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Ultrasonic Imaging and Quantitative Analysis of Defects in Ag-Cu-Zr Active Braze Joints

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Outline

- Background and Introduction
  - Ag-Cu-Zr active braze alloys
  - Design of Experiments (DOEx)
- Ultrasonic Imaging
  - Comparison to X-ray radiography
- Quantitative Image Analysis (QIA) of UT scans
  - Grayscale vs. Color QIA
  - Porosity measurement
  - Excessive braze flow (run-out)
  - Correlation with hermeticity tests
- Statistical analysis of DOEx "Main Effects"
- Application of QIA/UT to braze paste process
- Summary

Background

- **98Ag-2Zr and 97Ag-1Cu-2Zr ABA alloys is being developed with Zr as the active element, for Al_2O_3/Kovar joints**

1. J.J. Stephens, F.M. Hosking, F.G. Yost, C.A. Walker, and E. Dudley, "The Evolution of a Ternary Active Braze Filler Metal for KovarTM/Alumina Braze Joints", *Proc. 3rd Intl. Brazing and Soldering Conference*, San Antonio, TX, April 2006, ASM International, pp. 207-13, 2006.
2. M.K. Neilsen and J.J. Stephens, "Mechanical Behavior of the 98Ag-2Zr and 97Ag-1Cu-2Zr Active Braze Alloys", *Proc. 3rd Intl. Brazing and Soldering Conference*, San Antonio, TX, April 2006, ASM International, pp. 226-33, 2006.

- **Issues and Challenges:**
  - **Development of a robust processing schedule to increase acceptable (hermetic, high joint strength, low porosity, etc.) braze joint yields.**
  - **Develop methods to reduce/eliminate braze "run out" (excessive braze flow) on Kovar surface**
  - **Develop an active braze paste process**

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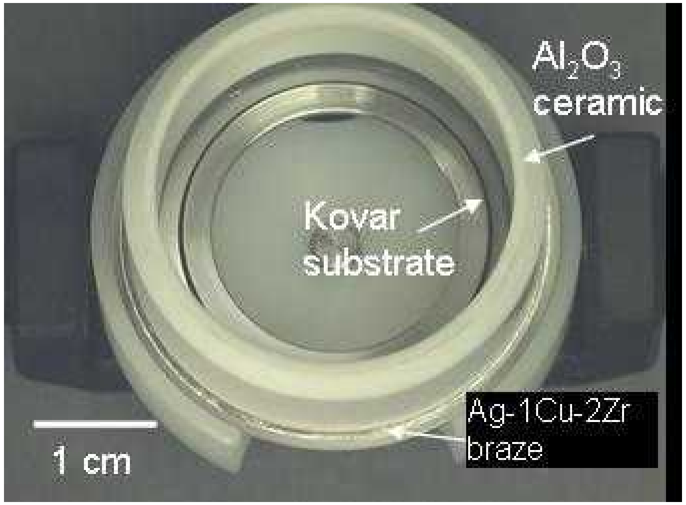
Introduction

- **A design of experiments (DOEx) approach was taken to study the many braze process variables and determine the "main effects".**

- **32 samples (16 braze runs with duplicates in each run)**
- **14 factors examined, *"screening (main effects) experiment"***



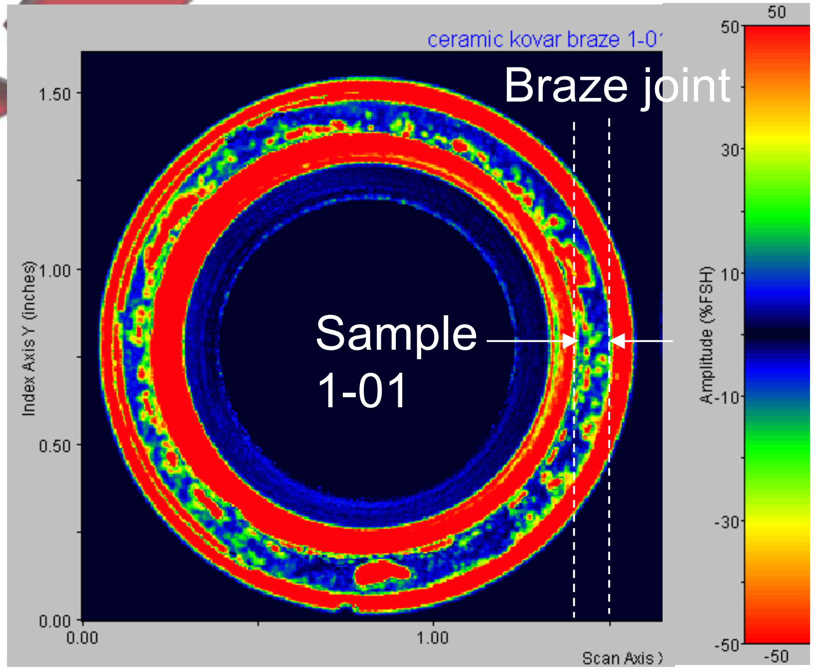
Macro view of a DOEx sample

- **Response variables: hermeticity, run out, underfill, porosity, fillet shape, fillet uniformity**

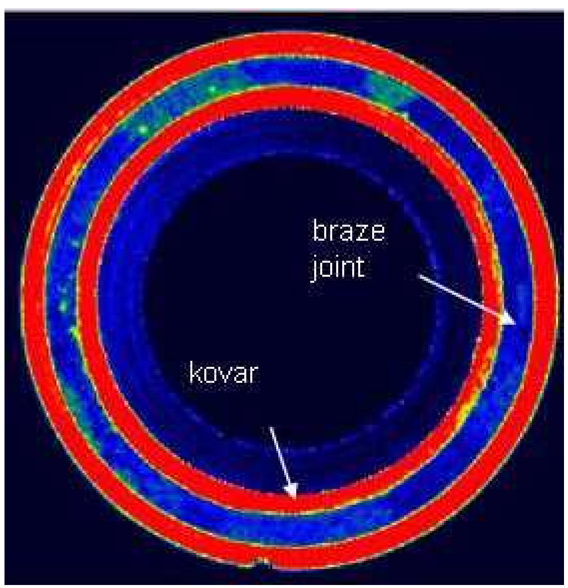
Challenge: How do we characterize the braze joints to provide good measurement of response variables?

List of factors in the brazing DOEx

Factor	Units	Levels
ceramic firing atmosphere	-	air or wet H
metallization thickness	-	none or thick
Kovar roughness	-	unetched or nitric etched
braze cement location	-	Kovar or alumina side
ceramic chamfer angle	degrees	30, 60
ceramic chamfer depth	microns	100, 200
braze alloy Cu content	wt. %	0, 1
braze washer thickness	microns	50, 75
braze washer O.D.	microns (relative to ceramic)	0, -250
braze washer I.D.	microns (relative to ceramic)	0, +250
braze furnace atmosphere	-	dry H or 1 torr Ar
applied load	fraction of baseline	0.25, 1.75
peak Temp.	˚C	955, 985
hold time at peak	minutes	3, 7



Example of a “poor quality” braze joint



Example of a “good quality” braze joint

Ultrasonic Imaging

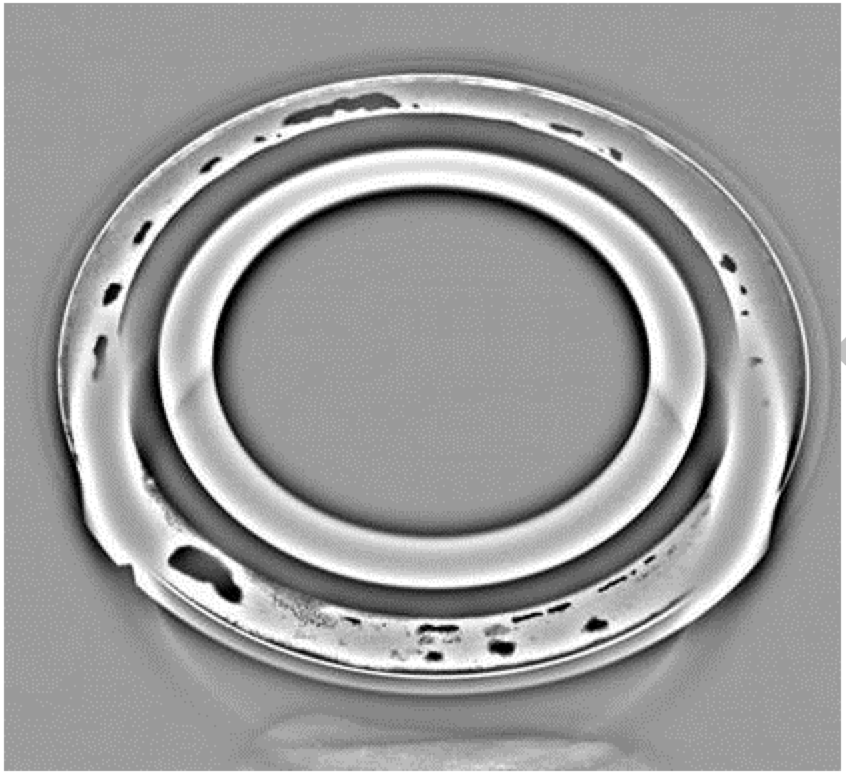
- **Ultrasonic scans were done on 31 (active) braze joints in design of experiments (DOEx)**
- **Color scale represents amplitude of reflected acoustic signal**
- **Advantage: Nondestructive**
- **Disadvantage: requires immersion**

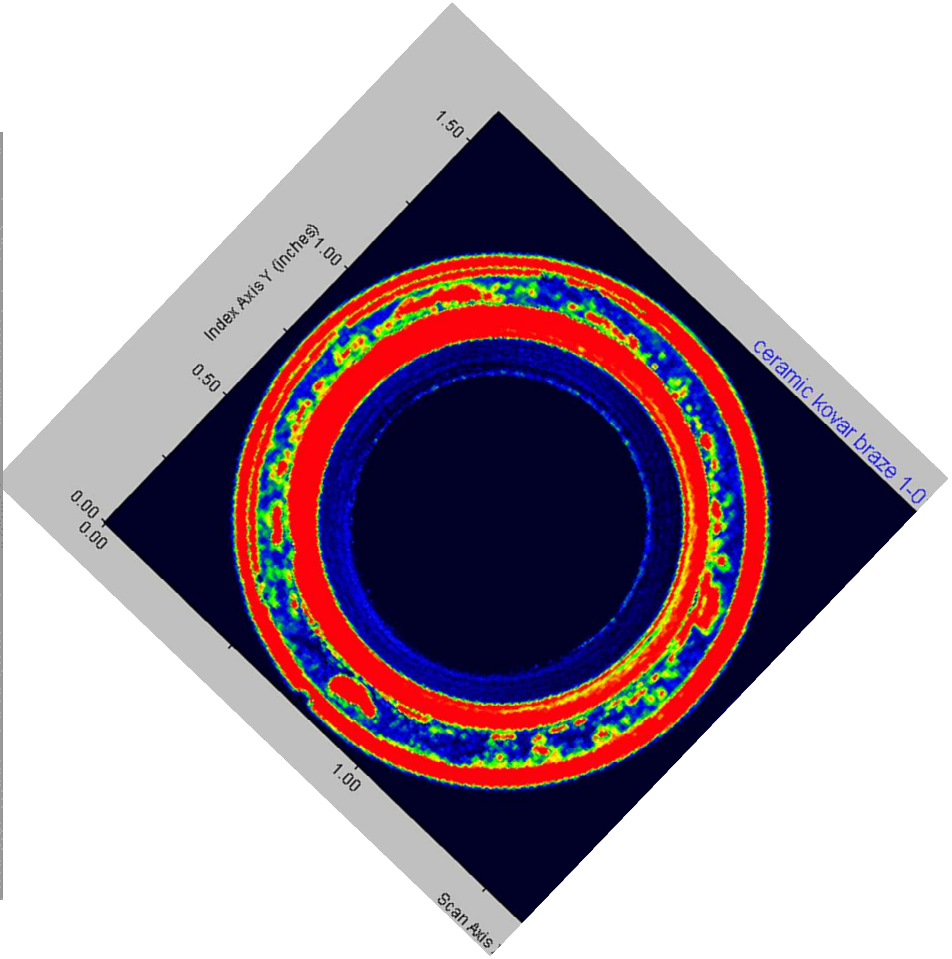
- **Red regions within braze joint represents porosity and/or poor bonding**

- **Blue within braze joint represents good bonding**

- **Green/yellow are “mixed regions”**

Comparison of X-ray radiography and Ultrasonic Imaging





- Traditional X-ray radiography confirmed the accuracy of the UT scans.
  - Disadvantages of X-ray: image distortion due to incidence angle, shadowing effect due to thick ceramic ring

Quantitative Image Analysis

• With such a large DOEx with so many factors, it was important to determine accurate, *quantitative* response variables. So, we combined UT imaging with QIA to measure porosity and other defects in the braze joints.

Traditional (grayscale) QIA with xray image has limitations

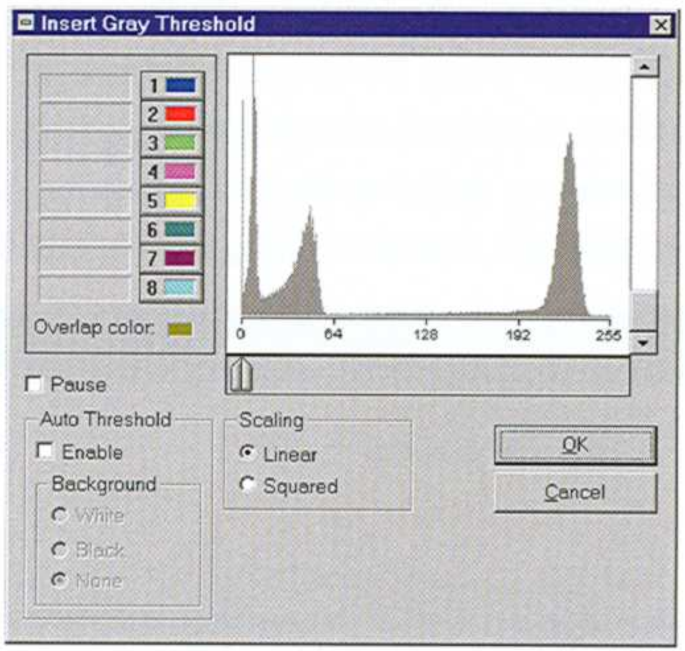
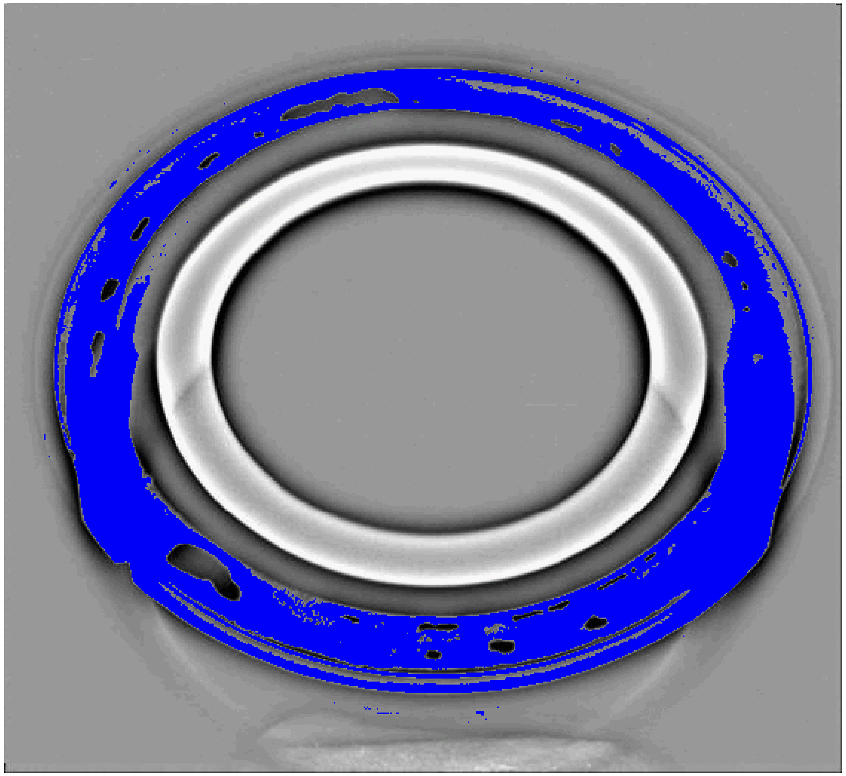


Figure 14-7: The Insert Gray Threshold dialog box.



(Clemex Vision PE, User's Guide, Version 4.0, Clemex Technologies Inc. (2005), pg. 14-7)

Color Image Analysis of UT Scans

Color Image Analysis used to quantify porosity vs. well-bonded braze regions (Clemex Vision PE image analysis system)

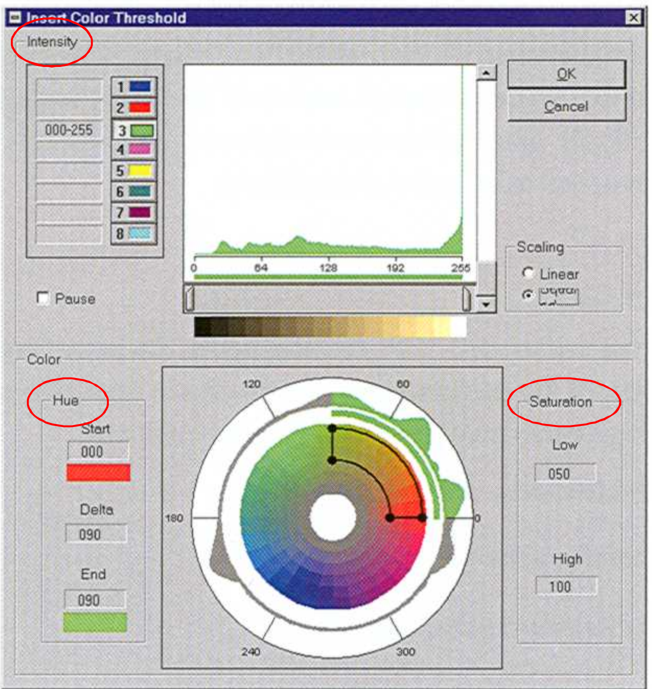
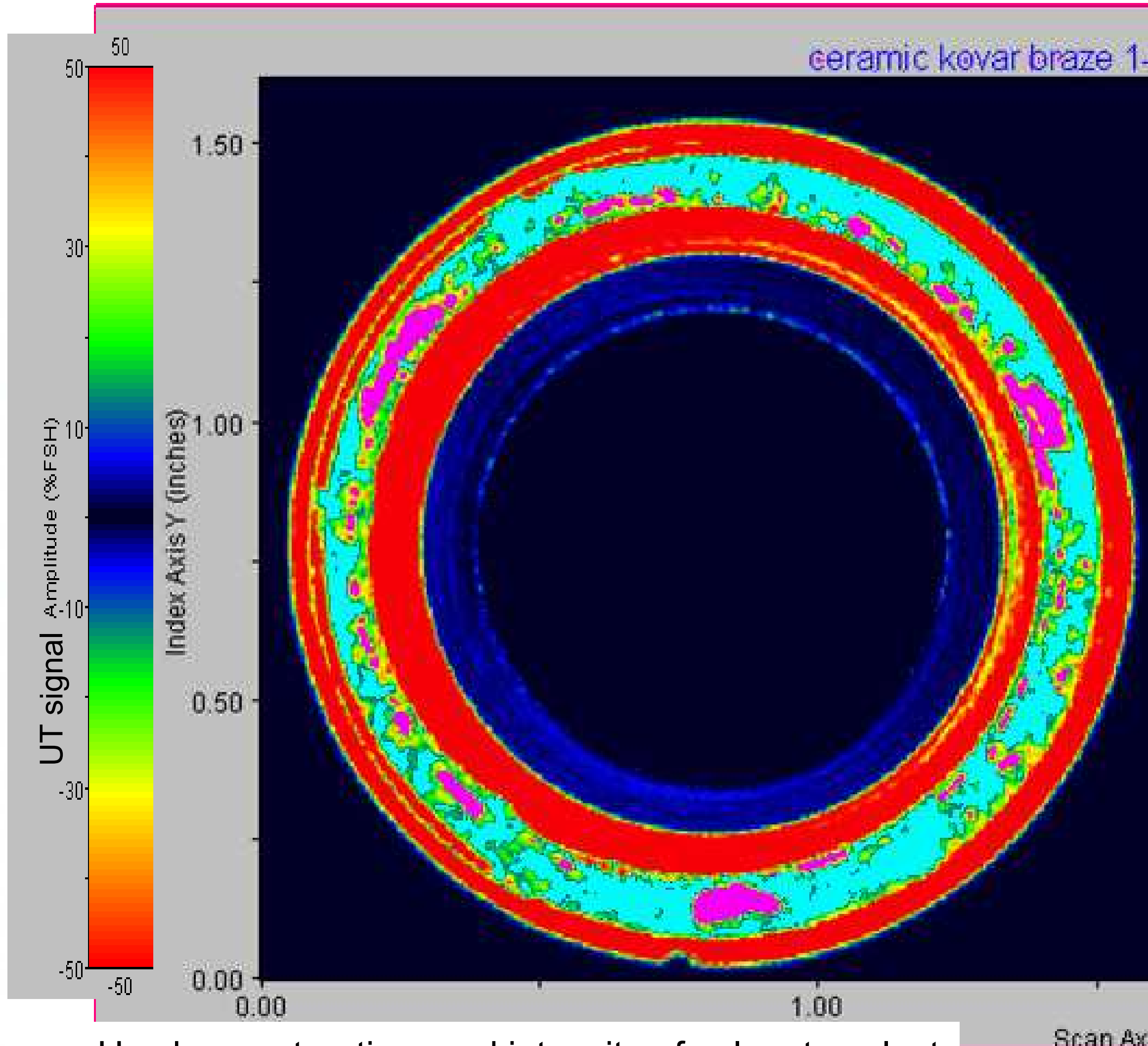


Figure 14-9: Use the pointer to select pixels in the Image window.
(Clemex Vision PE, User's Guide,
Version 4.0, Clemex Technologies Inc. (2005), pg. 14-9)



- Use hue, saturation, and intensity of colors to select regions of interest
- Use feature sizes to discard unwanted features

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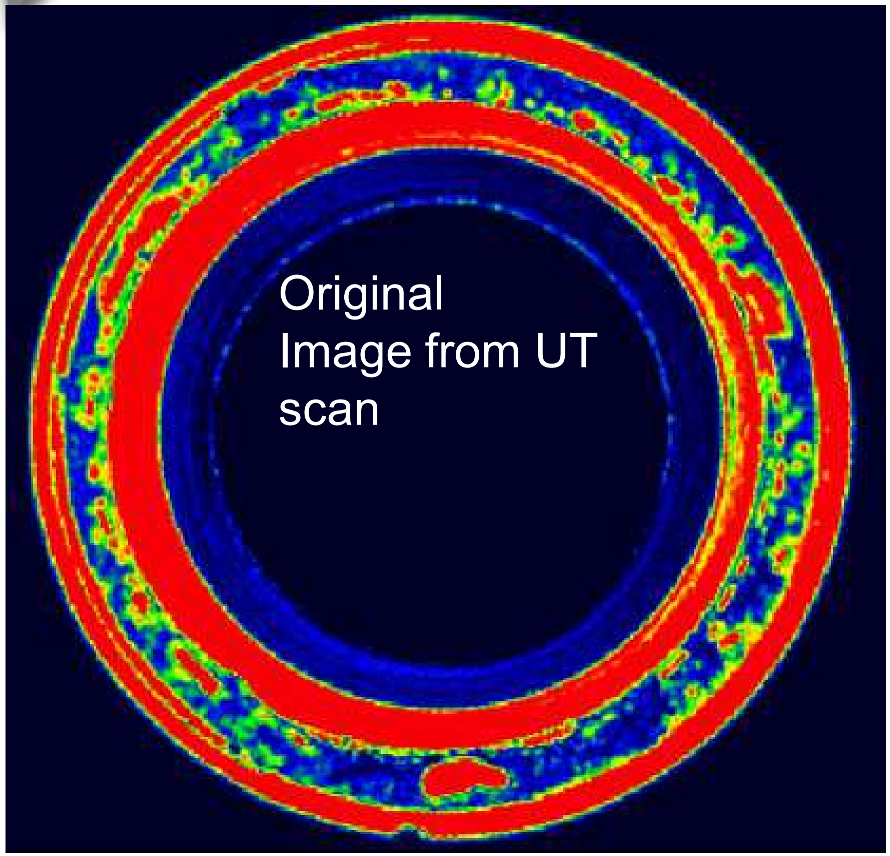
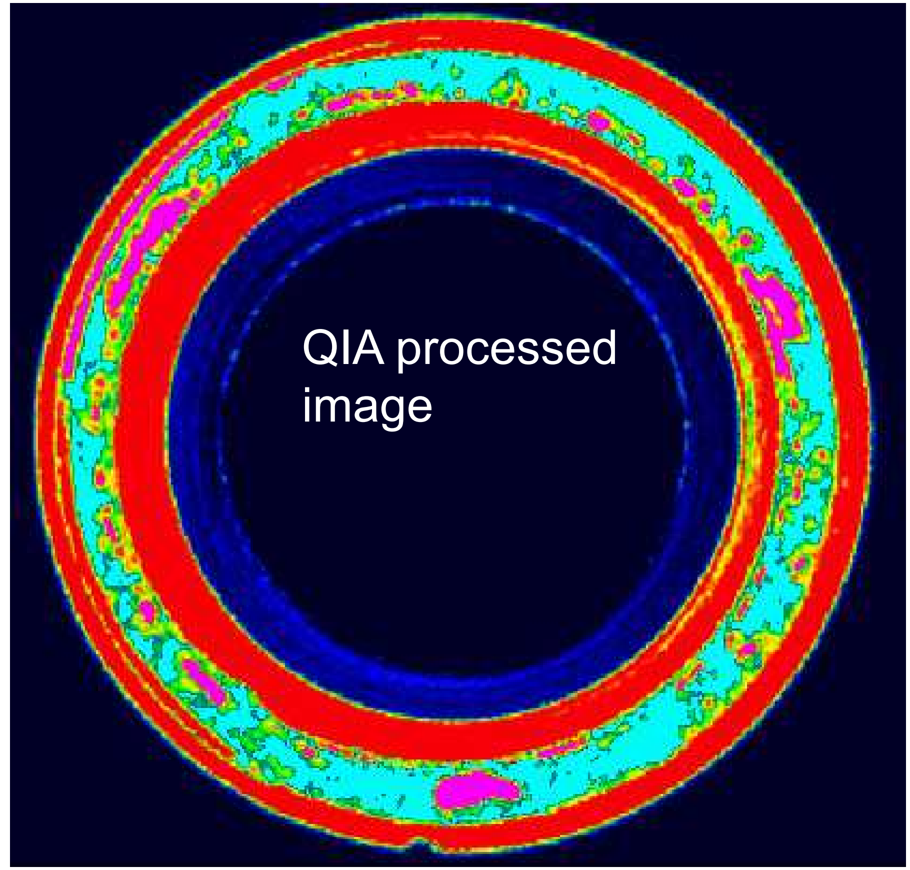
Color QIA Results





- **Quantitative Image Analysis (QIA) performed with color threshold to quantitatively measure the amount of good bonded braze joint and poor-bonded (porosity) regions.**
- **QIA system uses actual color information in the images (hue, saturation, intensity)**
  - Results can be analyzed as *% of total braze joint* using a nominal value for braze joint footprint,
  - Significant improvement over a joint "rating system" of 1-5

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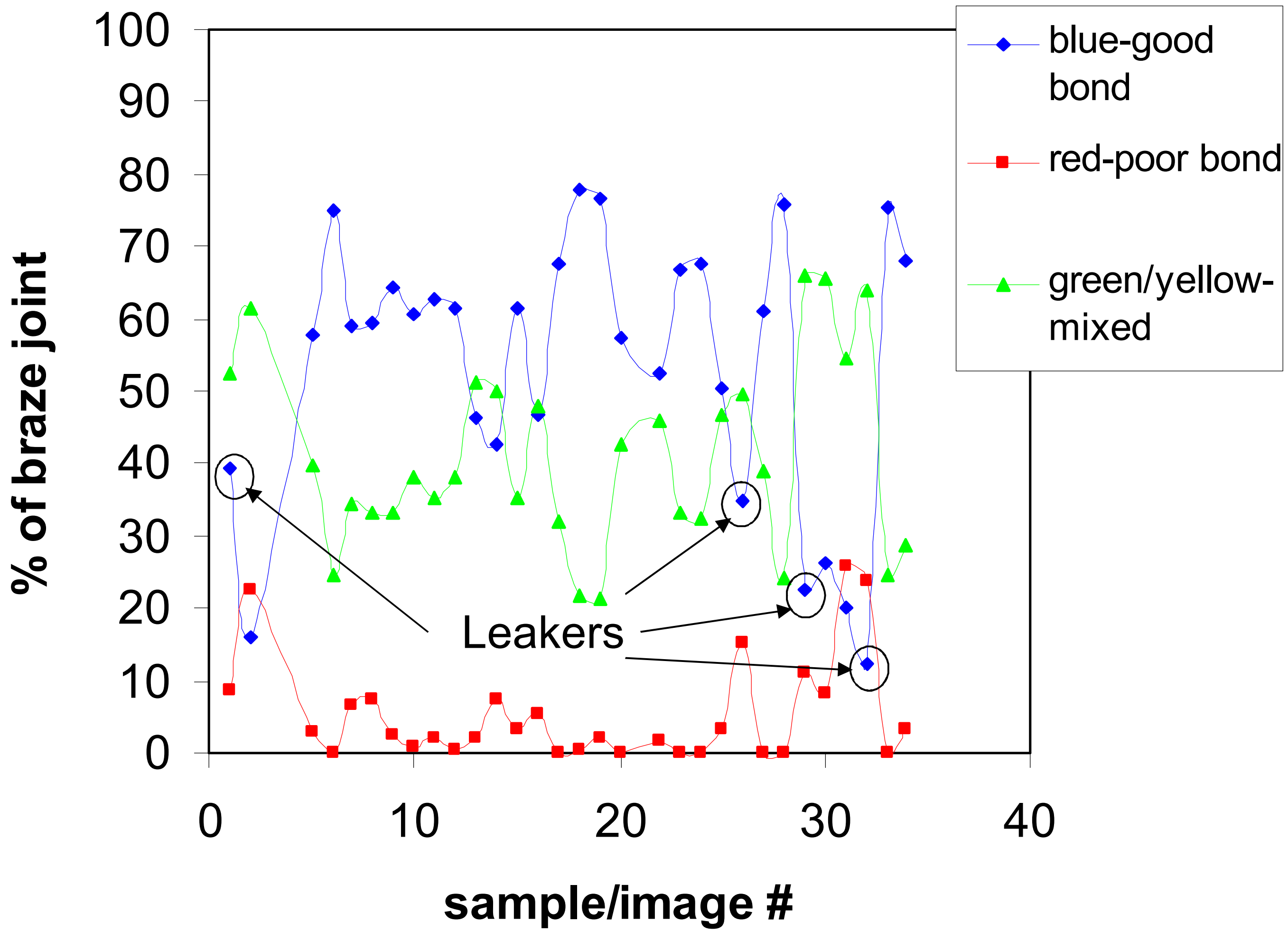
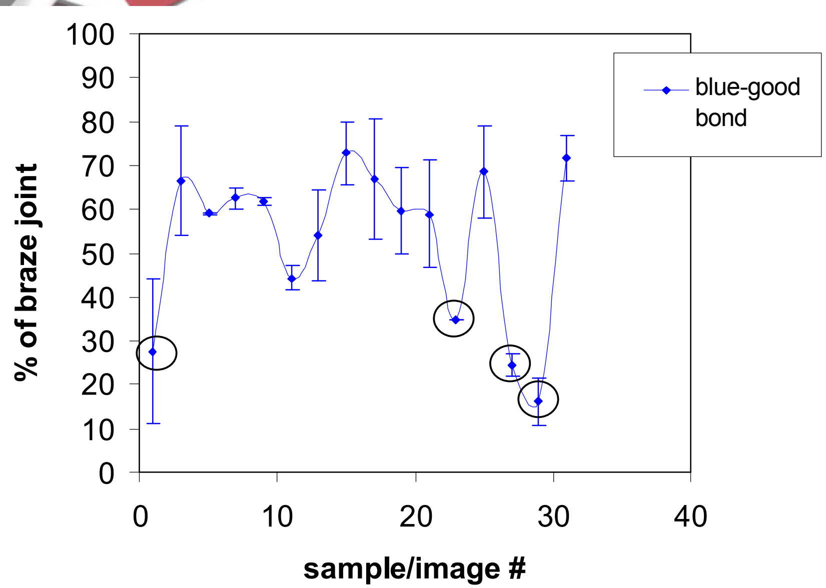
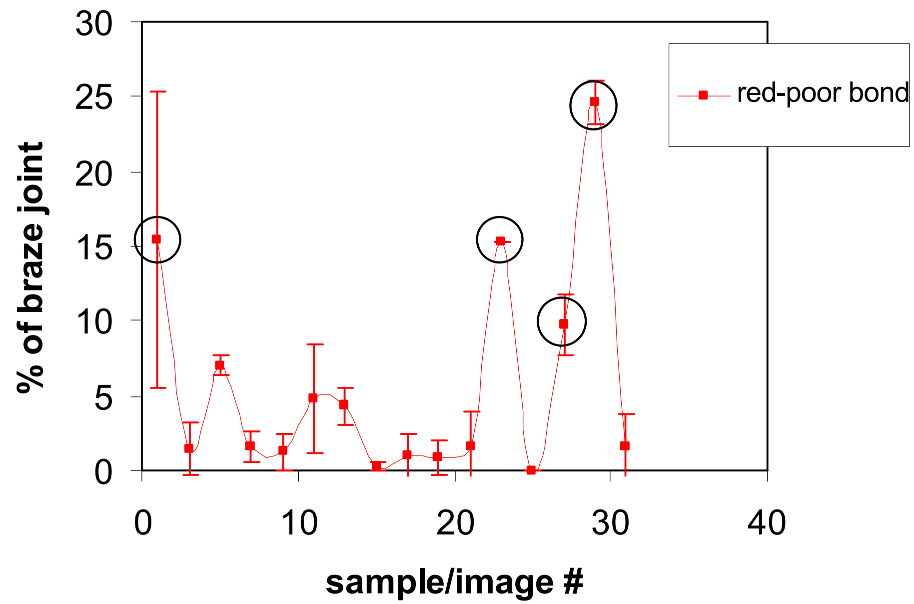
Image Analysis Results



- Leakers (non-hermetic) generally show low amounts of good bonding
- Correlation is not perfect due to *distribution* of porosity, i.e. continuous leak path needed for loss of hermeticity

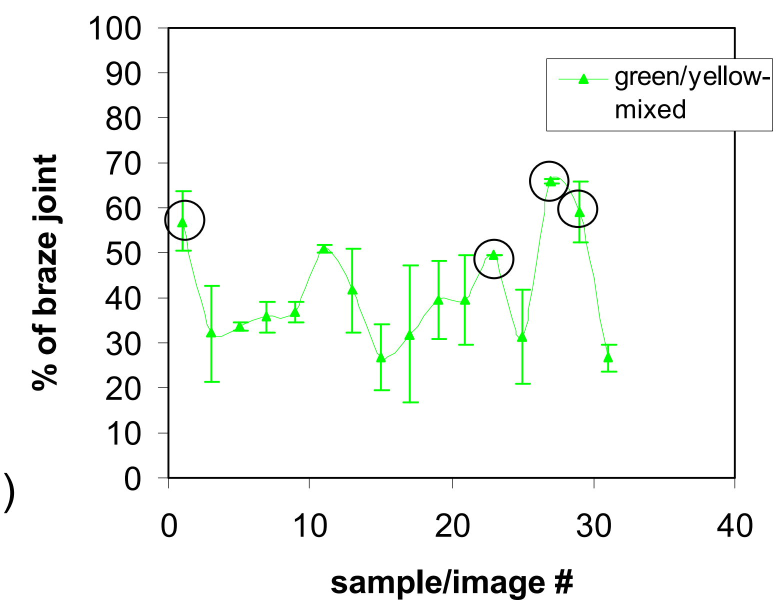




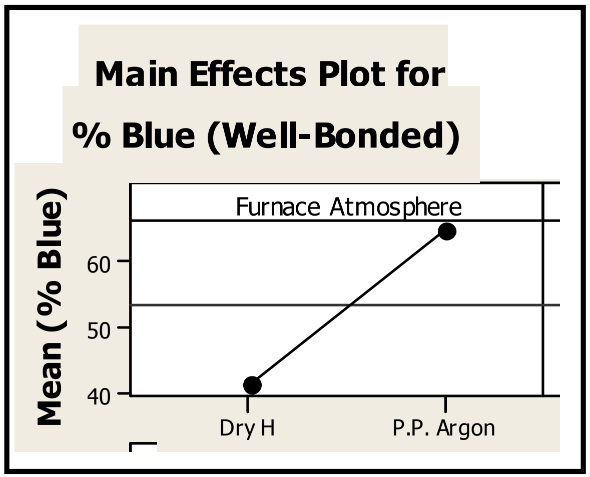
- Plots show *combined data* (16 averages and st.devs.from 32 duplicate runs)
- Non-hermetic joints correlate with low amounts of good bonding and high amount of porosity/poor bonding.
- **UT inspection is a good indicator of joint quality with regard to hermeticity**

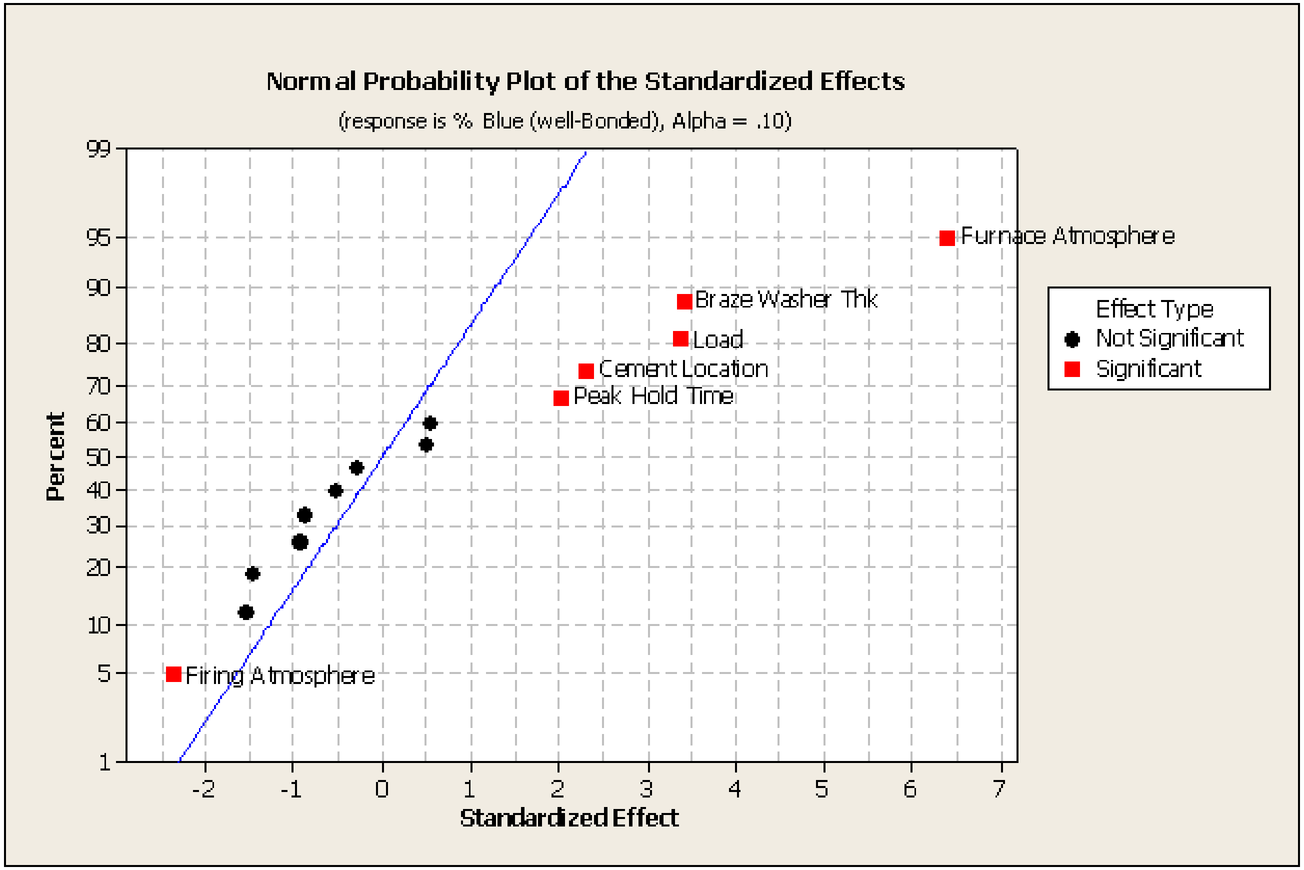
For good braze joints: Above ~40% blue
Below ~10% red
Below ~40% mixed (green)

- High amounts of mixed (green/yellow) regions correspond to poor joints, loss of hermeticity
- **Could be used to identify "marginal" braze joints**



DOEx Statistical Analysis





- "% blue" (well-bonded joint) was used as quantitative input to the DOEx
- Main effects identified include furnace atmosphere, braze washer thickness, and applied load
- Standardized effect (t value) > 2 means there is a correlation with > 90% confidence

Summary Statistics

Factorial Fit: % Blue versus Firing Atmosphere, Cement Location, ...

Estimated Effects and Coefficients for % Blue (coded units)

Term	Effect	Coef	SE Coef	T	P
Constant		53.462	1.781	30.02	0.000
Firing Atmosphere	-8.595	-4.298	1.781	-2.41	0.024
Cement Location	8.425	4.212	1.781	2.37	0.026
Braze Washer Thk	12.342	6.171	1.781	3.46	0.002
Furnace Atmosphere	23.192	11.596	1.781	6.51	0.000
Load	12.277	6.139	1.781	3.45	0.002
Peak Hold Time	7.366	3.683	1.781	2.07	0.050

S = 9.9   R-Sq = 78%

Best combination (predicted) based on above model for % Blue (Well-Bonded):

Firing Atmosphere: Air

Cement Location: Alumina Side

Braze Washer Thickness: 0.003

Furnace Atmosphere: Argon

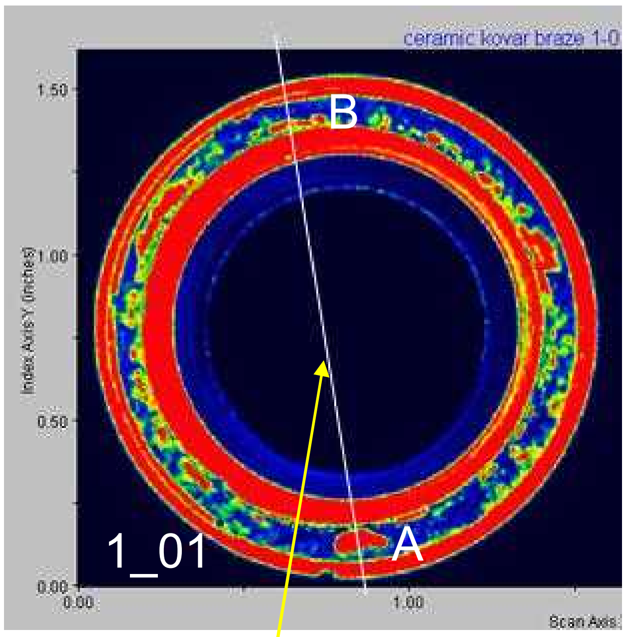
Load: 1.75

Peak Hold Time: 7

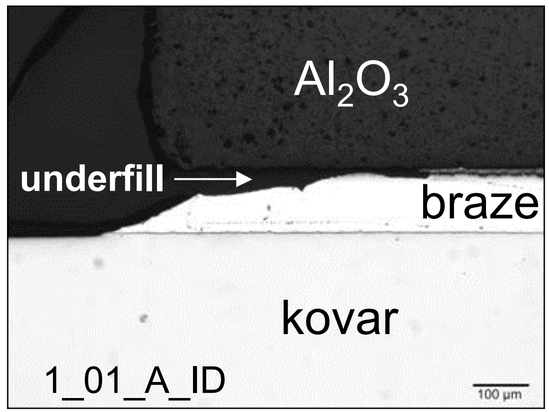
(all other factors do not matter)

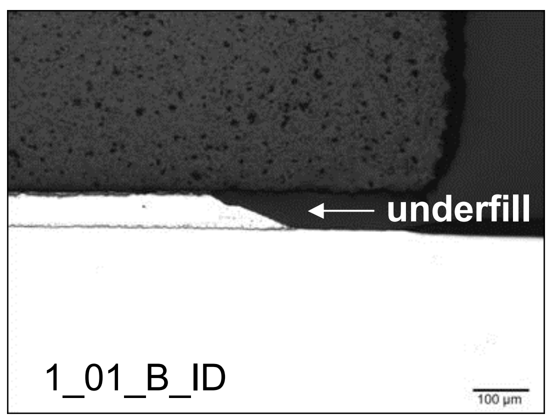
Metallographic Characterization

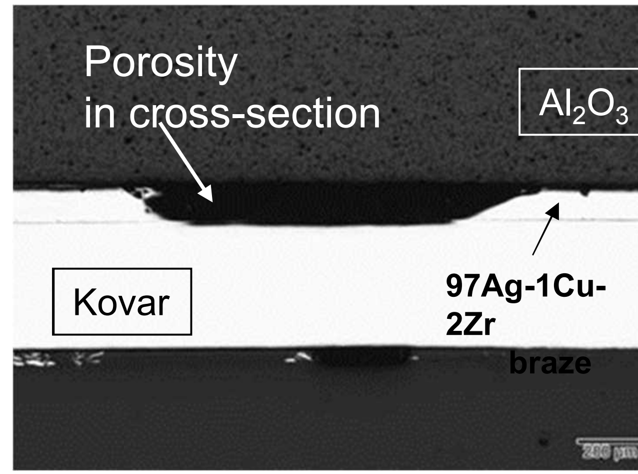
- All 32 samples were cross-sectioned to view the braze joint
- Features visible in cross-sections: 1) fillet size and shape, 2) reaction layer between Al_2O_3 and braze, 3) underfill, 4) run out, 5) porosity



Cross-section plane

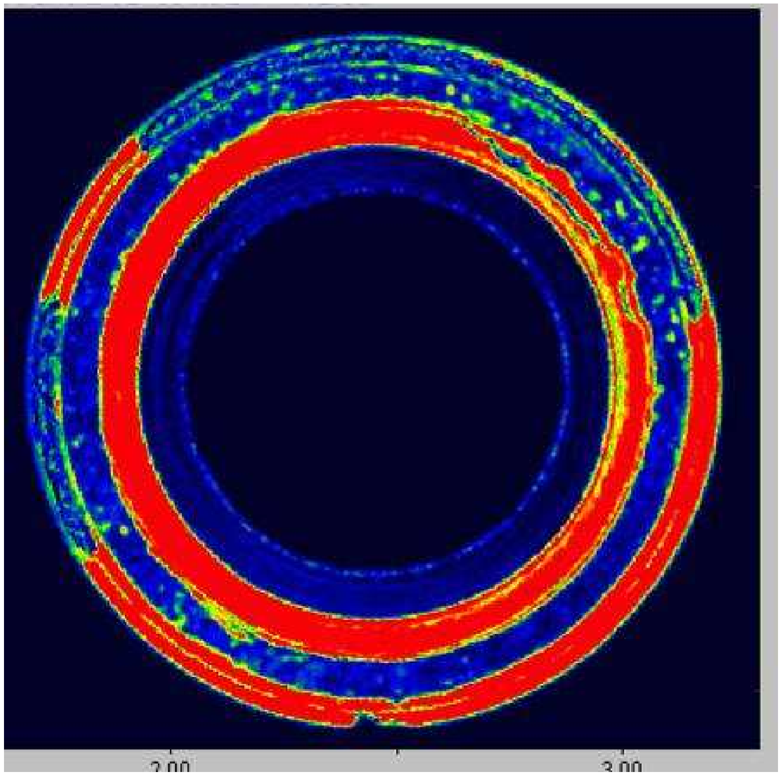


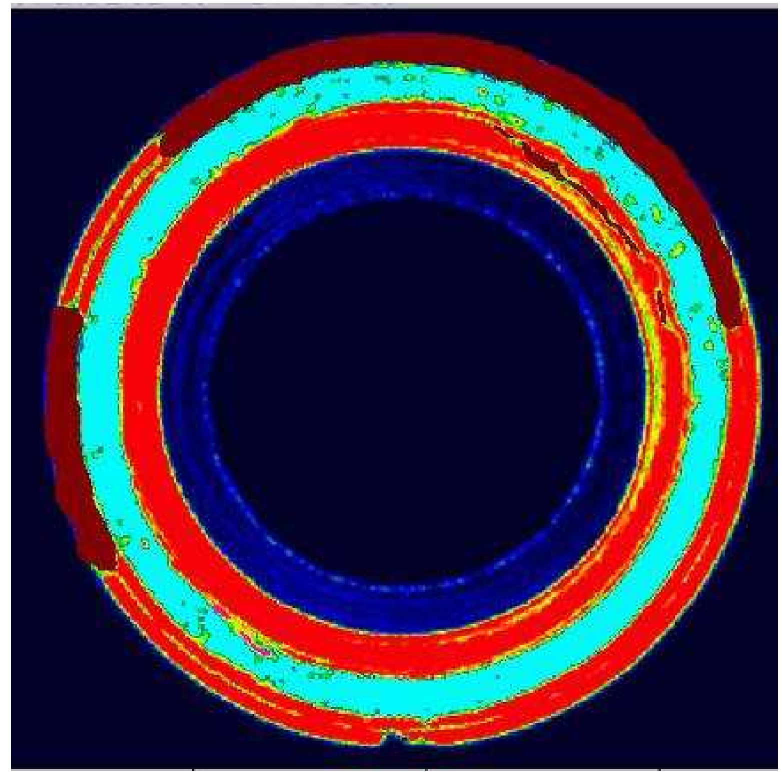




- Red regions in UT scans correspond to through-thickness voids, extending from Al2O3 to Kovar side of the joint (poor wetting)
- Green/yellow regions are fine-scale voids and/or partial-thickness voids
- good correlation with UT scans.

Continue to Observe a Braze Flow "Run-out" Problem

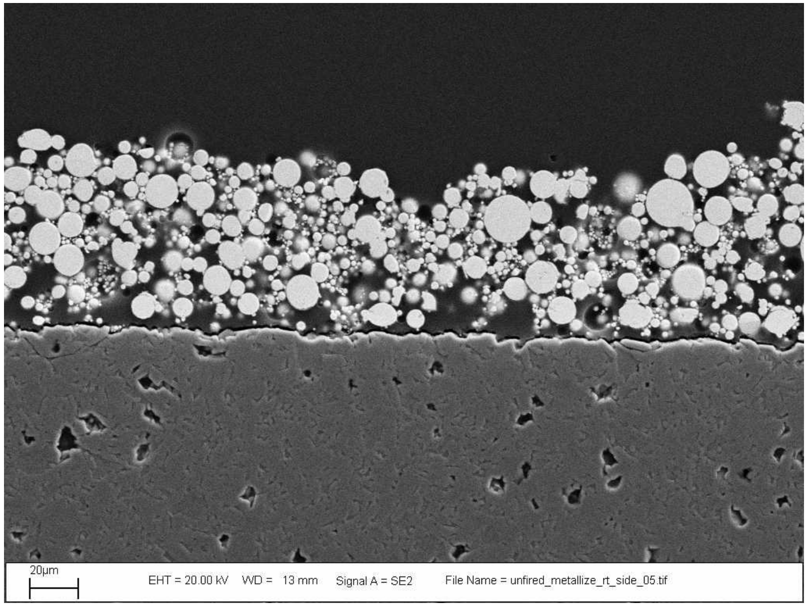


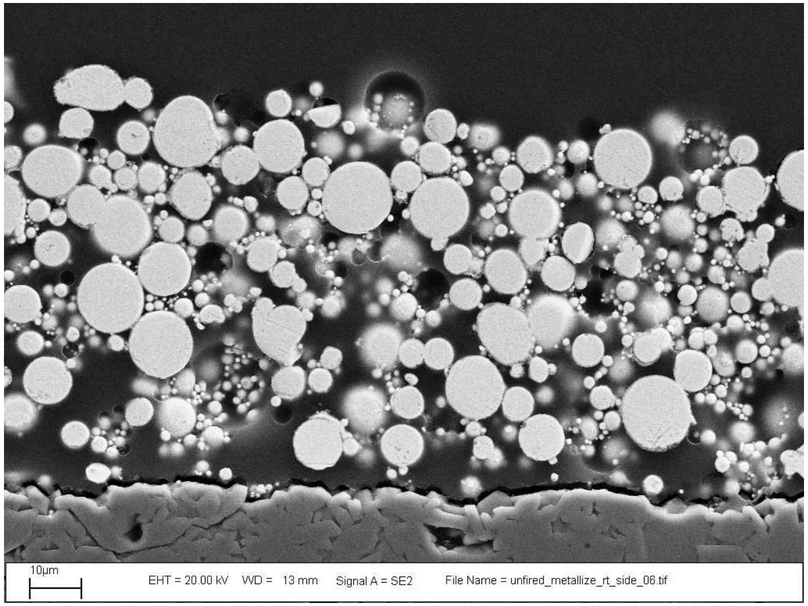


- Image analysis can also be used
to measure run out (braze overflow)
(for example: run out area, length of run out around the OD,
or % of OD with run out, …)

Development of Braze Paste Process

Screen printed braze paste





As-Printed and Air-dried Sections Analyzed

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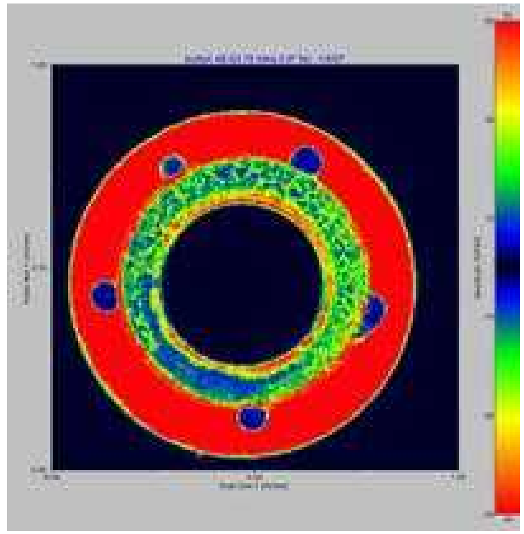
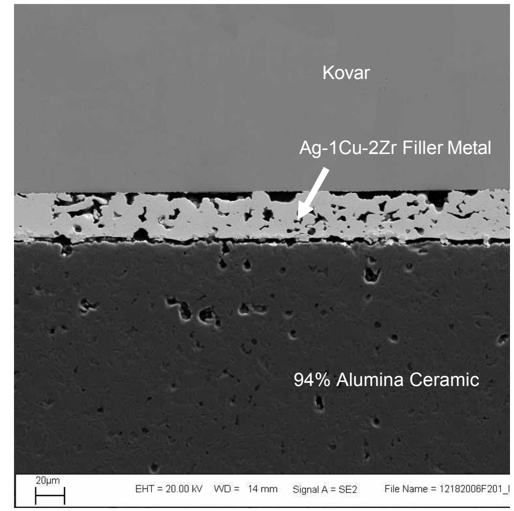
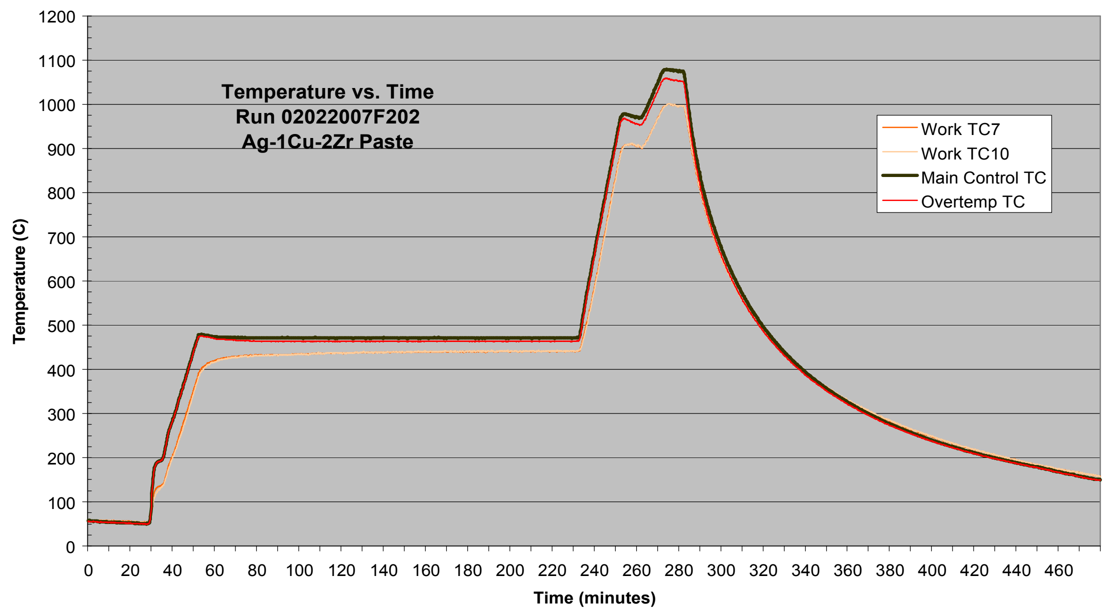
2nd Example of UT/QIA characterization technique: Braze Paste Development

1st attempts: high porosity content





- Changed binder burnout temperature and time (lower Temp to 425˚C, longer times ≥ 90 min.



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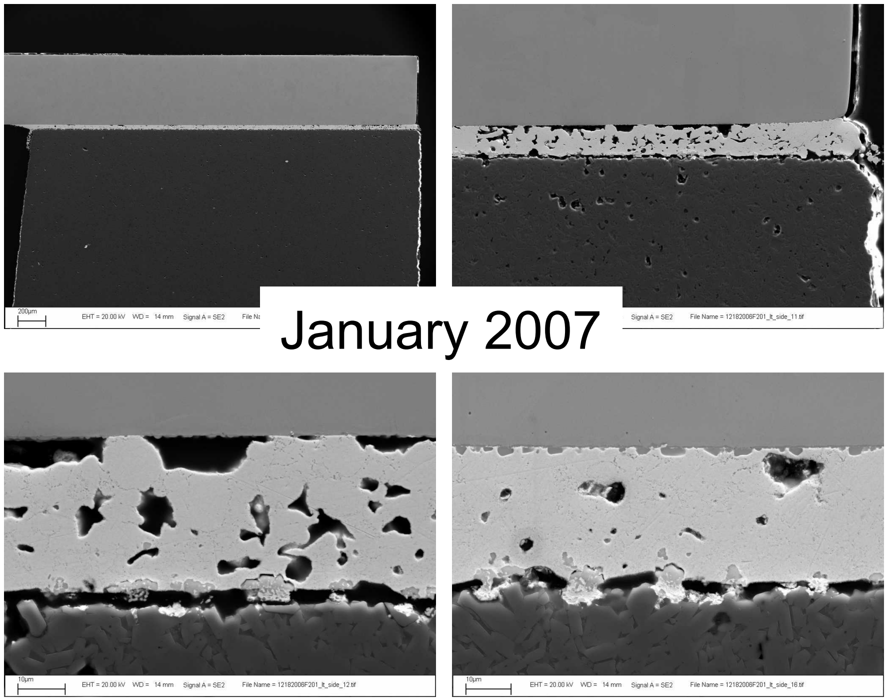
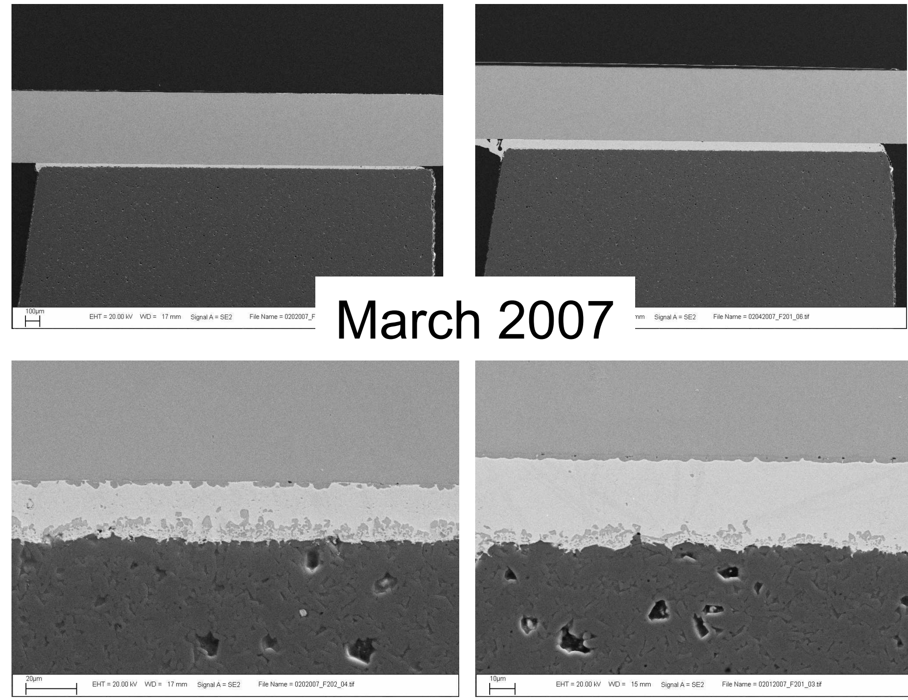
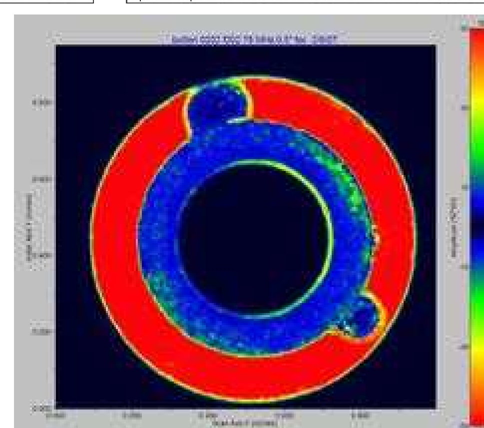
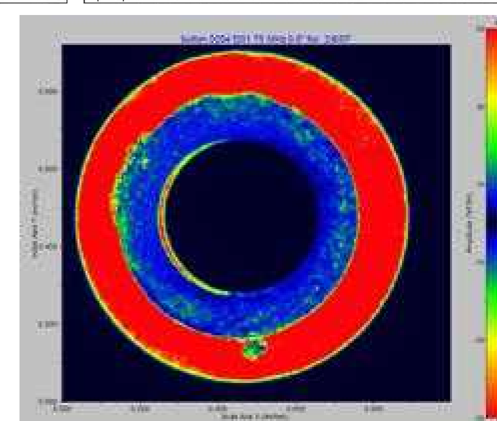
Joint Porosity Solved,
Confirmed by UT/QIA and Cross-Sections





- Changed binder burnout temperature and time (lower Temp to 425˚C, longer times ≥ 90 min.
- Much better results, quantified by UT/QIA
- Notice run-out is still a problem





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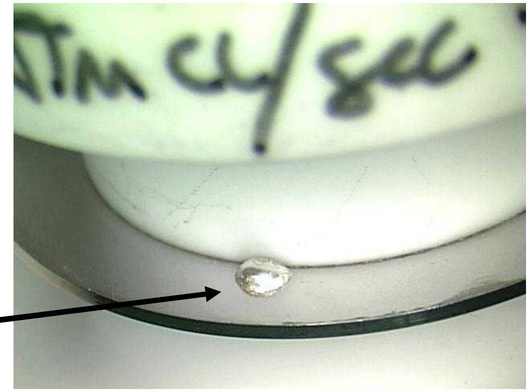
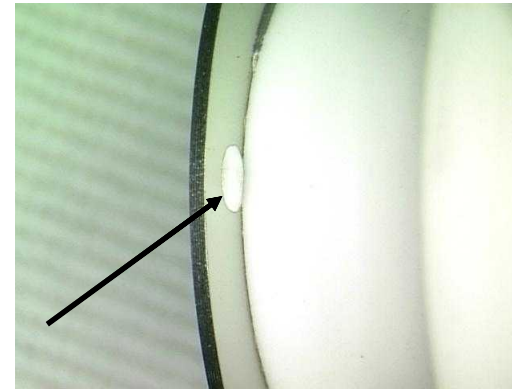
Braze Runout Unresolved

This condition, common with conventional braze washers could be mitigated by controlling volume (thickness) and applying surface treatment options





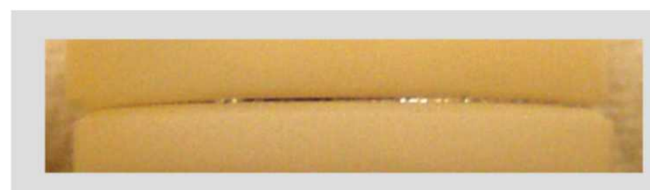
Current and Future Work

- Additions of ceramic powder to braze paste to control liquid viscosity and runout

- J.P. Choi et al. showed good results for Ag-CuO reactive air braze (RAB)

(J.P. Choi, J.Y. Kim, and K.S. Weil, "The Effect of High temperature Oxidizing and Reducing Atmosphere Exposure on a Novel Composite Braze Sealing Material", MS&T '07, Detroit, MI)

Ag2Cu



Ag2Cu + 5vol% Al_2O_3

Ag2Cu + 10vol% Al_2O_3

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Summary

- **UT inspection is an accurate method for determining Al_2O_3/Kovar braze joint quality (drawback is immersion requirement). UT results provide valuable information in addition to and complimentary to "go/no-go" hermeticity testing.**

- **QIA of UT scans provides quantitative measurement of "good" vs. "poor" bonding in braze joints, *identification of marginal braze joints*, quantitative measure of braze runout, and the effects of braze *paste* processing on joint porosity. The characterization methods provide reliable quantitative input for statistical analysis and correlation with DOEx parameters.**

- **Braze runout continues to be a concern for Ag-Cu-Zr active braze joints with both braze washer preforms and paste process. Current work focuses on runout mitigation.**

Acknowledgement

Thanks to Steve Crowder for DOEx statistical analysis, and Alice Kilgo and Debbie LaPierre for metallography