

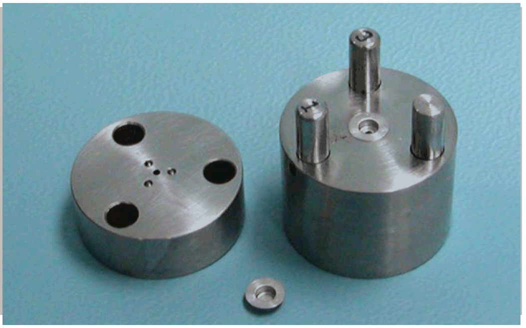

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39th International Brazing & Soldering Symposium

SAND2013-9788C

Controlling braze joint gap uniformity for exceptional tensile strengths

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U.S. DEPARTMENT OF ENERGY

NNSA National Nuclear Security Administration

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Outline

- Background: Why control the braze gap thickness?
- Gap (braze joint) control benefits
- Gap control methods (focus on dimpling)
- Fixtures & equipment needed
- Dimpling procedure
- Problems encountered w/proposed solutions
- Piece part dimpling results
- ASTM-F19 tensile button data

Why control gaps?

Problem 1: Low metal-ceramic braze strength.

Leaks developed in brazed assemblies previously determined to be hermetic/no detectable leak (NDL ≈ He leak rate < 5×10^{-12} atm-cc/sec) after subsequent processing (clamping & welding). The “new” leaks varied from gross to 10^{-8} atm-cc/sec …rather large leaks that would have been detected previously.

Problem 2: High-voltage breakdown due to cracks in brazed ceramic insulators and weakened brazements.

Previously tested “good” devices exhibited voltage breakdown following mounting in printed circuit boards. Failures were in locations having excess braze filler metal flow between metal and nonmetal components causing other regions to become starved for material.

Problem 1: Low metal-ceramic braze strength

Material set: Kovar®, Alumina ceramic (94ND10) and 97Ag-1Cu-2Zr active braze filler metal.

Qualified Brazing Method[1]: Furnace, combination of high-vacuum and partial pressure argon.

Peak Braze Temperature & Peak Soak Time[1]: 985˚C, 5 minutes

Brazement joint thickness: 0.002" – 0.003" (~50-75µm)

Typical brazed joint tensile strength[2]: 18-21 ksi

Actual Brazing Method[3]: Argon, partial pressure or atmospheric pressure

Peak braze temperature, time: 956˚C - 963˚C, 1-2 minutes.

Brazement joint thickness: <0.001" – 0.006" (<25-150µm)

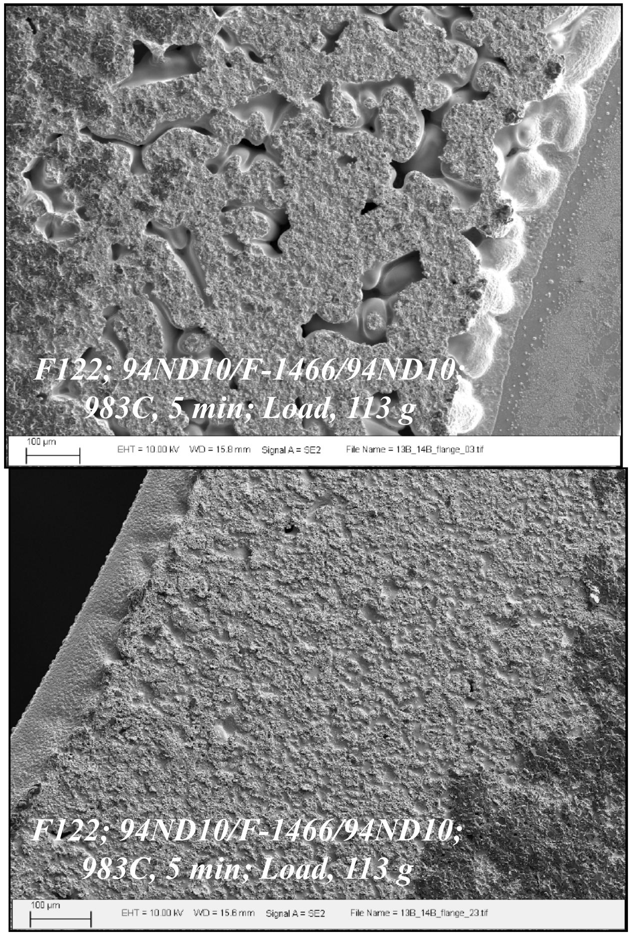
Typical brazed joint tensile strength: (unknown)

1 – Recommended and/or used during product qualification.

2 – Historical data

3 – Furnace hot zone was very "dirty"

The two images were taken at diametrically opposed sides of the same joint.



Paul Vianco et al. – Oct 2011 internal SNL presentation

Problem 1: Low metal-ceramic braze strength

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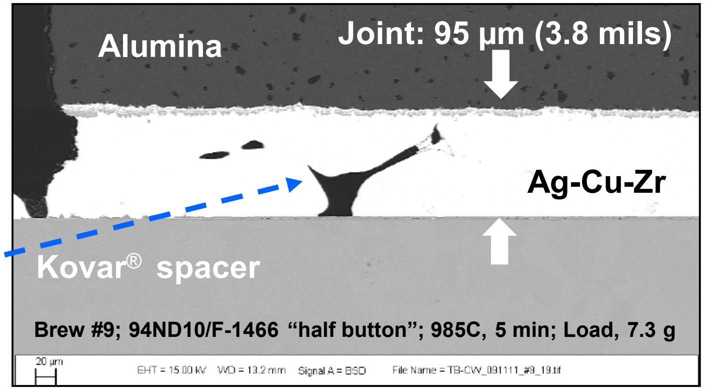
The Ag-Cu-Zr brazing filler metal joint microstructure is sensitive to the brazement thickness as follows:

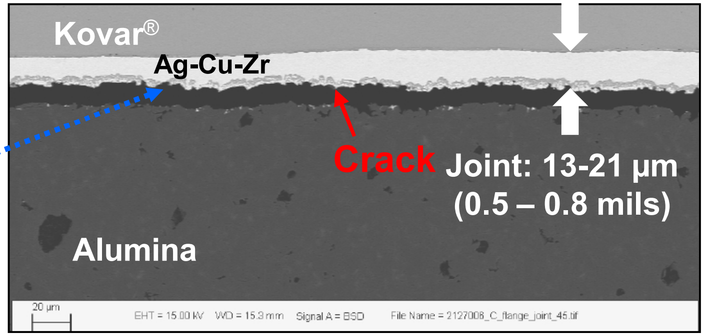
Joints too thick develop **solidification shrinkage** which is the source of what the customer termed "channeling".



Joints too thin can develop:

(a) **cracks in the ceramic** due to the lack of filler metal creep needed to accommodate the thermal expansion mismatch between Kovar® and Al_2O_3

(b) **intermittent reaction layers** caused by the reduced volume of available filler metal.



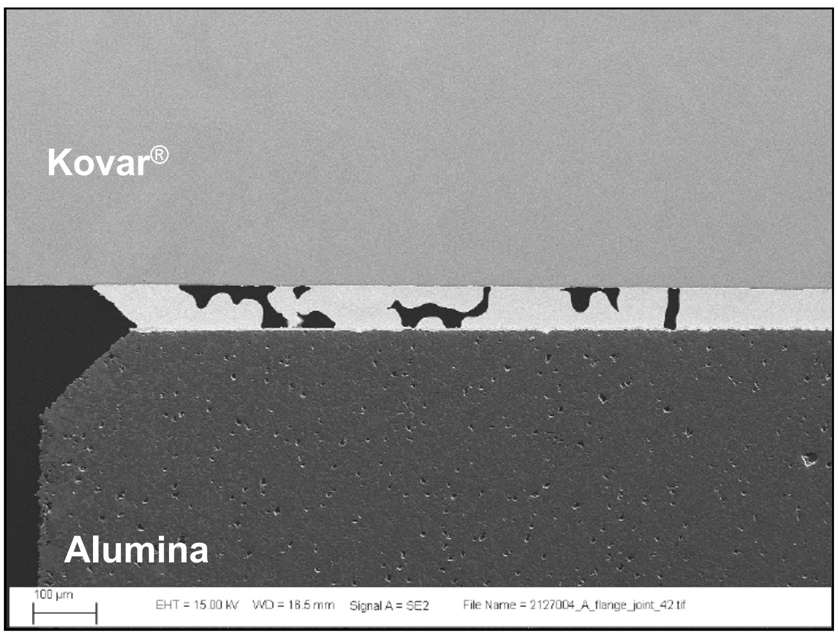
Thick and thin joints are found in the same brazements and are a function of three variables:

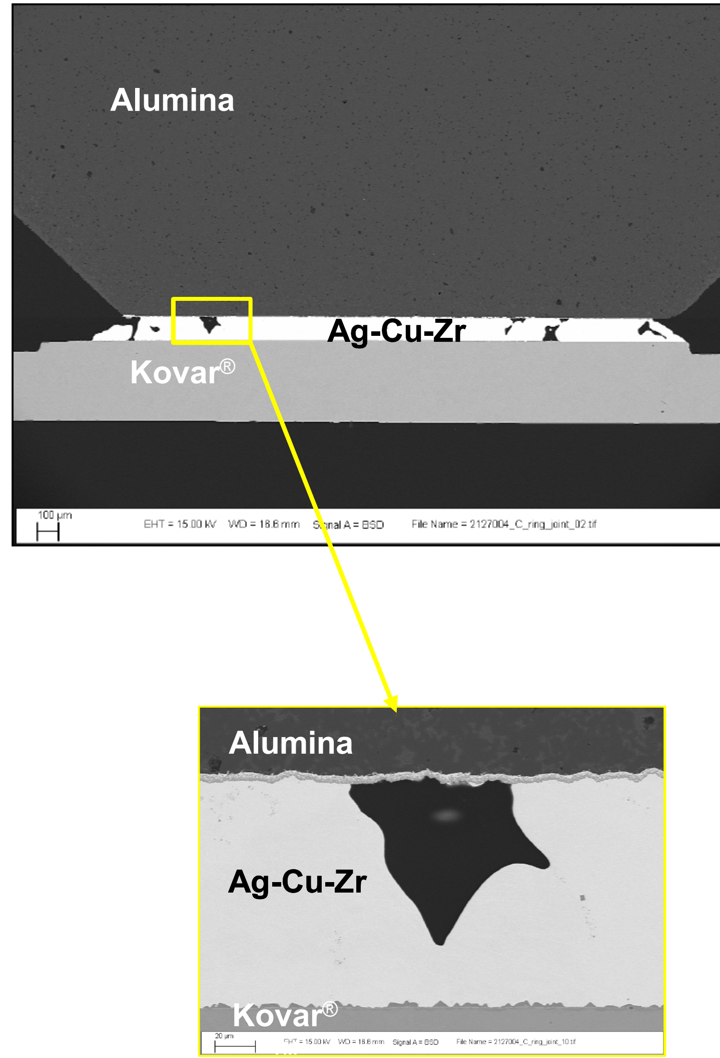
- Alloy composition (Ag-Cu-Zr has a single melting point).
- Weight distribution (preload) used to locate the piece parts.
- Quantity of filler metal (thickness and footprint)

This was one of the drivers to develop a method to control joint thickness.

Problem 1: Low metal-ceramic braze strength

Note that the presence of reaction layers at both the alumina and Kovar® interfaces indicates previous contact with the liquid braze filler metal during the brazing process. (*Supports solidification shrinkage mechanism as reason for joint porosity.*)





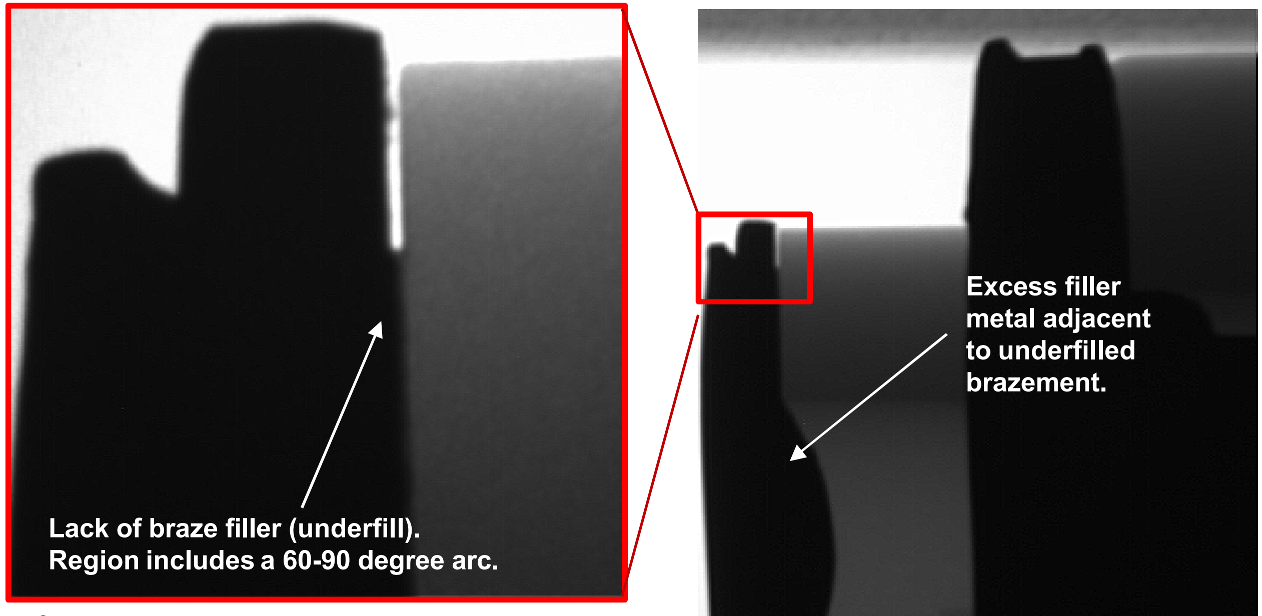
Problem 2 – Weak/Cracked brazes

June 2011

Device failure investigation

Test fault: Failure to hold-off voltage

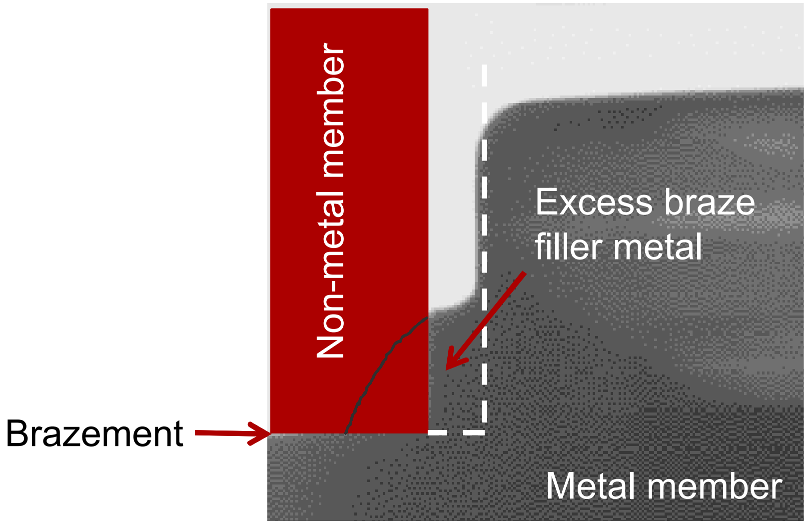
Previously "hermetic" vacuum envelope was compromised resulting in a high-voltage breakdown

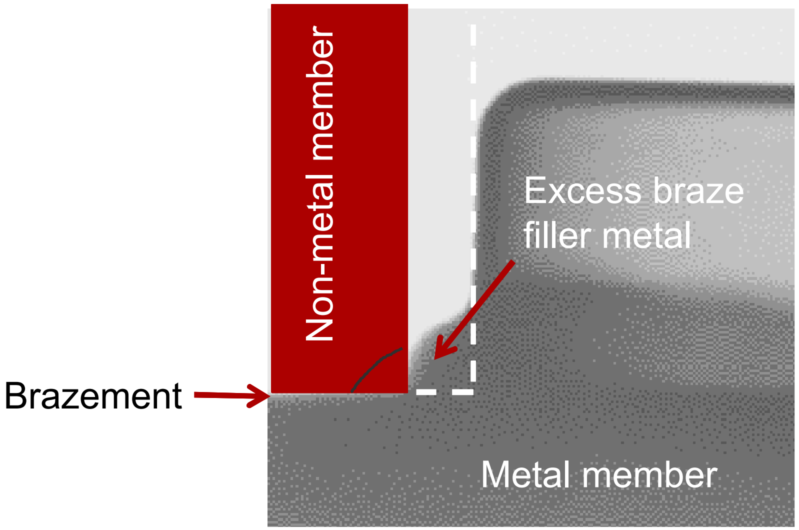


Findings from the investigation:

- **Fillet formation on the ID of the header ceramic contributed to an under-filled brazement.**
- The under-filled brazement led to reduced braze joint area and subsequent loss of joint strength.
- **The large fillet resulted in higher than normal residual stresses** in the metal-ceramic braze joint.
- Direct application of high, **localized heat source** (soldering iron) **generated high stresses leading to** the (reduced size) brazement **failure**.
- **To minimize the risk of this failure reoccurring** it is recommended that:
  - the **fillet formation be minimized** through brazing thermal-cycle and/or and
  - that less severe soldering methods be used requiring broader/indirect sources of heat.
  - Post-brazing inspection requirements include **lack of visible (10X) braze fillet as a cause for rejection**.

Problem 2 – Cracks in insulators



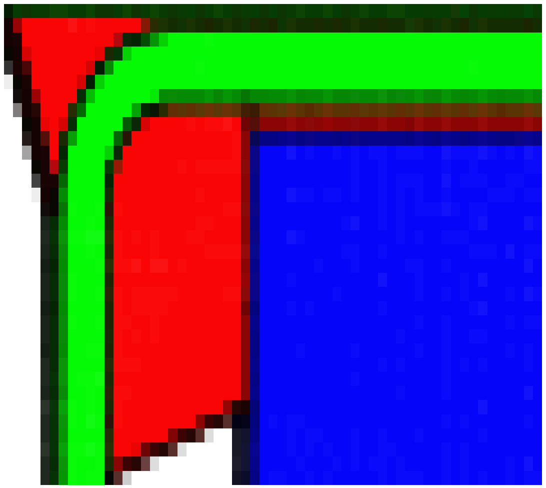


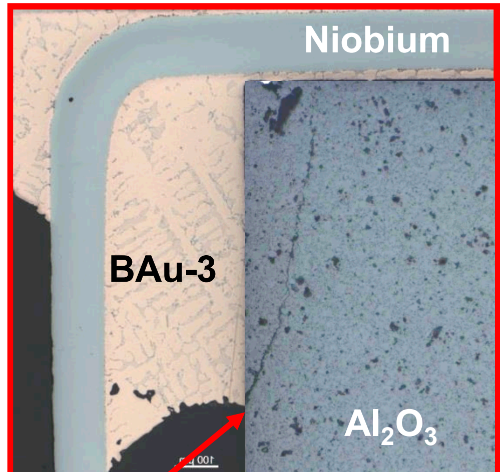
Regions with excess braze material between deep-drawn cups and ceramic cylinder wall

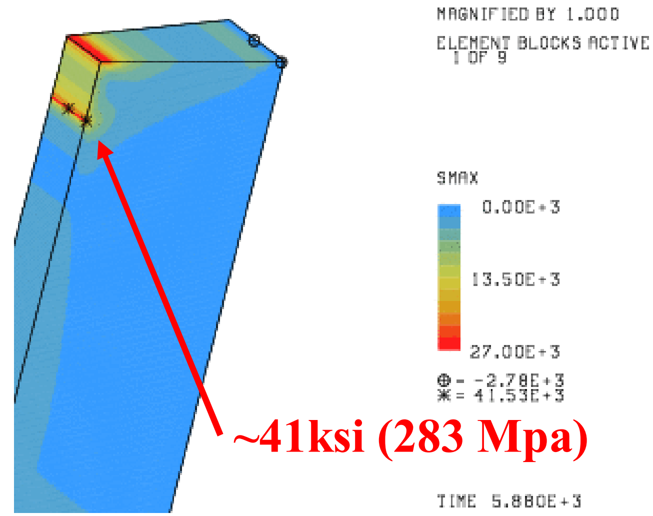
1) Regions with excess braze filler material between drawn cups and ceramic cylinder wall will have higher residual stresses upon solidification.

2) Next assembly high localized heating (soldering iron) applied in these regions could lead to excessive stresses applied to the ceramic or ceramic/metal interfaces causing brittle material failure and loss of hermeticity.

Nicoro™ (BAu-3) brazing simulations – 1000 to 20 C, cool at 10C/min to room temperature



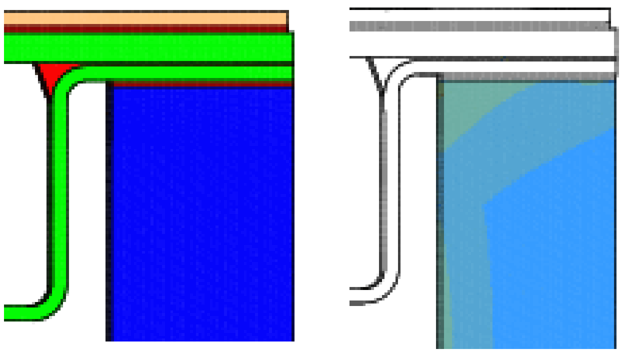


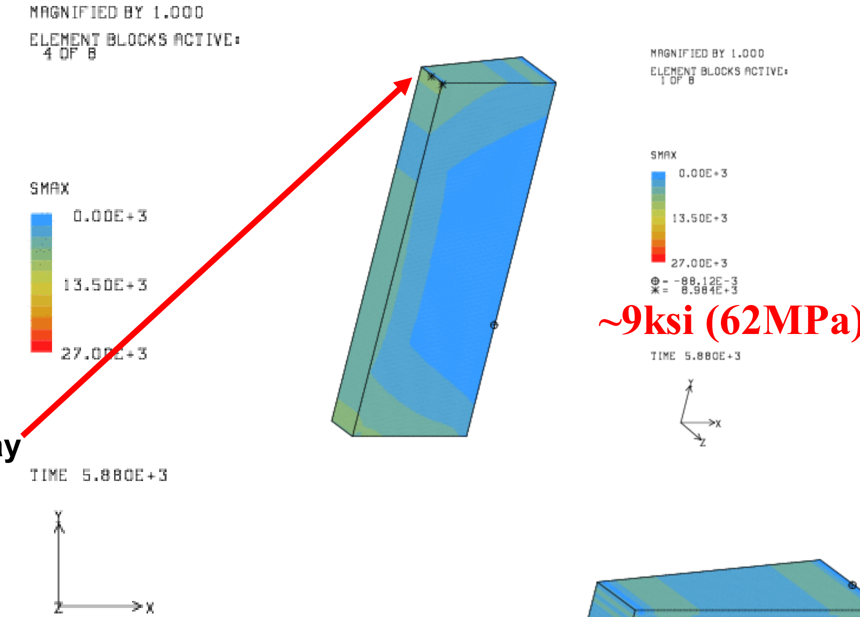


The observed crack results from residual stresses in the excess braze filler metal: the tensile strength of 94% alumina is 27 ksi, or ~2/3 the simulation residual stress value of 41 ksi in the brazement.

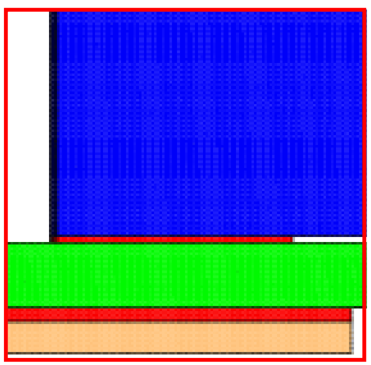
Mike Neilsen, Internal SNL Memo, 2013

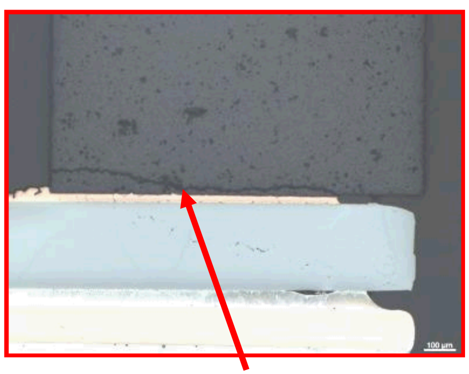
Nicoro™ brazing simulations – 1000 to 20 C, cool at 10C/min to room temperature

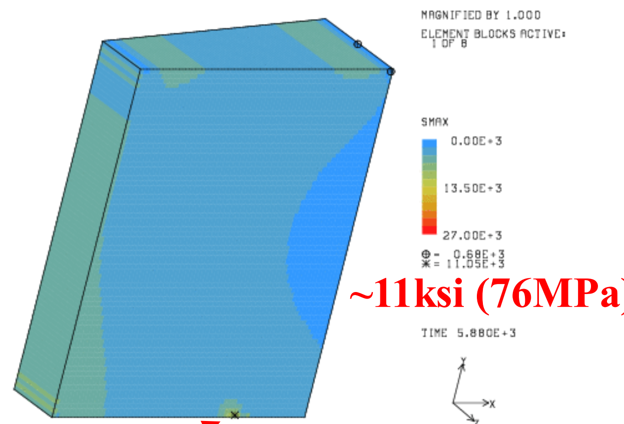




remove excess braze and stress goes away





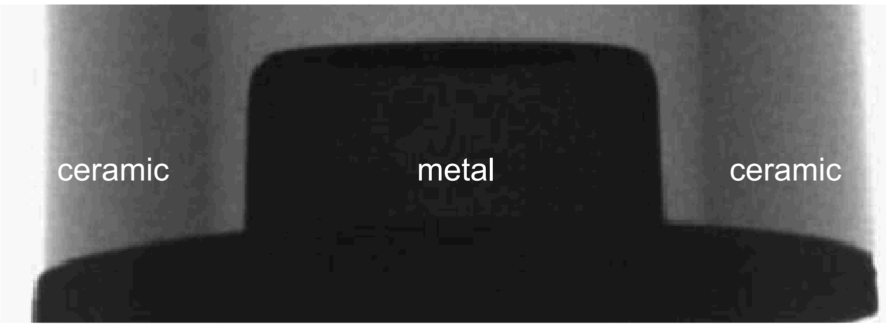


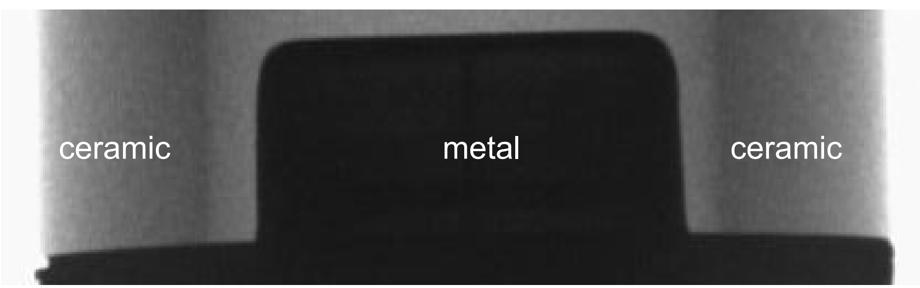
some tensile stress from brazing but not enough to cause observed crack

Mike Neilsen, Internal SNL Memo, 2013

Remedy: dimpled metal substrates

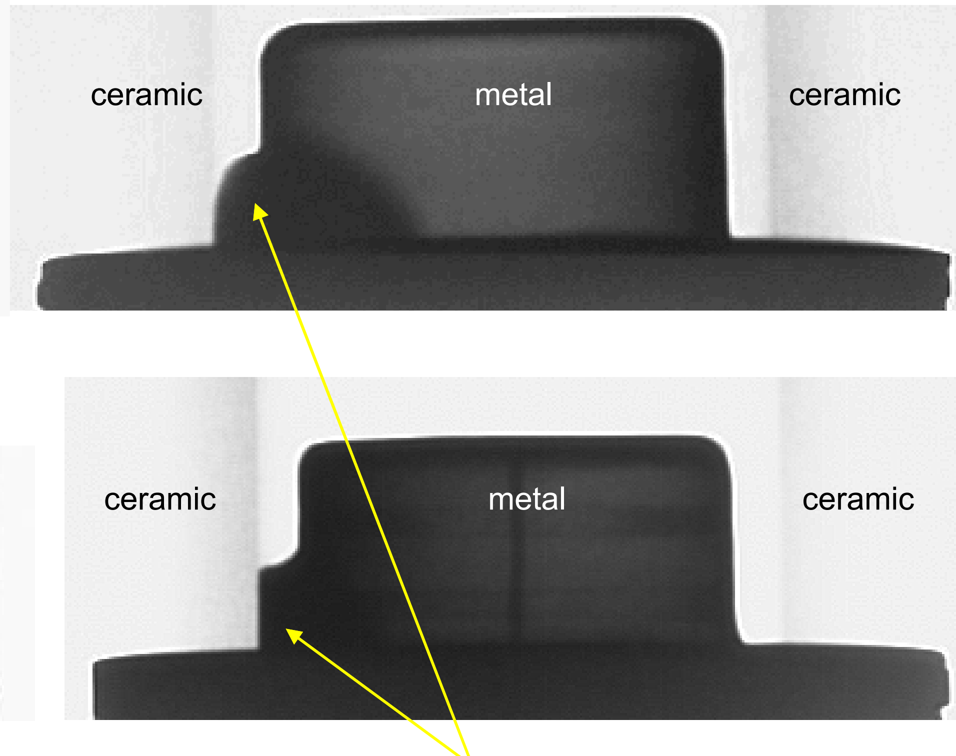
X-ray of brazed assemblies
(metal substrates with 0.0015" dimples)





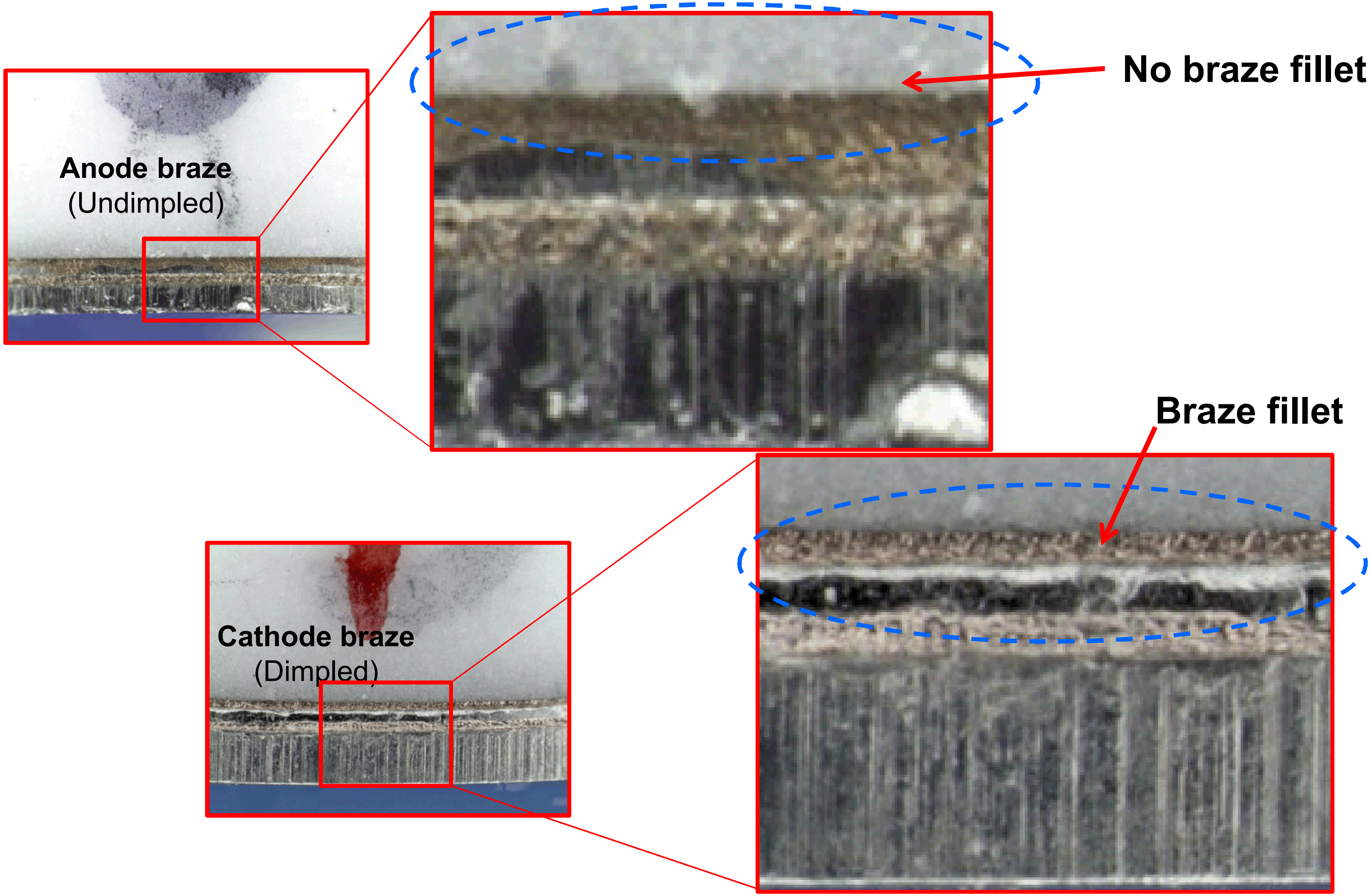
No excess braze filler metal flow
(20/20 assemblies had no visible excess flow)

X-ray of brazed assemblies
(metal substrates without dimples)



Excess braze filler metal flow
(18/20 assemblies had one or more places with excess flow)

Dimpled substrates = uniformly thick braze fillets (fewer rejected assemblies)



Gap control Benefits

General Benefits

- **Proper braze joint clearance is maintained***
  - ✓ **Shrinkage voids minimized or eliminated ***
  - ✓ **High joint stresses from collapsed joints eliminated ***
- **Greater braze joint tensile strengths ***
- **Assembly stack-up error is reduced ****

Application specific – *high voltage devices*

- **Less shot-to-shot variation****
- **Elimination of cracking due to large fillets***
- **Improved voltage stand-off* & shot-life****
- **Improved visual inspection capability***
- **Reduced braze filler metal run-out***

***proven benefit**

****accumulating data**

Gap control Methods

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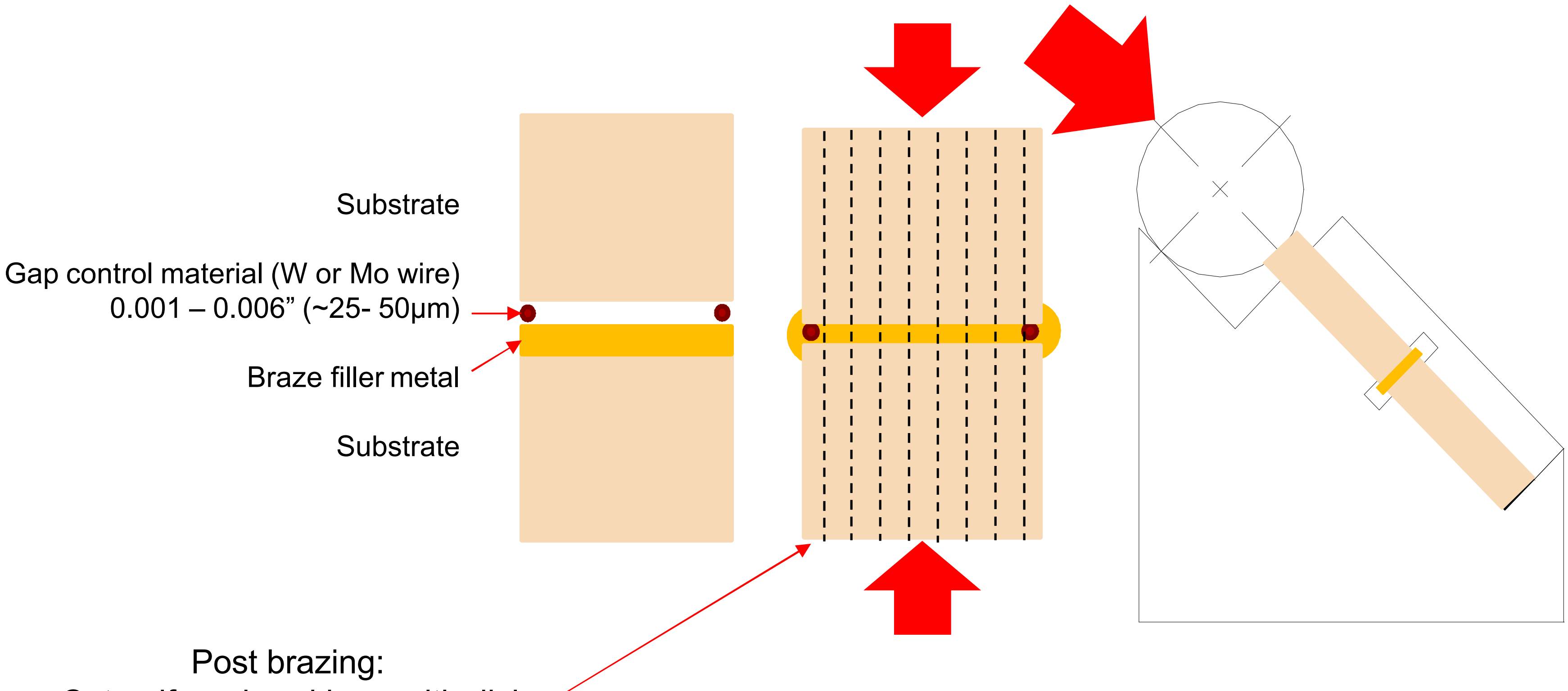
Added material(s)

- Wires, shims, preforms
  - ✓ Low solubility in liquid braze filler metal (refractory metals, parent material)
  - ✓ No adverse reactions with parent materials (eutectic/low-melt reactions, brittle compound formation)
  - ✓ No adverse reactions with brazing process atmosphere (i.e. Ta or Ti wires or preforms in a hydrogen furnace)

Modification of base material substrates

- Machining
  - ✓ Material removal (standard or EDM machining)
  - ✓ Material addition (thermal or cold spray, LENS)
- Forming
  - ✓ Dimpling

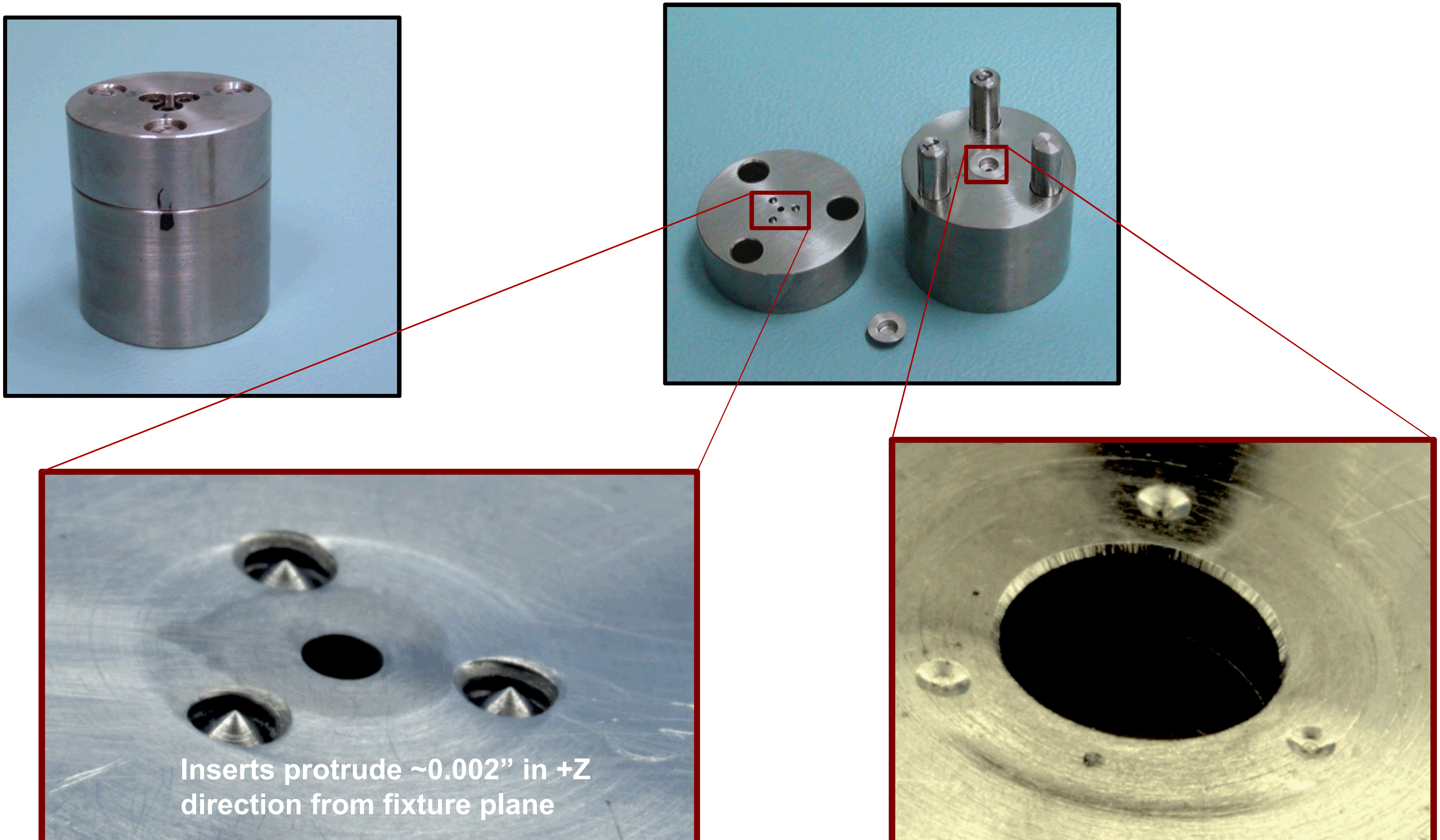
Example: Ceramic/Ceramic 4-pt bend specimens w/tailored joint gaps*



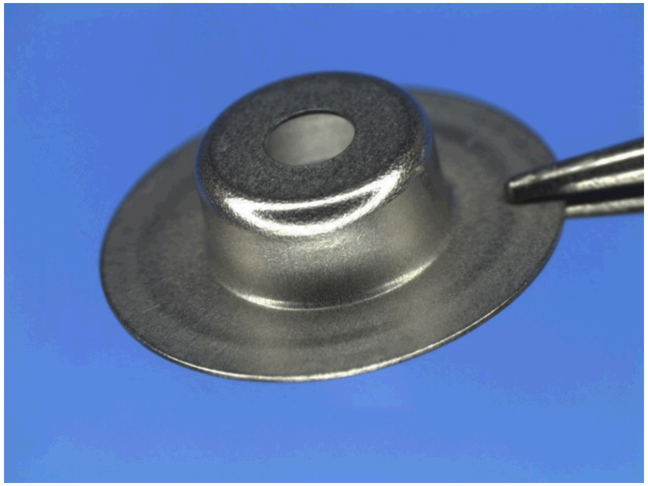
Post brazing:
Cut uniform bend bars with dicing saw & grind to final dimension

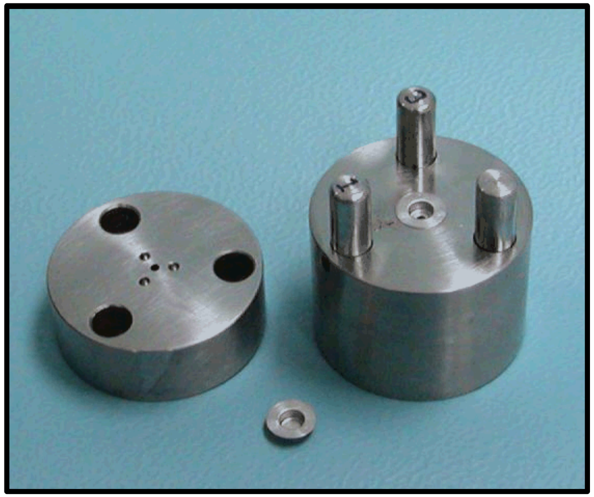
*Sandia Report, SAND2000-1559, S. J. Glass et. al., *Joining Si3N4 for Advanced Turbomachinery Applications*, July 2000, p 2-52

Metal substrate single-stage dimple fixture



Switchtube single-stage dimple fixture





Dimpling & compliance measuring equipment

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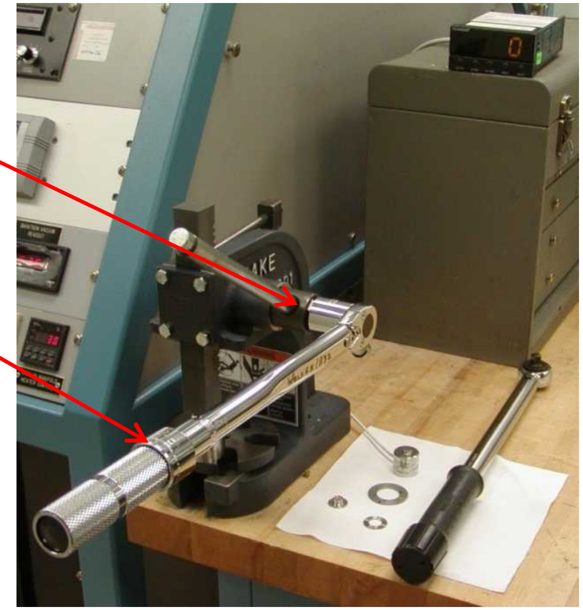
Modified arbor press: (Nut welded onto pinion)

An adjustable **torque wrench** allows a repeatable force to be applied by the ram onto dimpling dies.

Required force varies with material & thickness.

A **load cell** measures ram force (lb_f) applied by a specific torque value (ft-lbs) to assist with process refinement.

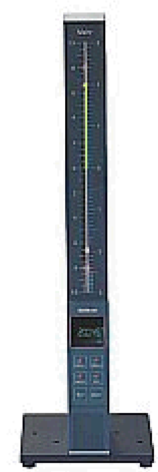


Mahr GmbH, Millimar S1840 column amplifier, comparator stand & Inductive probe P2004B (4µin repeatability)

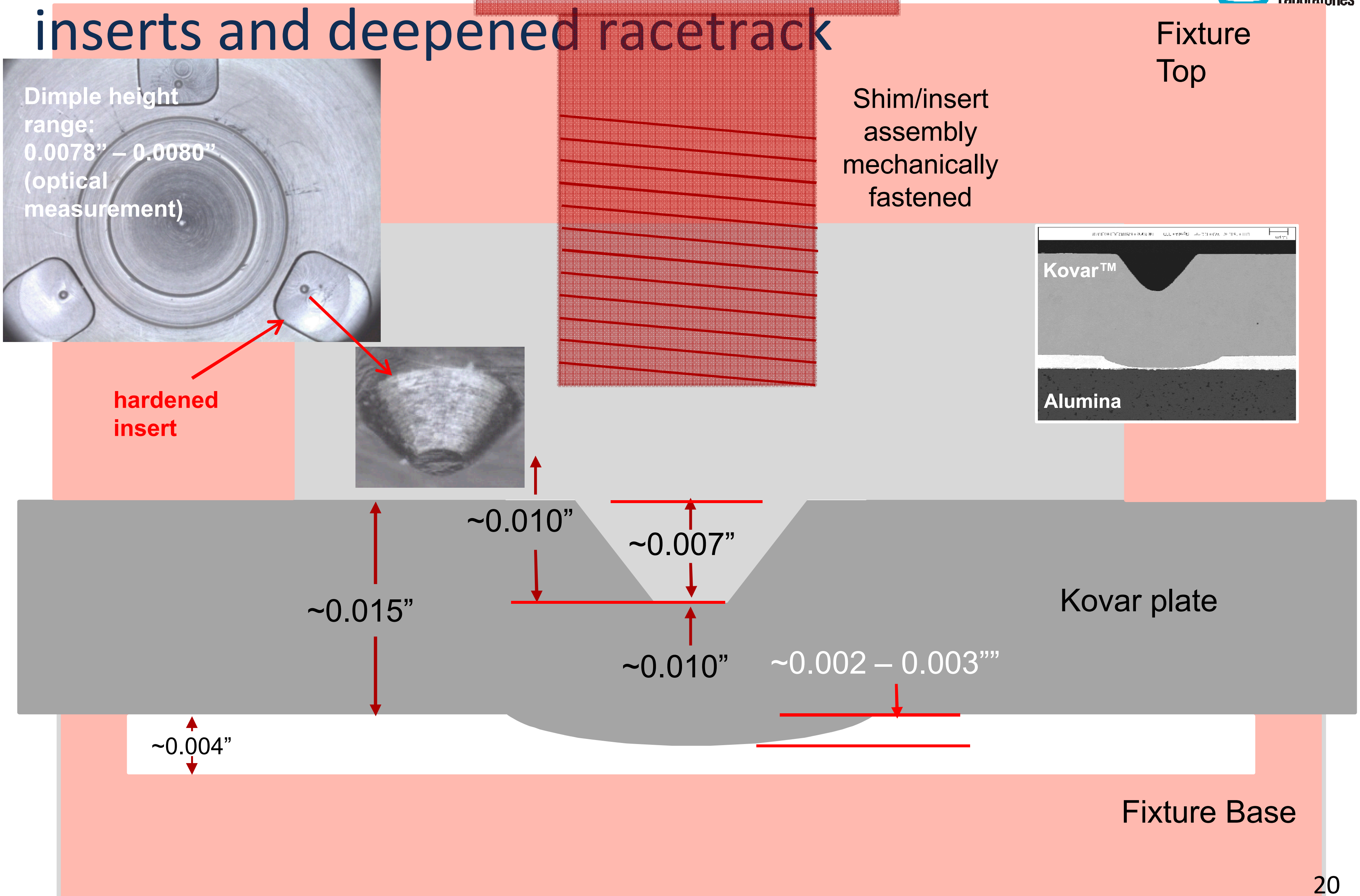
Pneumatic foot-operated inductive probe actuator allows hands free measurements.

Column amplifier with 3-color display allows for easier, more reliable measured value assessments (Go/No go) at a glance.

PC interface & software allows for data collection and analysis.



~250 lbs Stage 1 force w/precision ground dimple inserts and deepened racetrack

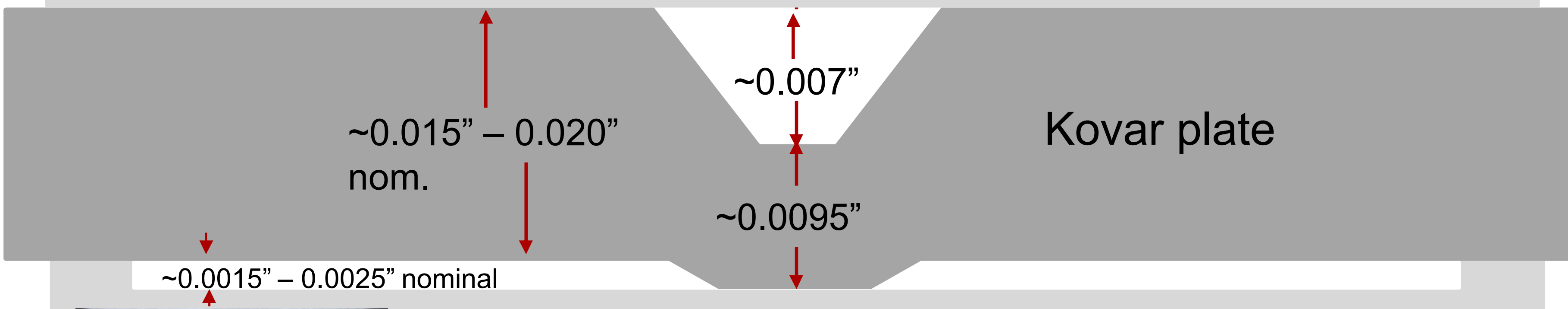


Dimples made using reduced height inserts have been successfully reformed using the stage 2 die.

Stage 2 dimple adjustment reforming operation: 20-50 ft-lbs torque on arbor press.

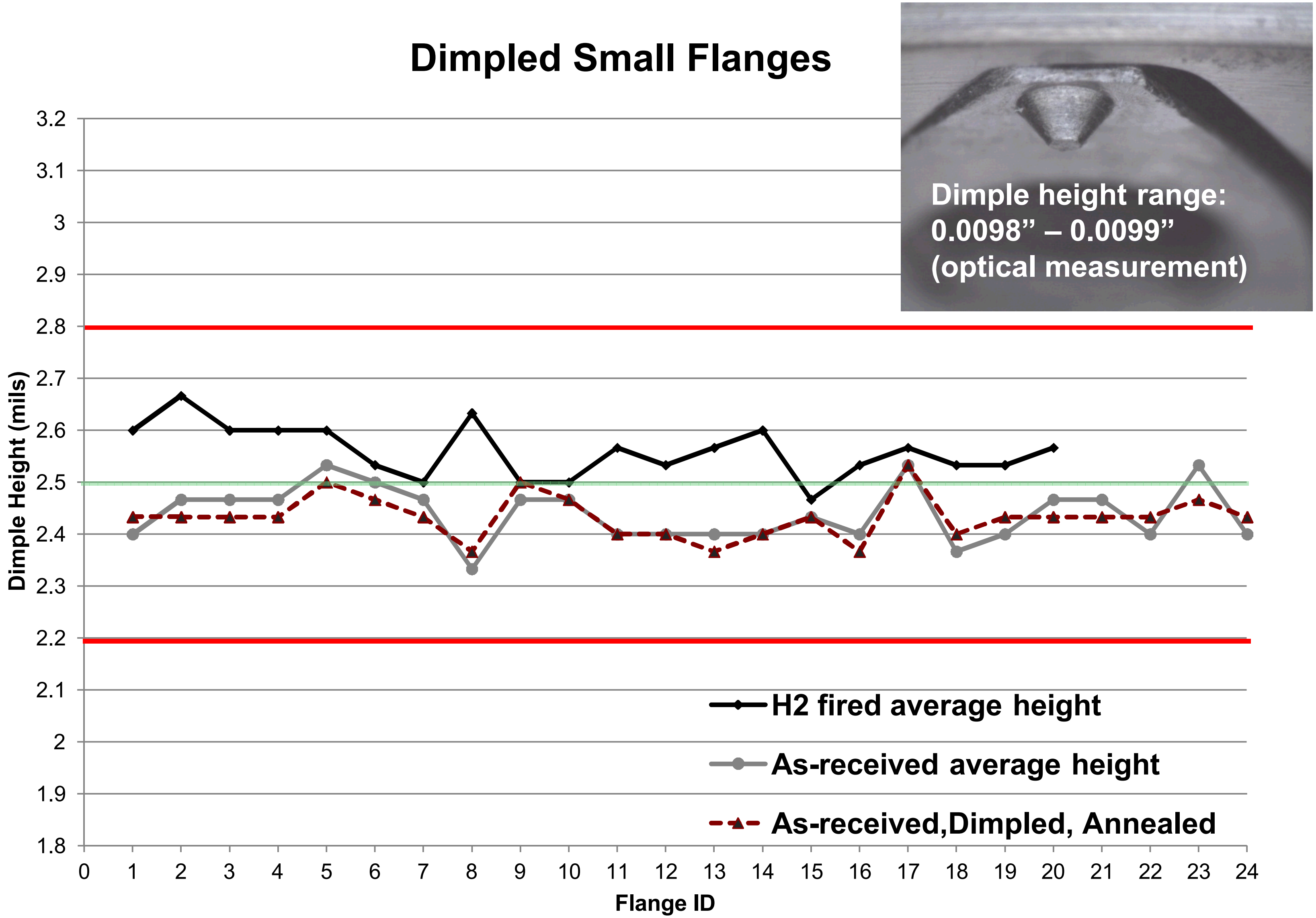
Resulting stage 1 dimples are easily adjusted to desired range (0.0015” or 0.0025” ± 0.0003”)

Stage 2 Top

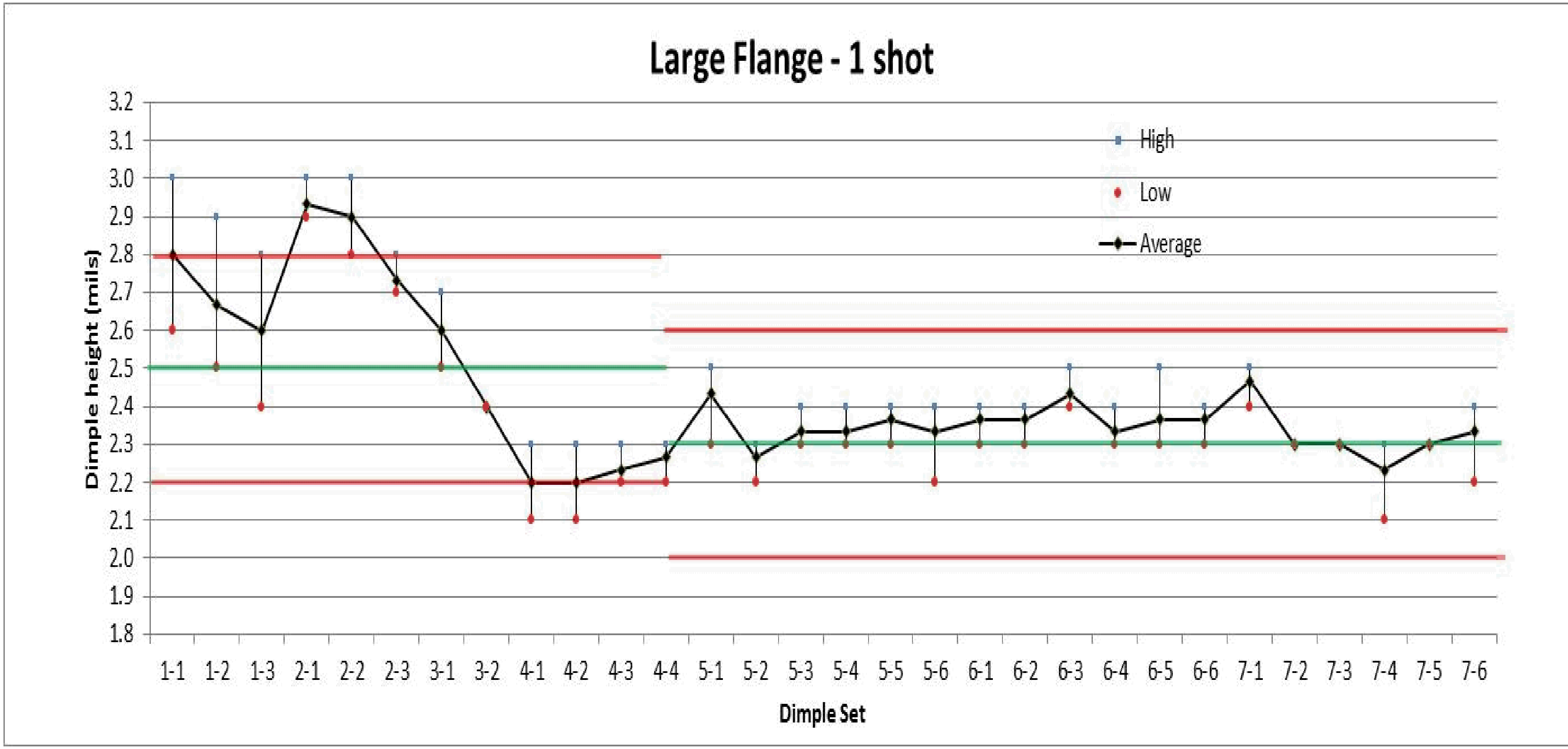


Stage 2 Bottom

Initial Small Flange Dimpling Trials



Kovar flange dimpling: 1-shot method

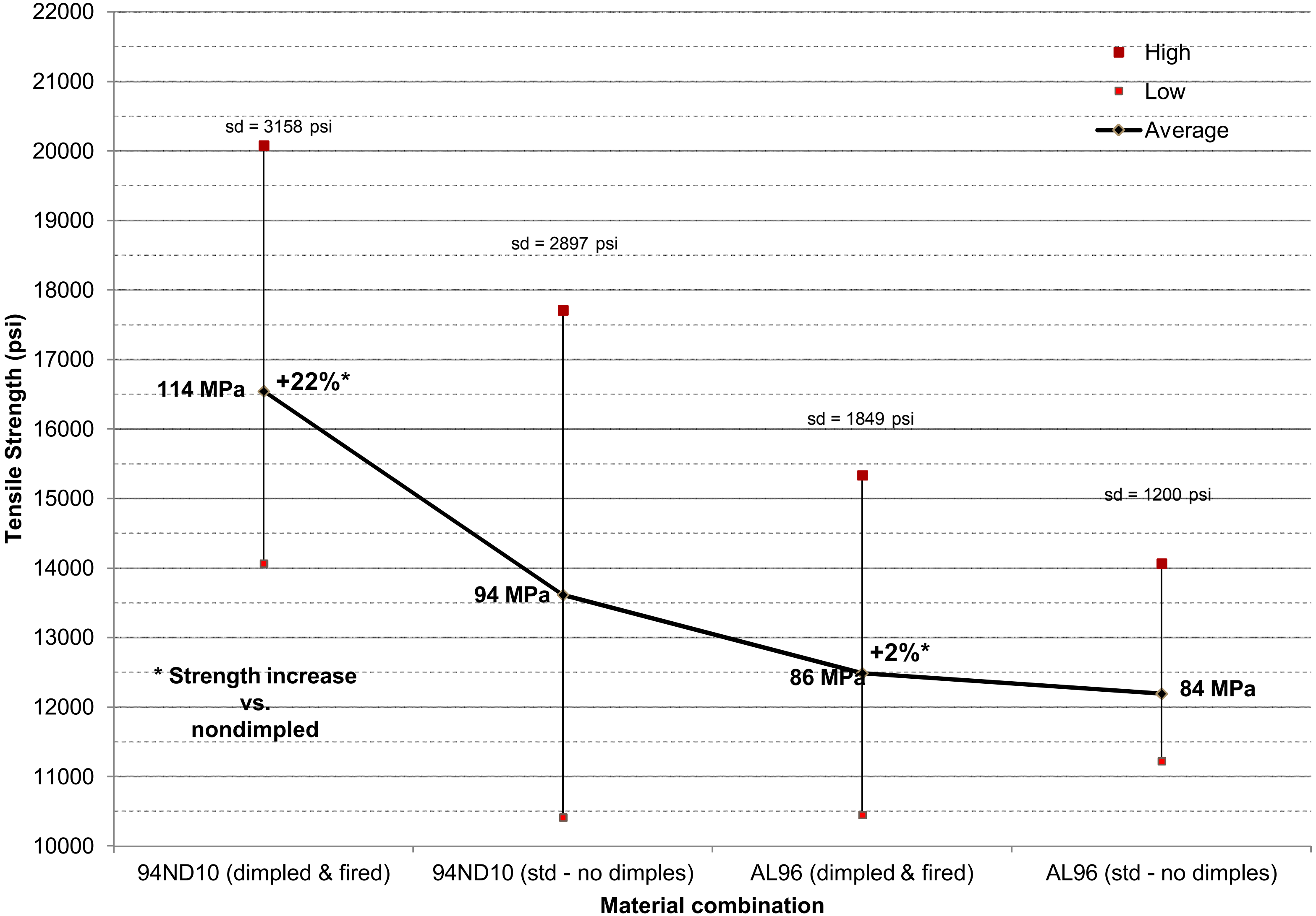


1-shot dimpling process:

Stage 1 dimple insert die used in combination with the Stage 2 dimple reforming die

- Time saving process
- Meets dimensional tolerance of ±0.0003" (± 0.0076 mm)
- Nominal dimple height still needs to be dialed in

Tensile Strength: AL96 vs. 94ND10 Nicoro+2%Ti braze filler metal
(std & dimpled niobium interlayers)



Active Filler Metal Brazing
ASTM-F19 Tensile Button Test Results
…now with dimples!

Filler Metal	Non-metal Substrate	Metal Substrate	Brazing Temperature	Furnace Atmosphere	Tensile Strength ksi (MPa)
97Ag-1Cu-2Zr	94% Alumina	Fe-29Ni-17Co	963°C, 3 minutes above liquidus	Partial pressure Ar	21 ± 3 (147 ± 21)
97Ag-1Cu-2Zr	96% Alumina	Fe-29Ni-17Co (dimpled, 0.002”)	963°C, 3 minutes above liquidus	Partial pressure Ar	24 ± 4 (165 ± 21)
62Cu-35Au-2Ti-1Ni	94% Alumina	Niobium	1030°C – 2 minutes	Vacuum	14 ± 3 (94 ± 21)
62Cu-35Au-2Ti-1Ni	94% Alumina	Niobium (dimpled, 0.0015”)	1030°C – 2 minutes	Vacuum	17 ± 3 (114 ± 21)

Test Samples:
ASTM-F19 Tensile Buttons

(94% alumina with Fe-29Ni-17Co interlayers)

- Tensile strength (crosshead speed = 8.38E-03 mm/sec)
- Hermeticity Data (helium leak rates <5E-12 atm-cc/sec)

Averages are ± 4 ksi / 21 MPa