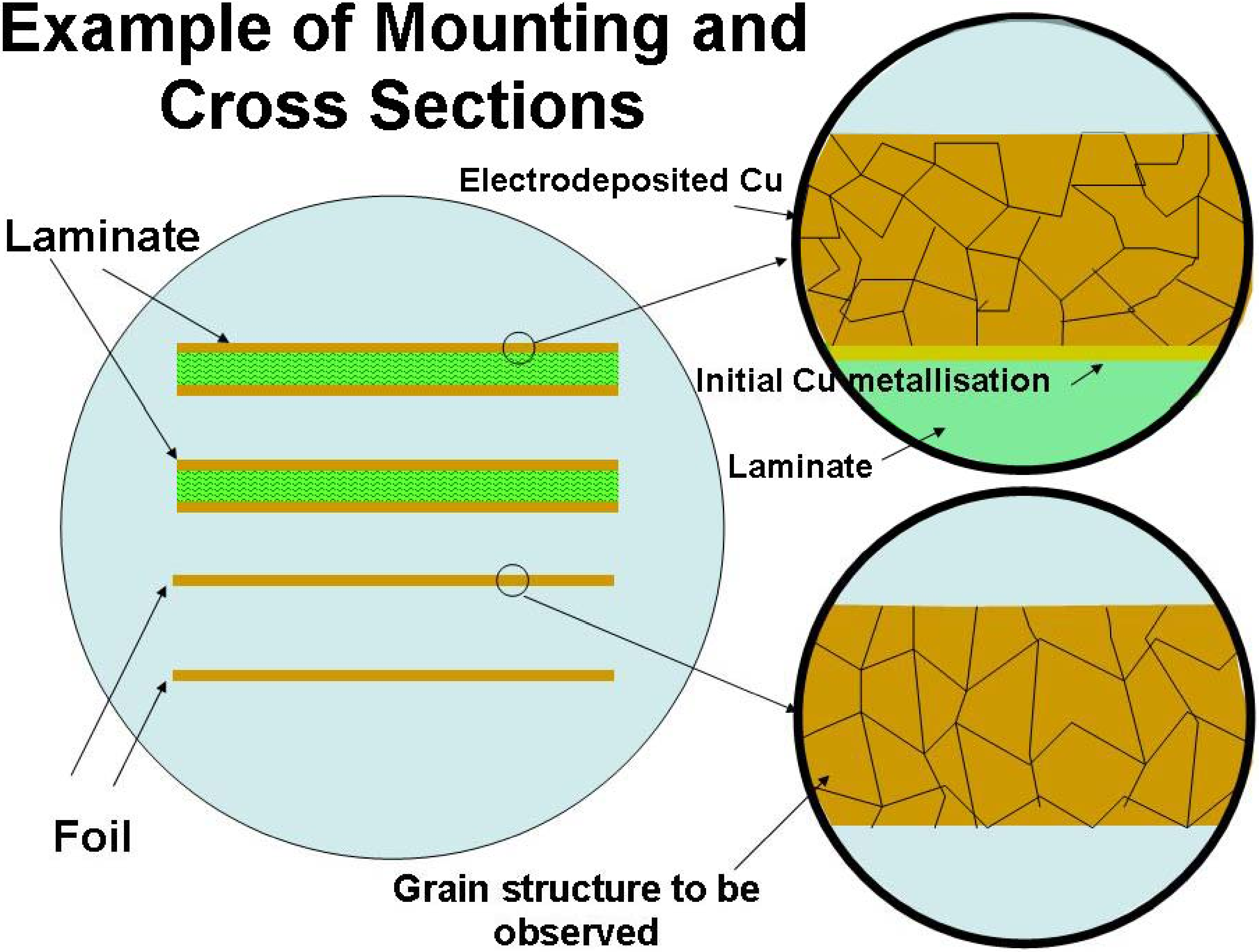
- Tensile specimens tested per IPC TM-650 procedure
- Both laminates and tensile specimens examined metallographically
- Results of copper loss during soldering compared with UTS and elongation, and grain structure

Experimental Design



Sample Preparation

Example of Mounting and Cross Sections



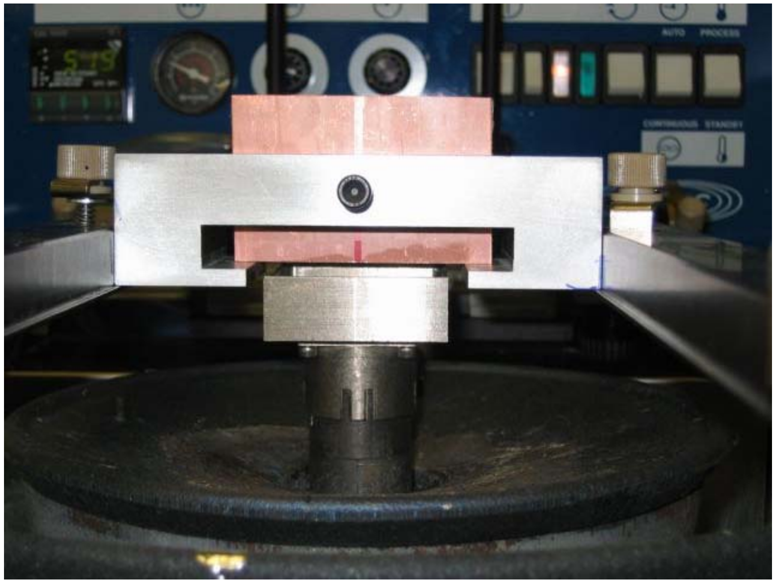
Tensile Tests

- Foils annealed for 1 hour at 125C
- Four specimens per supplier sample
- Measurements averaged
- Ultimate Tensile Strength (UTS) and percent Elongation (Elong %) reported
- IPC-6012B describes minimum:
  - UTS: 248 MPa
  - Elong %: 12

Copper Loss Tests

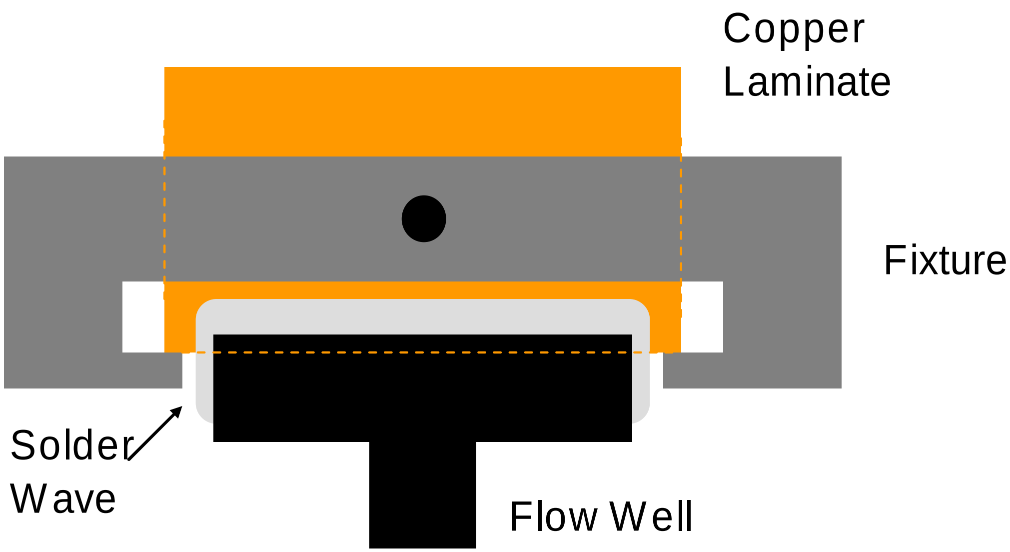
- Laminate sheets, 18 x 24 inches
  - Polyclad 370-HR – all from same lot
  - Plated by 10 fabricators with 1 mil (nominal) electrodeposited copper
  - Cut to 9 x 12 inches
  - Entek® Plus HT process applied
  - Cut to 2 x 3 inch test coupons
- Fixture designed to repeatably position test coupons over the flowing solder

Copper Loss

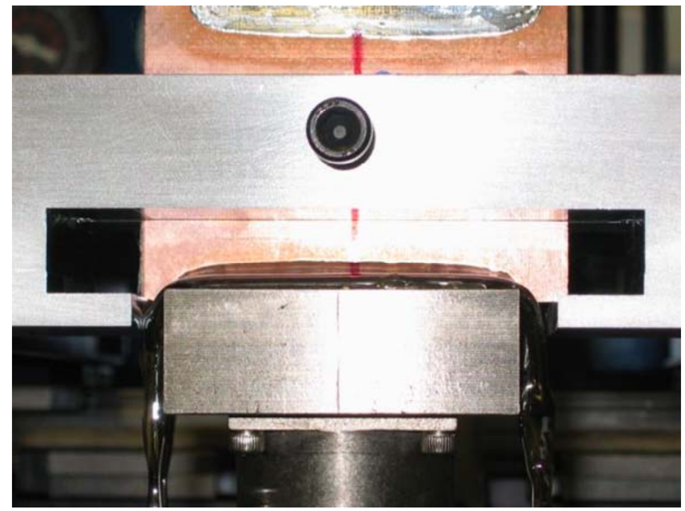


Test fixture used to position samples over Air-Vac PCBRM15 selective soldering and rework system

Copper Loss



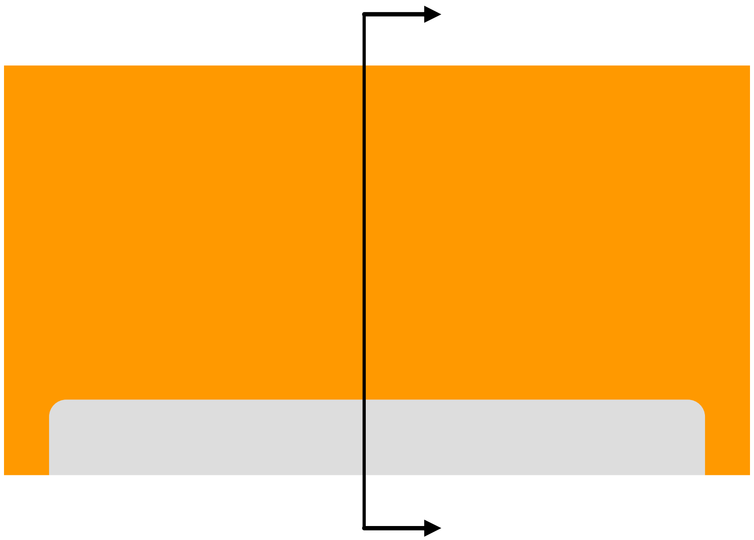
Pictorial Diagram of Setup



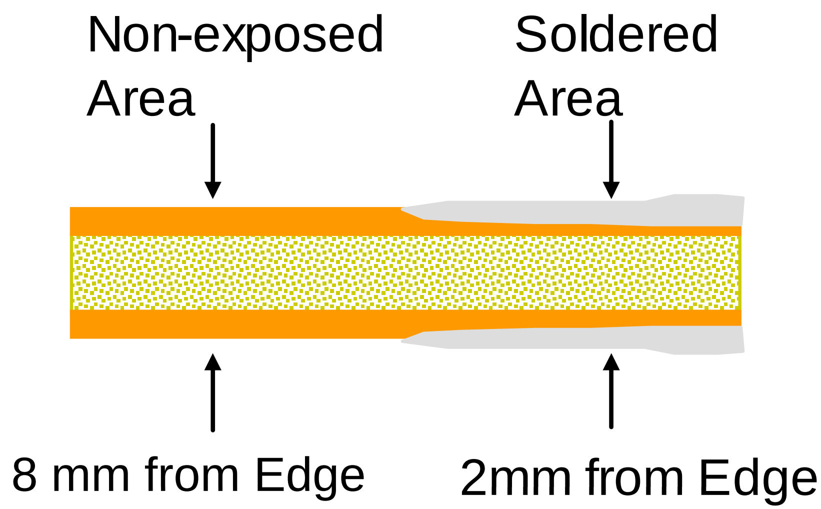
Actual Setup

Details of solder exposure test fixture setup

Copper Loss



Solder Cu Laminate



Cross-sectional View

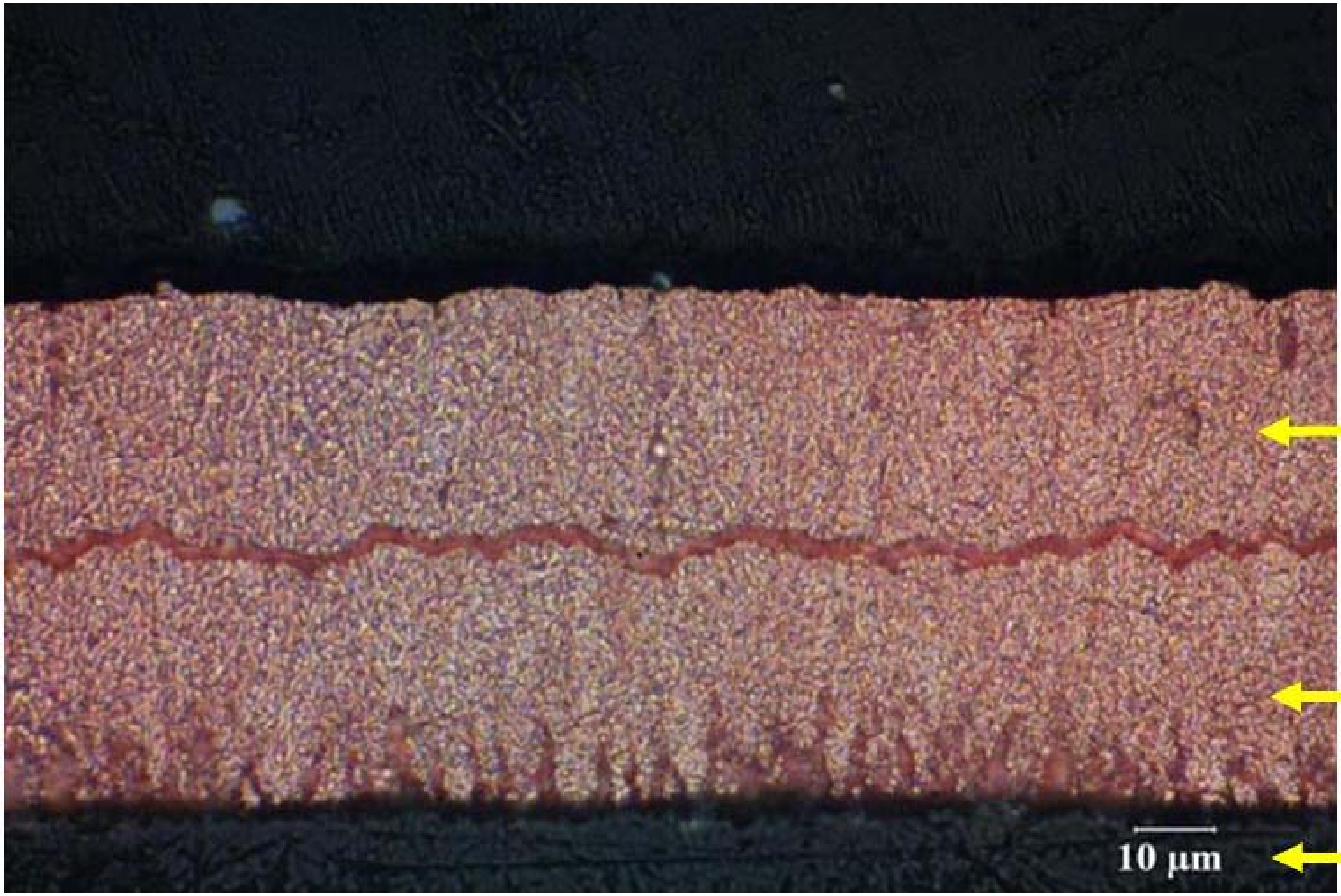
Measurement Locations

Findings

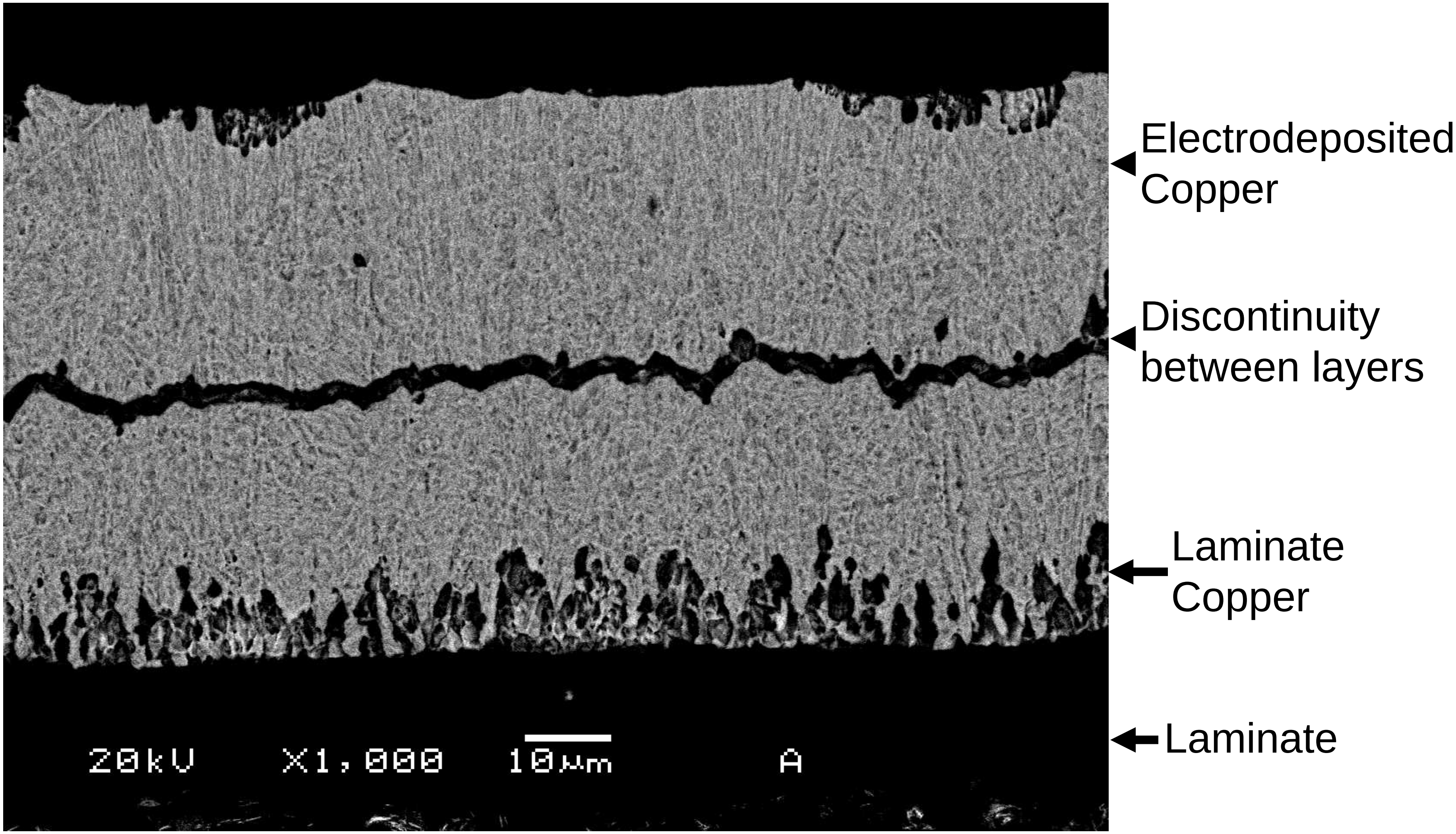
Metallography

HUGE variation observed among the submitted samples!

Sample A Laminate Optical MicroGraph



Supplier A
Laminate Cross-Section



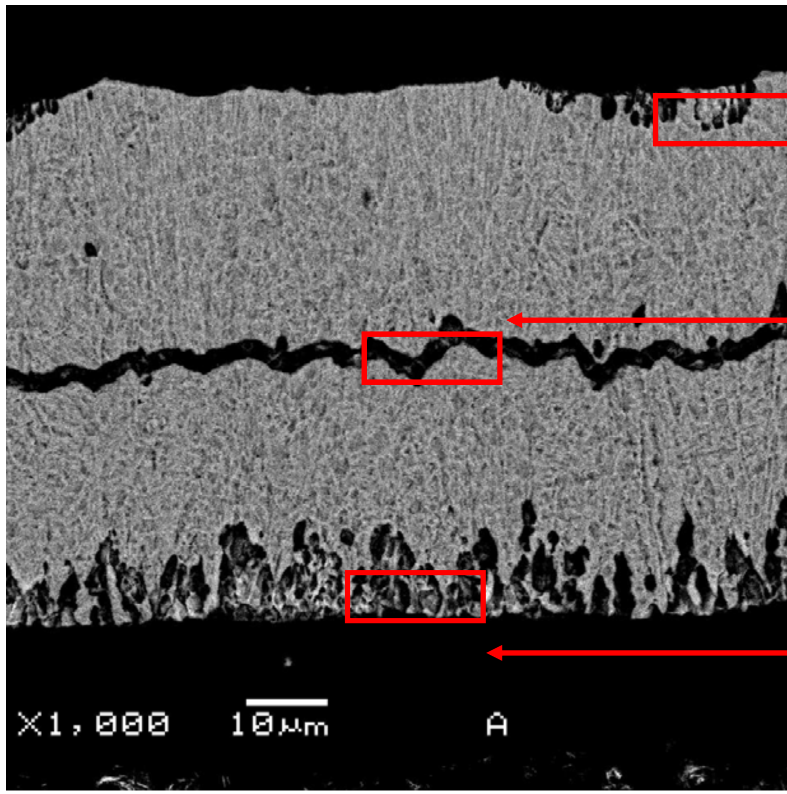
Supplier A
Laminate Cross-Section

Areas where EDX analysis was done to determine nature of dark features in etched microstructur

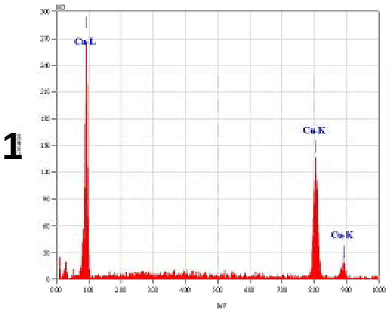
Porosity in the copper provides access for etchant that may result in deeper etching

Metallurgical discontinuity between copper layers is more vulnerable to attack by etchant

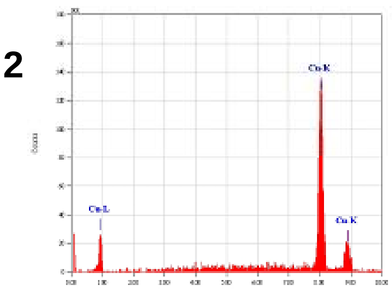
Porosity in the copper provides access for etchant that results in deeper etching in that area



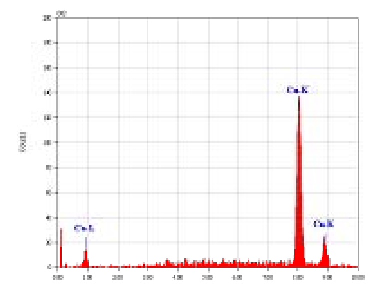
Area 1



Area 2

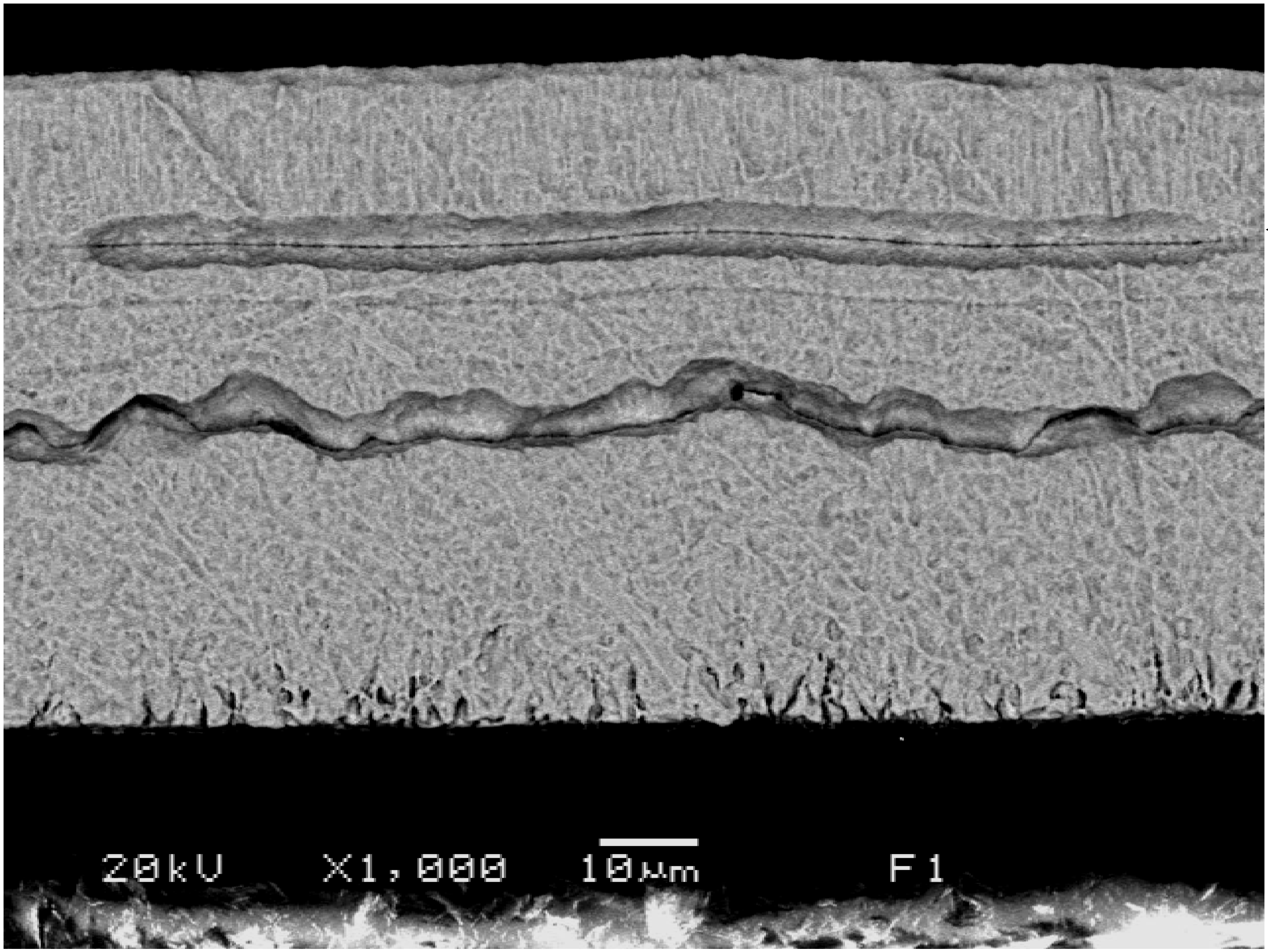


Area 3

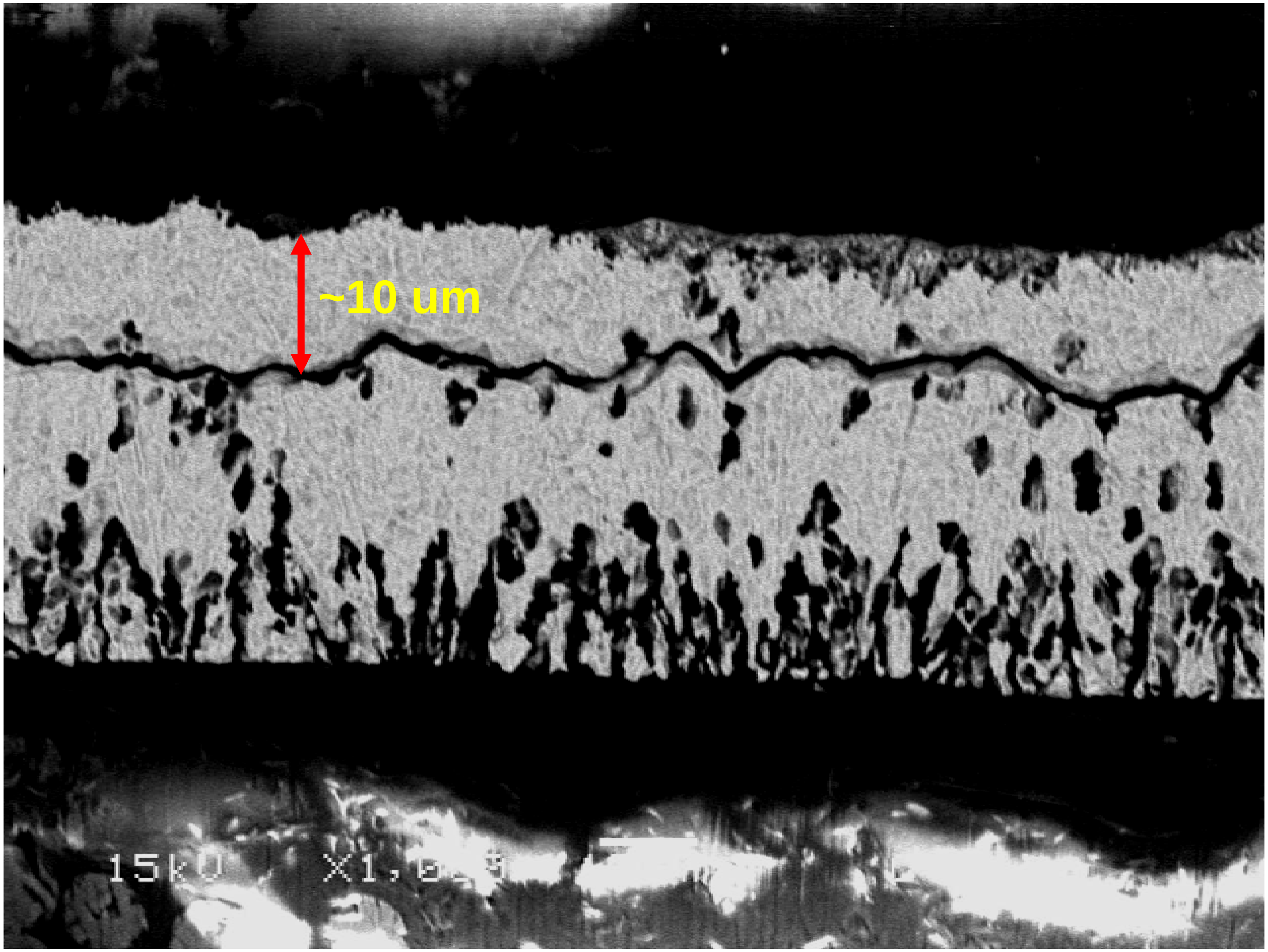


Only copper detected in all three regions tested

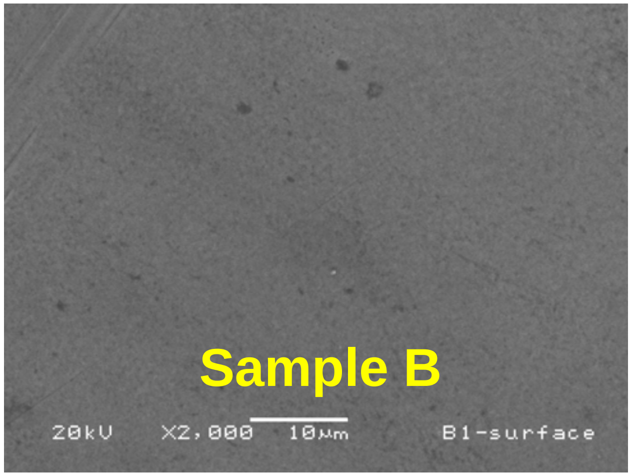
Supplier F
Laminate Cross-Section



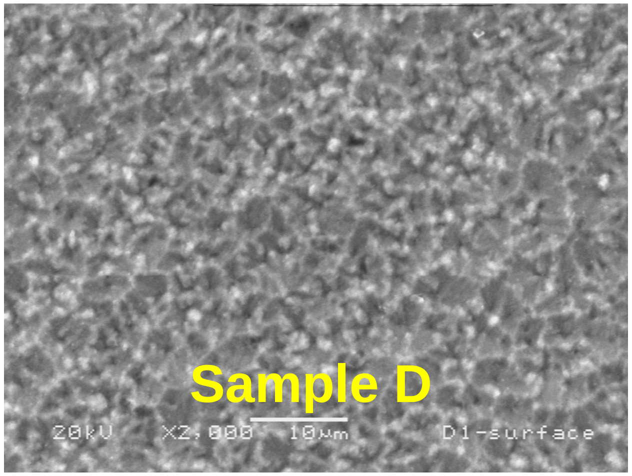
Sample C SEM Micrograph 1000X

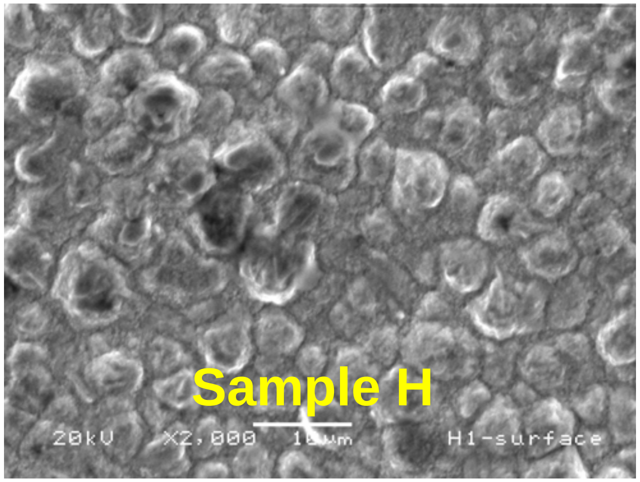


Copper Surface Morphology



2000X
Magnification
SEM



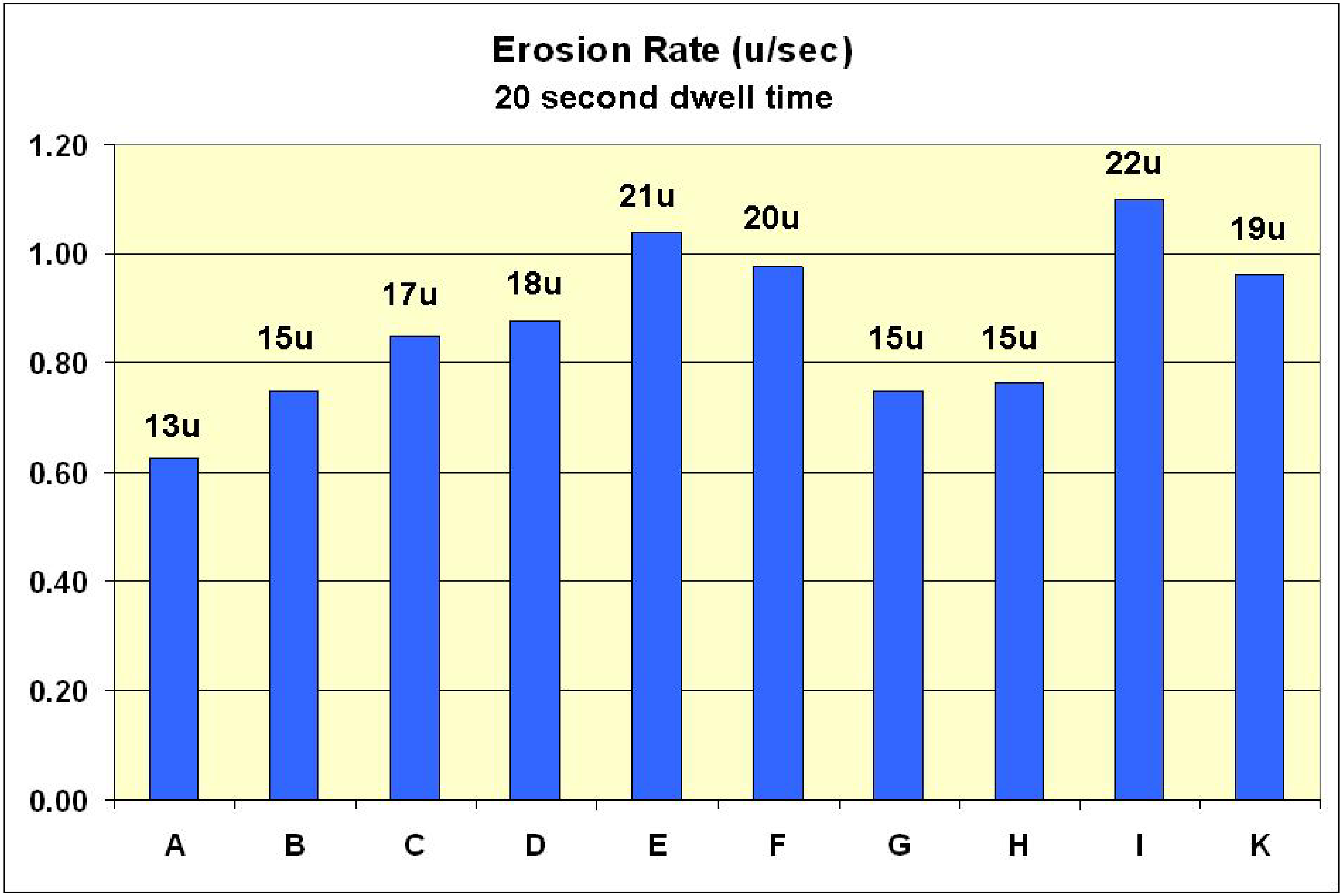


Tensile Results

Sample	UTS N/mm^2	Elong %
A	289	19.3
B	317	11.8
C	-	-
D	215	14.5
E	-	-
F	293	14.0
G	245	16.2
H	241	22.6
I	295	6.1
K	299	18.7

Suppliers C and E did not submit foils for tensile testing

Copper Loss – SAC305



Total copper loss @ 20 sec dwell annotated above bars

Correlations?

- Definite differences in erosion rates among suppliers: by a factor of **1.7x**
- No immediate correlations found among grain structure, elongation, and erosion rates with SAC305 alloy
- Work continues with SACX0307 and Sn100C alloy
- More information will be published as it becomes available

Conclusions to Date

- Erosion rates vary by plating bath
  - Not just by fabricator, but by bath
  - One fabricator submitted samples from three different baths that produced three very different results
- Thicker copper does *<u>not</u>* necessarily mean less susceptibility to erosion defects
  - Prior guidance suggested increasing minimum plating thickness from 18 um to 25 um
  - A thinner layer of slower eroding copper may sustain longer solder dwells than a thicker layer of faster eroding copper

Continuing Work

- SACX0307 and Sn100C copper loss to be determined (completion of phase 1)
  - Comparison of each copper with three lead-free alloys may uncover trends and/or smooth out experimental error induced by manual processes
- Purity/contamination levels of electrodeposited copper to be investigated
- Effect of etchant to be removed from metallograhpic analysis
  - Superfine polish w/polarized viewing
- Comparison between this study's results and PTH soldering sought (phase 2)

Reminders

- Tests to define differences in erosion rates were performed with a perpendicular “dip” into the flowing solder
  - Actual PWB soldering occurs with different flow dynamics – parallel to the board
- Copper loss rates in this setup may not be indicative of loss rates on PWBs
- Electrodeposited copper erosion properties were the focus of the investigation – actual circuit boards have ED copper and base copper on traces and annular rings, but PTH barrel and knee areas have *only* ED copper

Suggestions (1)

- Root cause mechanism(s) that influences copper erosion rates not yet pinpointed
  - Analogous to “black pad” phenomenon of the 1990’s
  - Much work to be done to identify governing characteristic (grain structure, contamination, porosity, plating parameters?)
- Findings to date indicate that PWBs should not be viewed as commodity products in the lead-free era

Suggestions (2)

- Review visual results presented in Appendix
- Discuss concerns or erosion behaviors with PWB fabricator(s)
- If erosion becomes a problem, look into fabricators/date codes to isolate issue
- Input from entire industry is welcome
  - Contact one of the principal investigators on this study

Principal Investigators

- Chrys Shea, cshea@cooksonelectronics.com
- Jim Kenny, jkenny@cooksonelectronics.com
- Keith Sweatman, ksweatman@aol.com
- Quyen Chu, quyen_chu@jabil.com
- Girish Wable, girish_wable@jabil.com

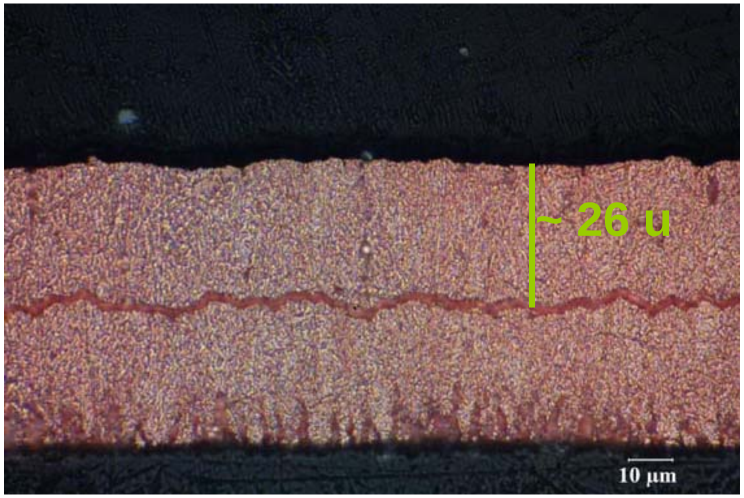
Appendix
Summary of Findings to date
(September, 2007)

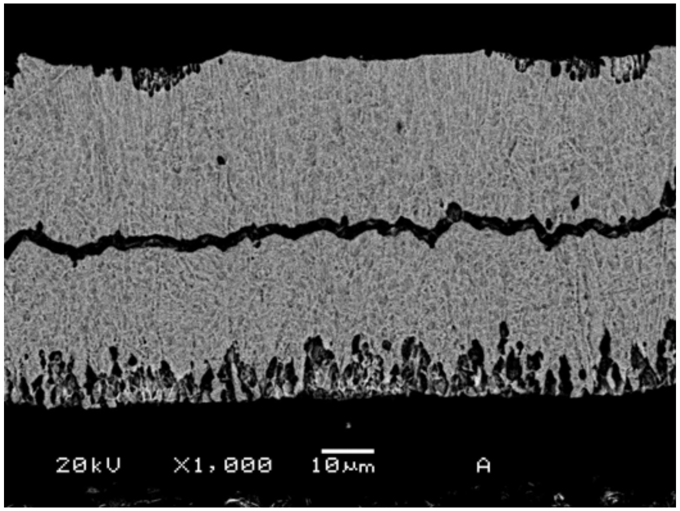
Sample A

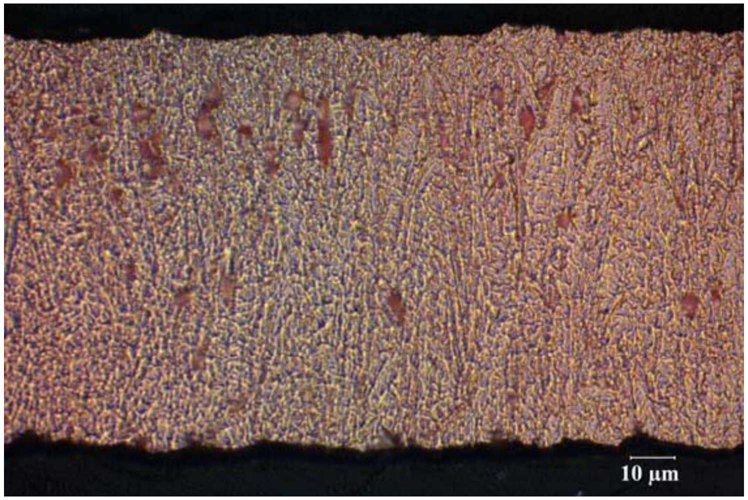
Erosion rate: 0.63 u/sec   Total copper loss (20 sec): 13 u

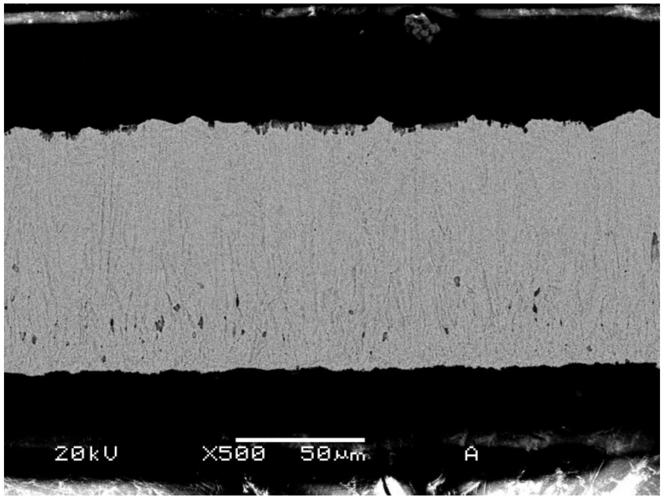
UTS: 289 MPa   Elongation: 19.3 %

Erosion Rank: 1 (lowest)







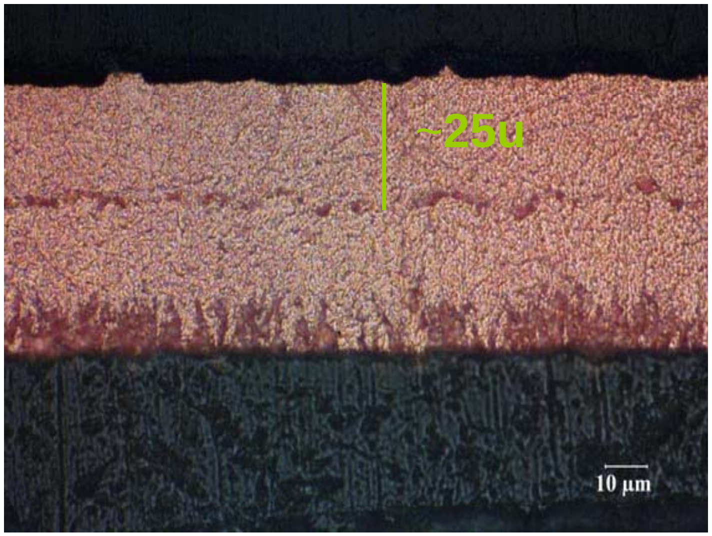


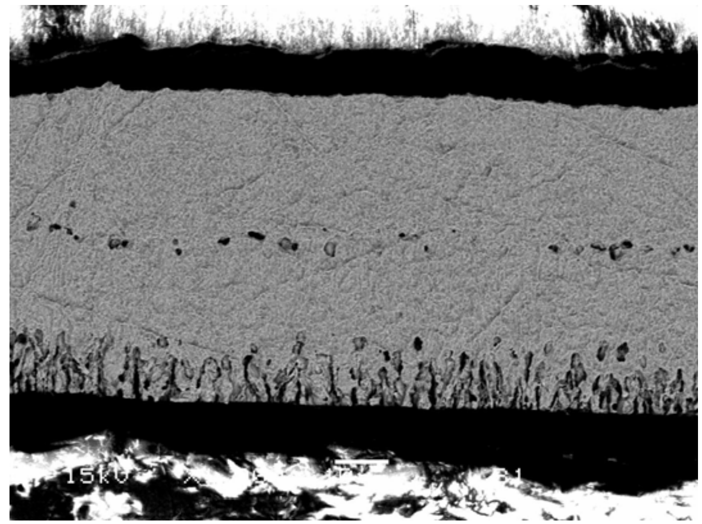
Sample B

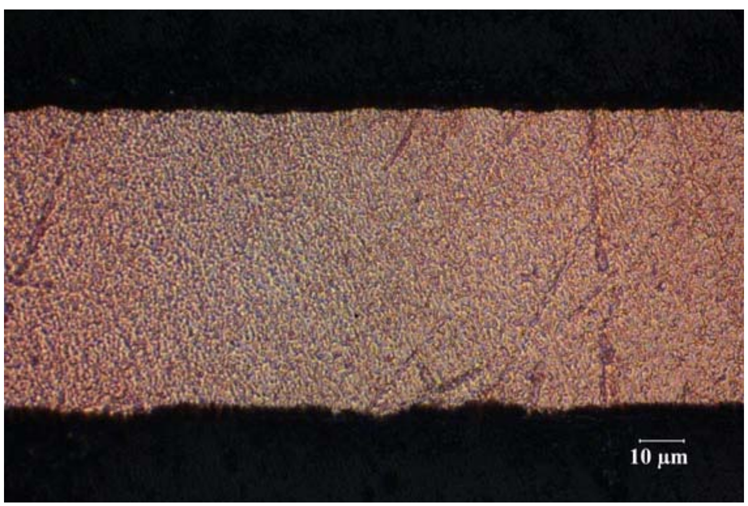
Erosion rate: 0.75u/sec   Total copper loss (20 sec): 15 u

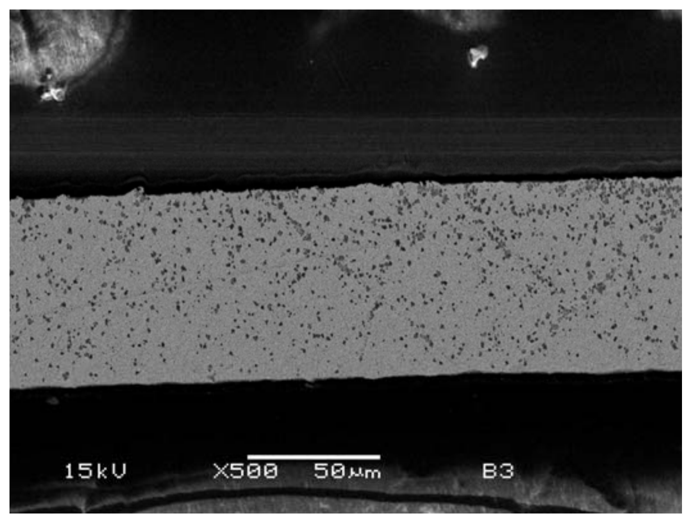
UTS: 317 MPa   Elong: 11.82 %

Erosion Rank: 2 (low)







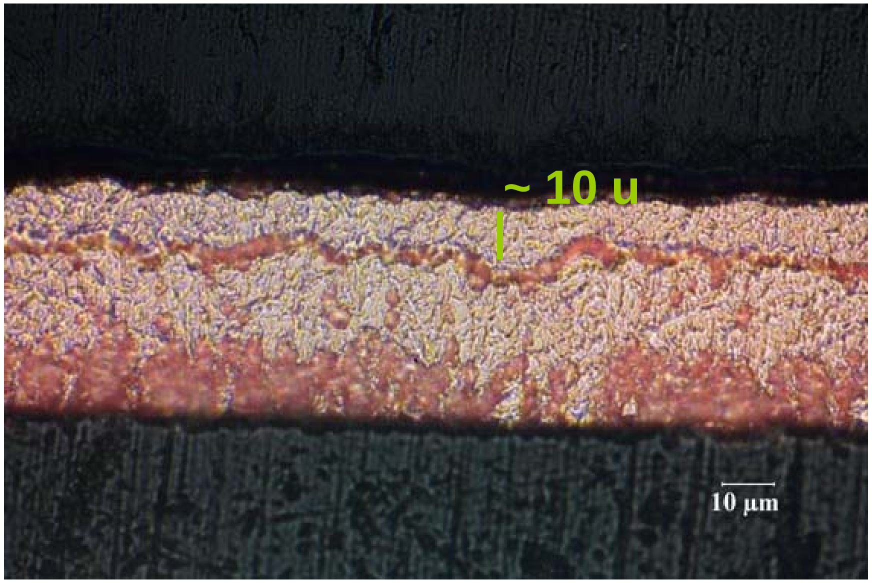


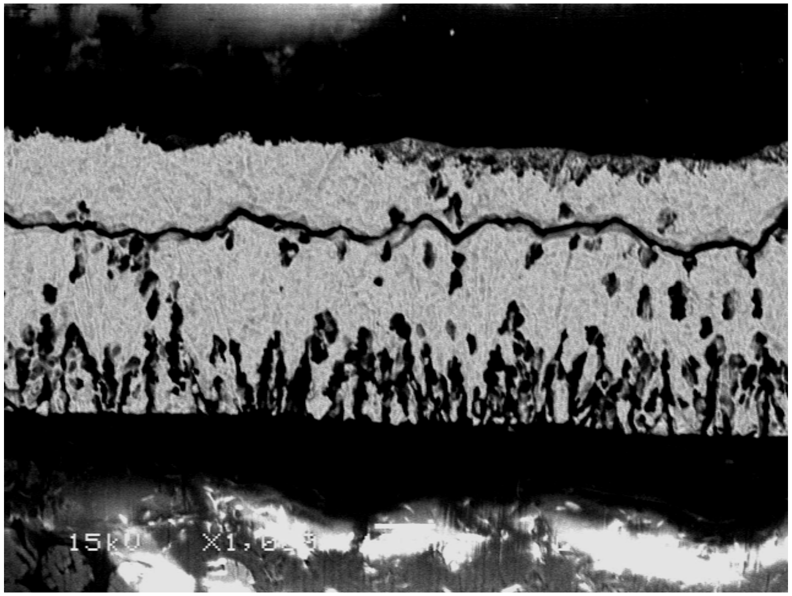
Sample C

Erosion rate: 0.85 u/sec   Total copper loss (20 sec): 17u

Broke thru to laminate Cu

Not Ranked





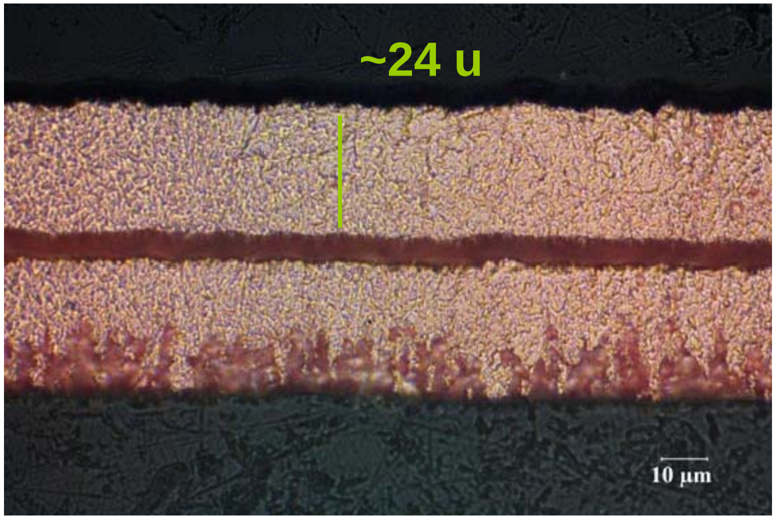
No foil submitted

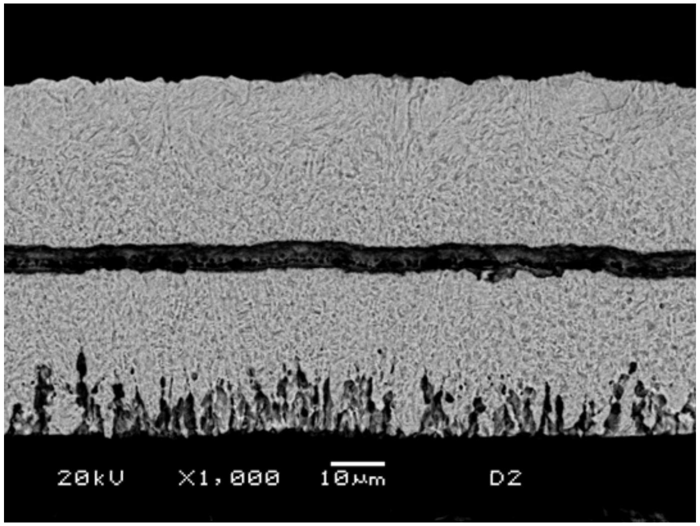
Sample D

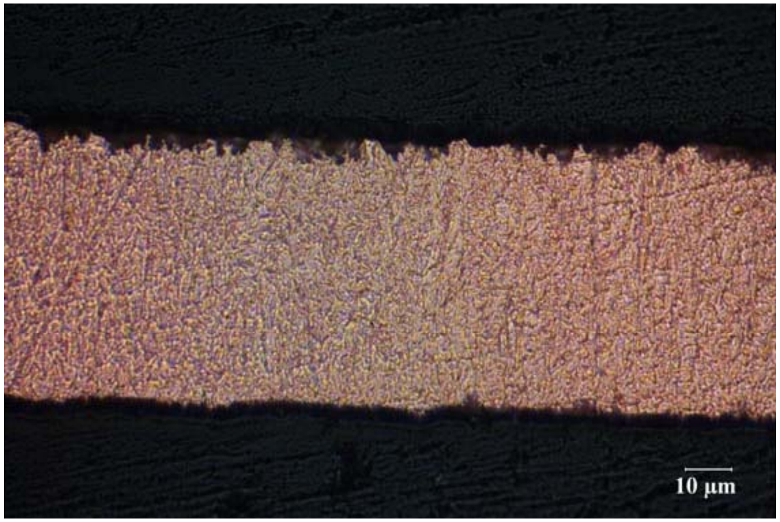
Erosion rate: 0.88 u/sec   Total copper loss (20 sec): 18 u

UTS: 215 MPa   Elongation: 14.5%

Erosion Rank: 3 (medium)





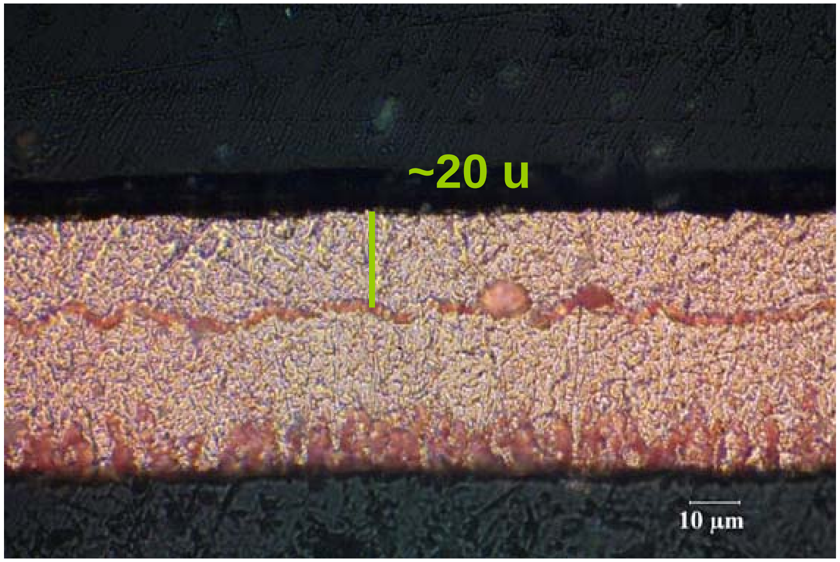


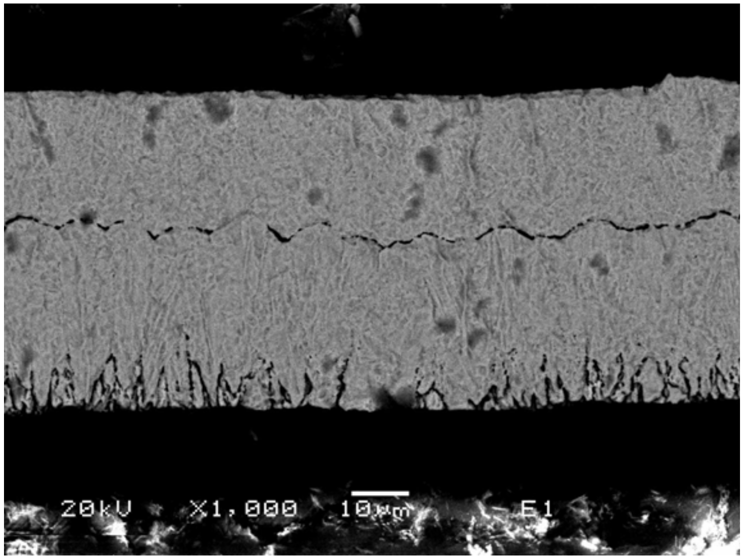
Sample E

Erosion rate: 1.04 u/sec   Total copper loss (20 sec): 21 u

Bordering break thru to laminate Cu

Not Ranked





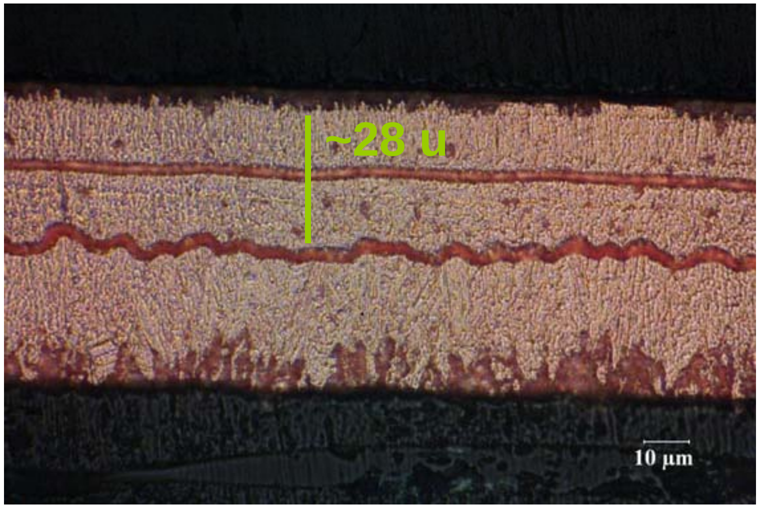
No foil submitted

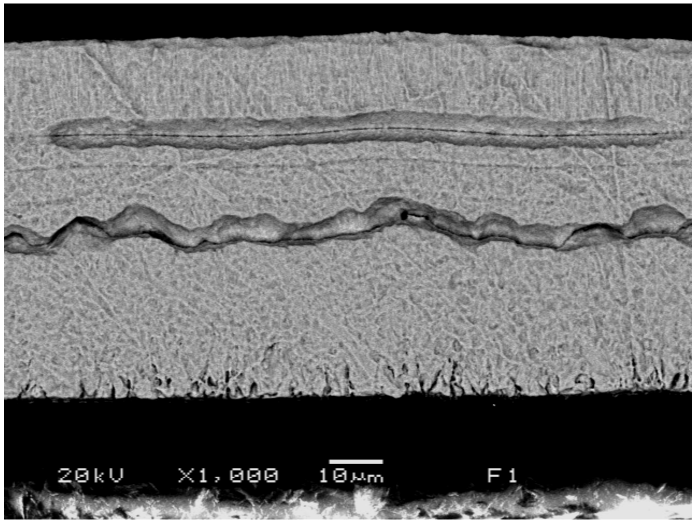
Sample F

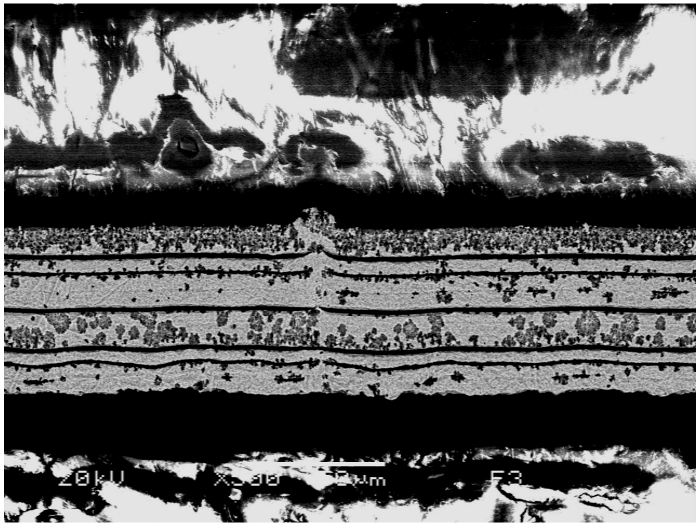
Erosion rate: 0.98 u/sec   Total copper loss (20 sec): 20 u

UTS: 293 MPa   Elongation: 14.02 %

Erosion Ranking: 4 (high)





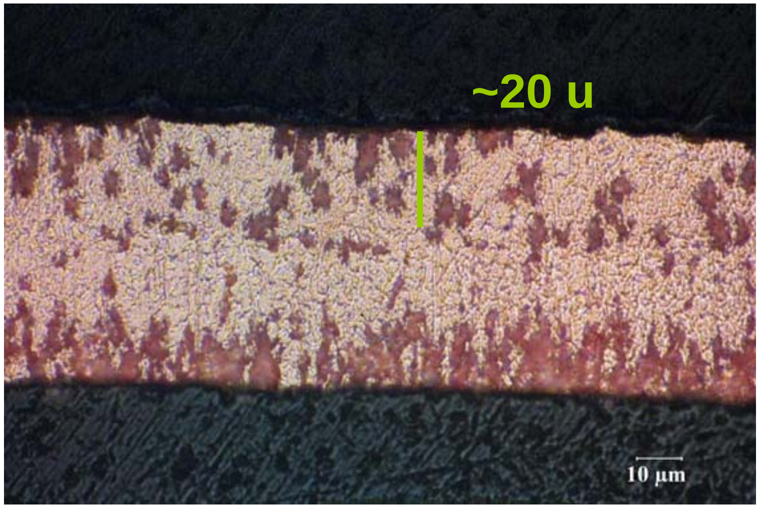


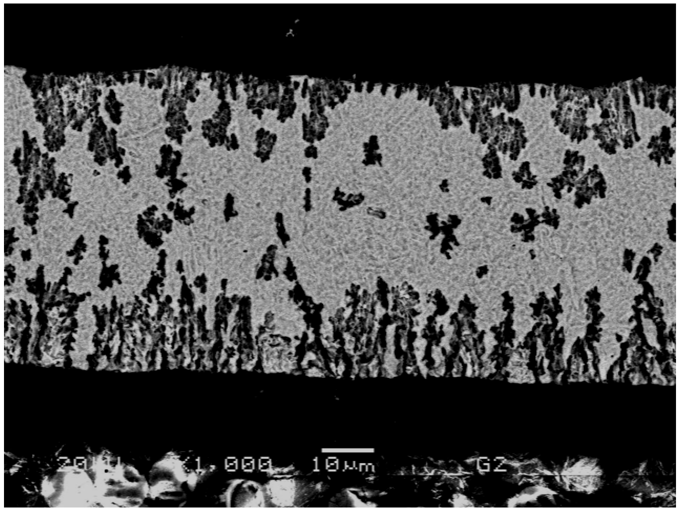
Sample G

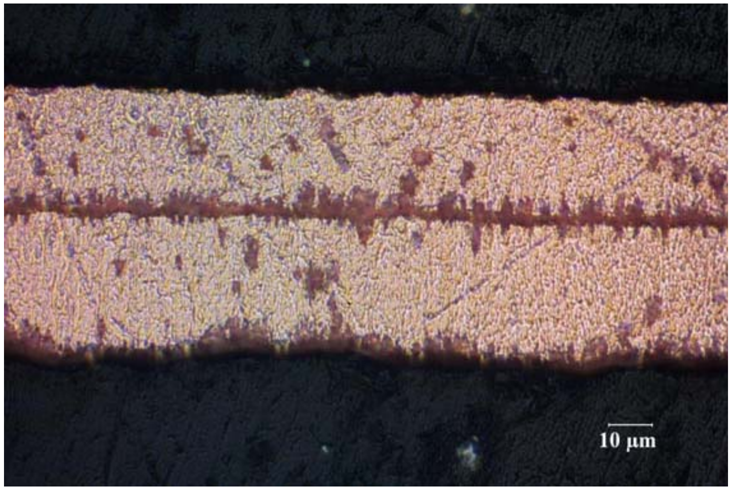
Erosion rate: 0.75 u/sec   Total copper loss (20 sec): 15 u

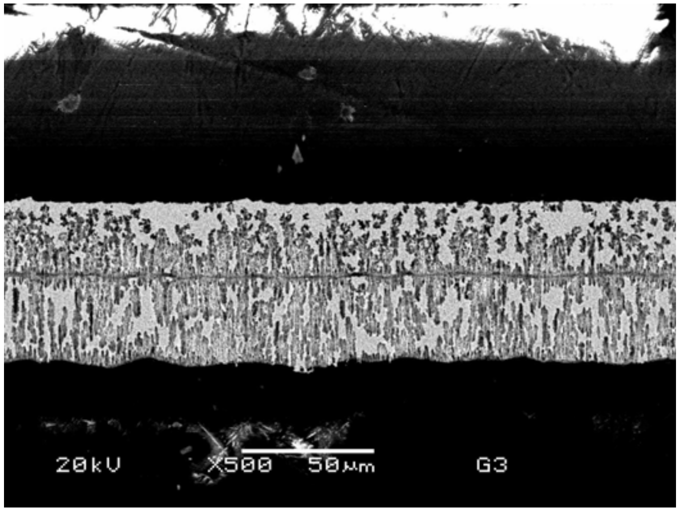
UTS: 245 MPa   Elongation: 16.2%

Erosion Rank: 2 (low)







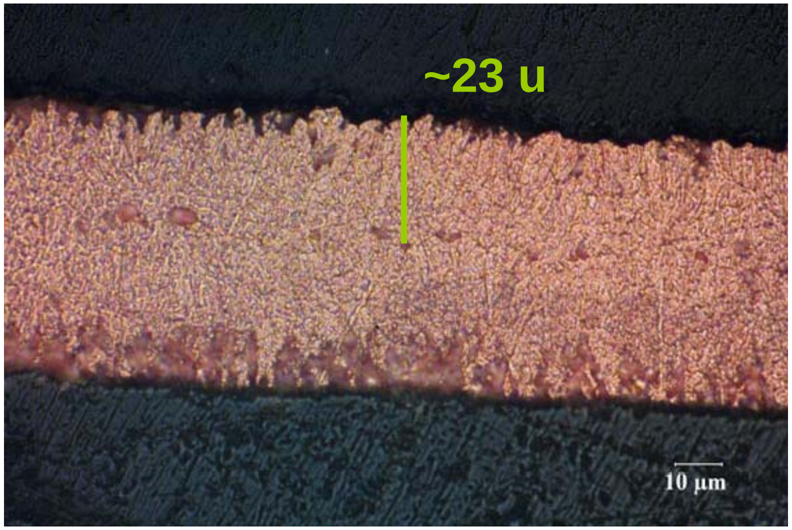


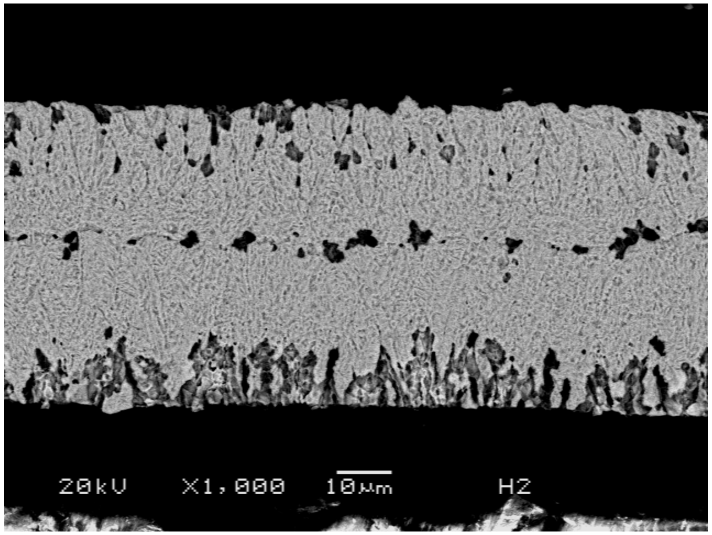
Sample H

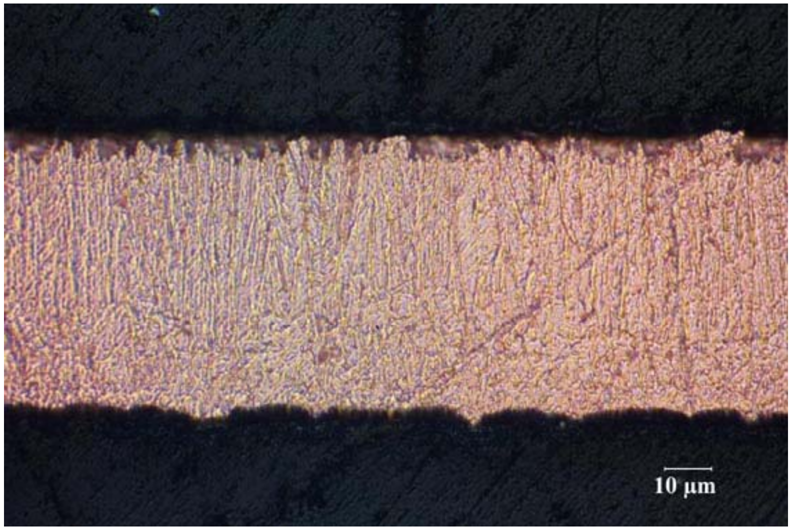
Erosion rate: 0.76 u/sec   Total copper loss (20 sec): 15 u

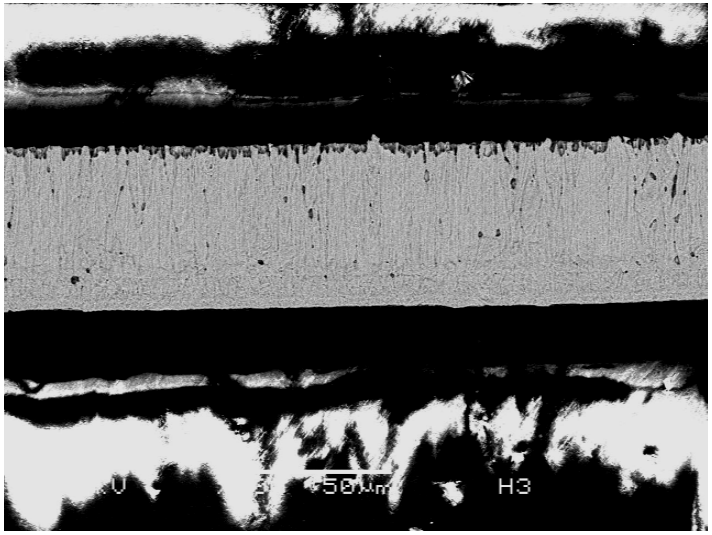
UTS: 241 MPa   Elongation: 22.6%

Erosion Rank: 2 (low)







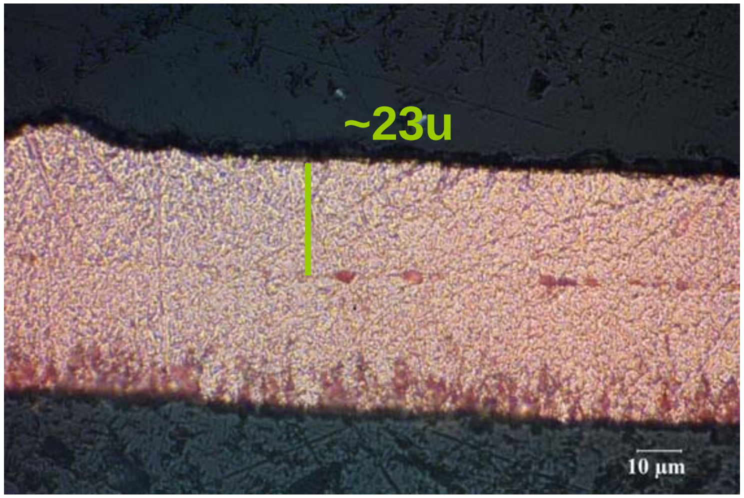


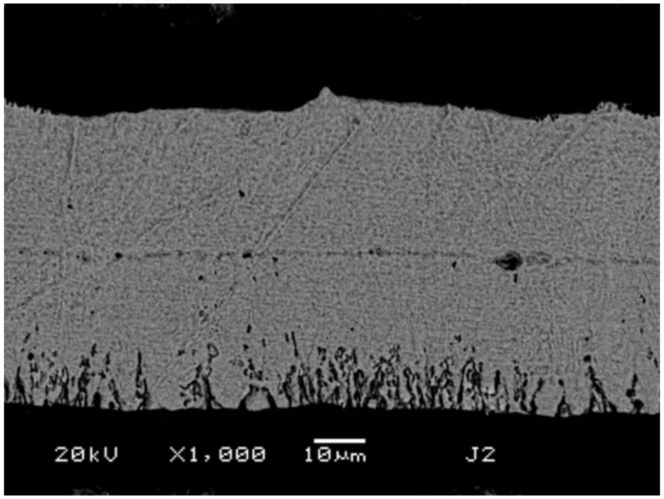
Sample I (J)

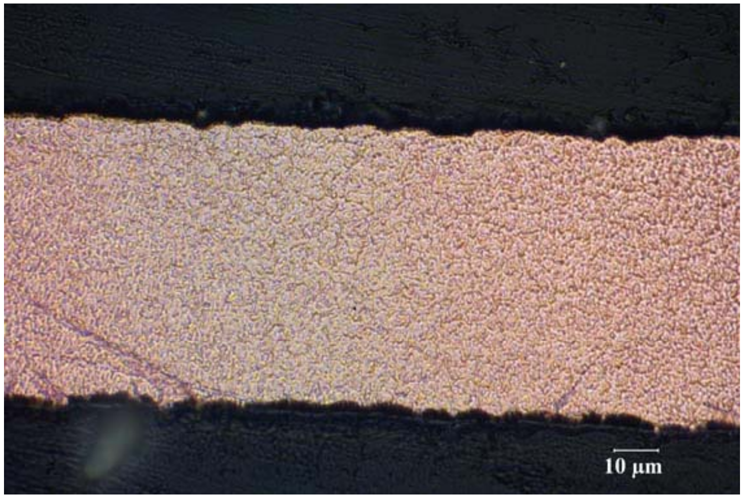
Erosion rate: 1.1 u/sec Total copper loss (20 sec): 22 u

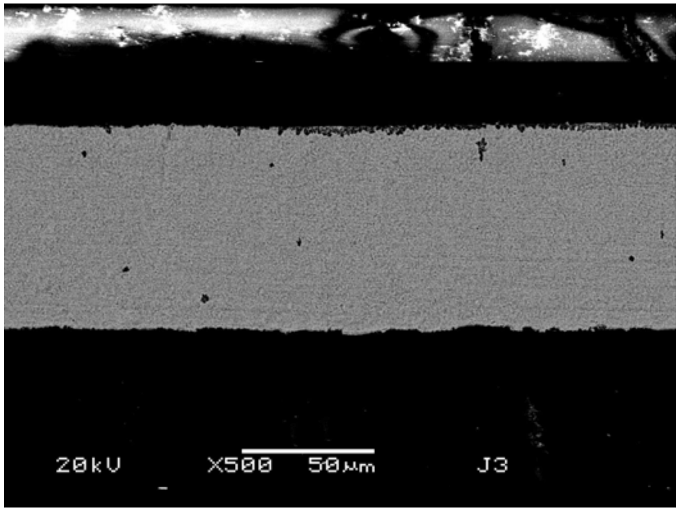
UTS: 295 MPa Elongation: 6.14%

Erosion Rank: 5 (highest)







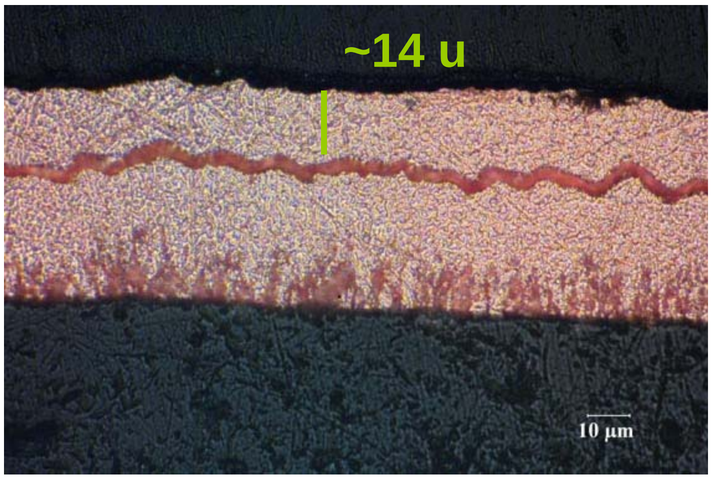


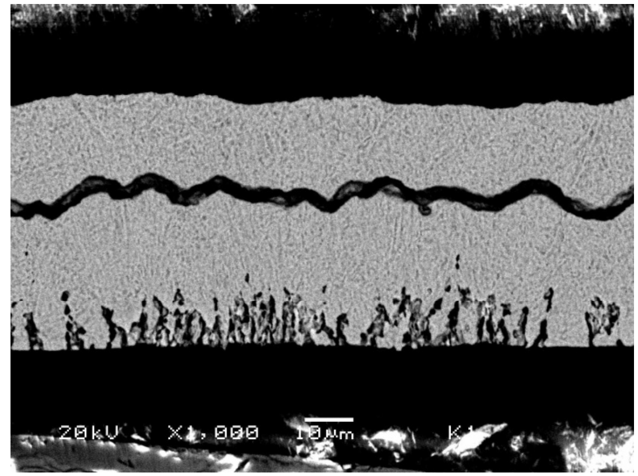
Sample K

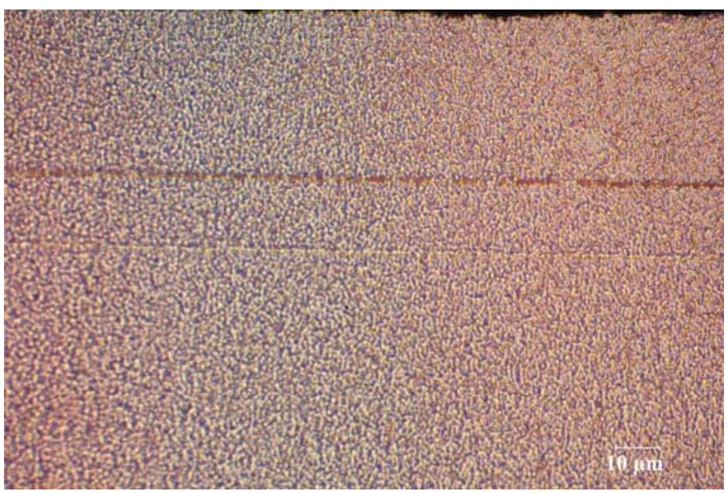
Erosion rate: 0.96 u/sec Total copper loss (20 sec): 19 u

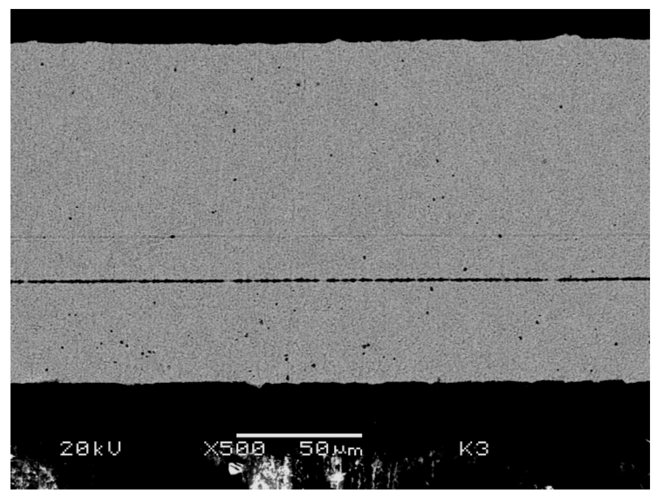
UTS: 299 MPa Elongation: 18.7%

Break through to laminate Copper – Not Ranked







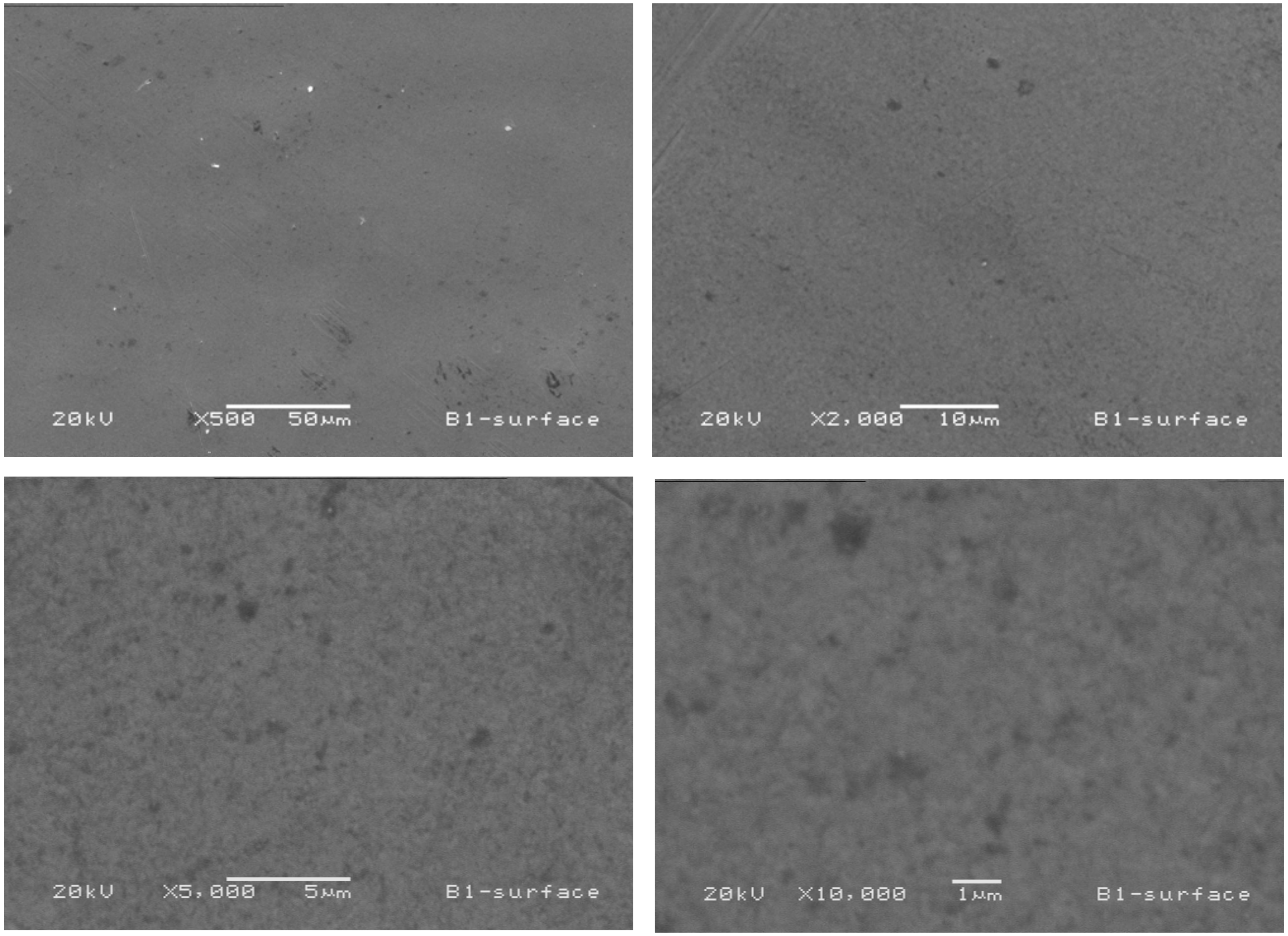


Sample B Surface

Erosion rate: 0.75u/sec   Total copper loss (20 sec): 15 u

UTS: 317 MPa   Elong: 11.82 %

Erosion Rank: 2 (low)

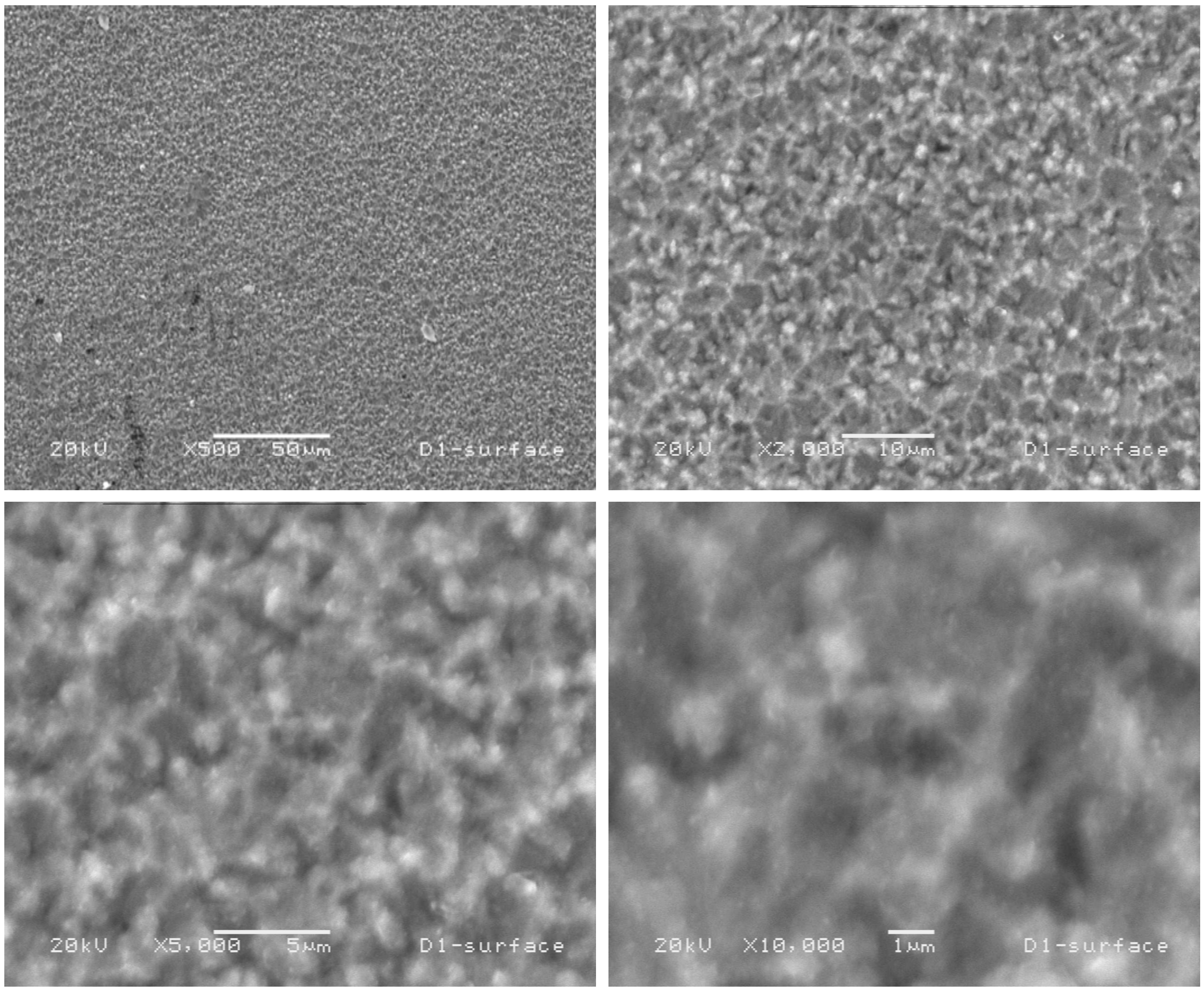


Sample D Surface

Erosion rate: 0.88 u/sec   Total copper loss (20 sec): 18 u

UTS: 215 MPa   Elongation: 14.5%

Erosion Rank: 3 (middle)

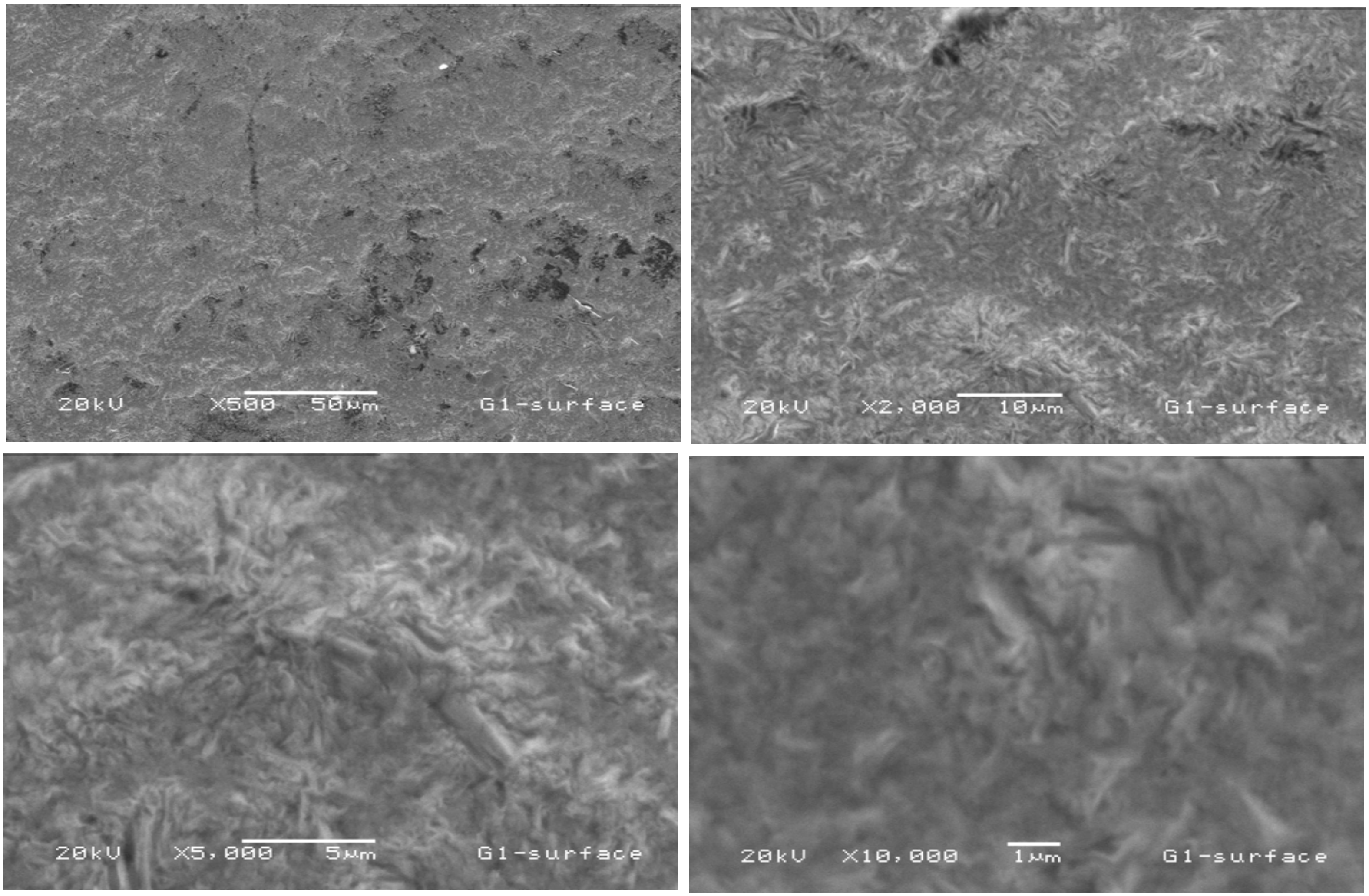


Sample G Surface

Erosion rate: 0.75 u/sec Total copper loss (20 sec): 15 u

UTS: 245 MPa Elongation: 16.2%

Erosion Rank: 2 (low)



Sample H Surface

Erosion rate: 0.76 u/sec   Total copper loss (20 sec): 15 u

UTS: 241 MPa   Elongation: 22.6%

Erosion Rank: 2 (low)