SAND2013-5371C

A Pin Pull Test to Assess the Adhesion of Thin Film Conductors on LTCC Substrates

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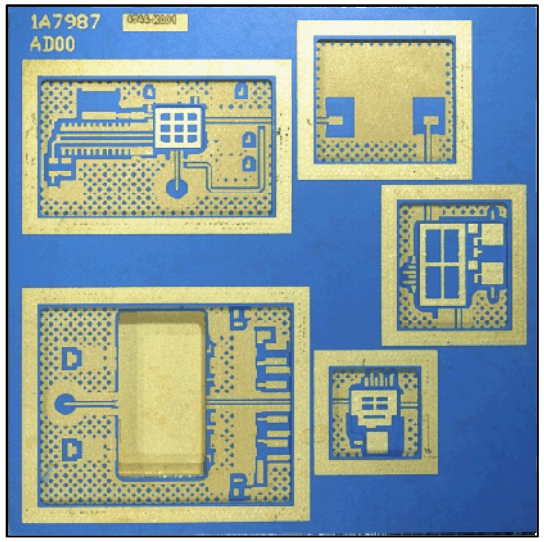
*Sandia National Laboratories is a multi-program laboratory operated by Sandia Corporation, a Lockheed Martin Company, for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-AC04-94AL85000.

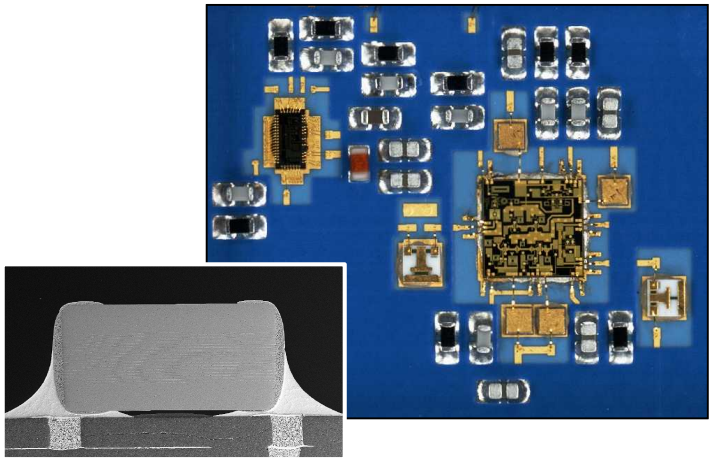
Introduction

- The replacement of thick film networks with thin film conductors will enable the further miniaturization and increased functionality of hybrid microcircuit (HMC) technologies.

- The thin film conductors must provide, not only a path for electrical signals, but also the mechanical attachment of components to the ceramic substrate.

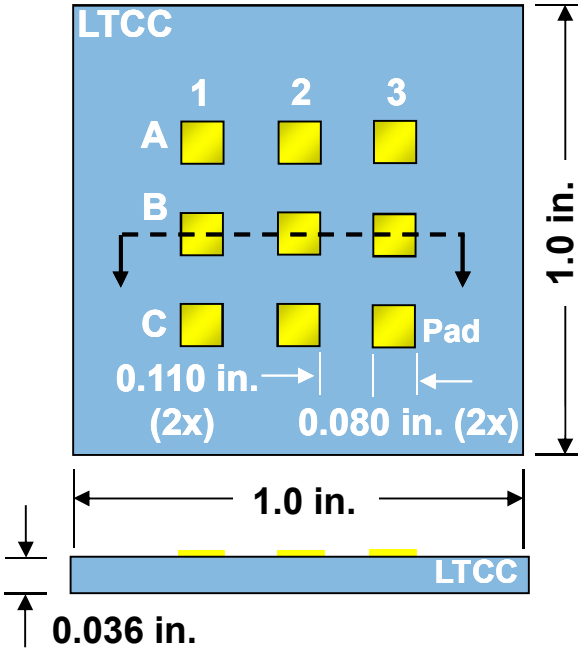
- A test technique was required to quantify the adhesion of soldered thin film conductors in order to be able to predict their long-term reliability in service.

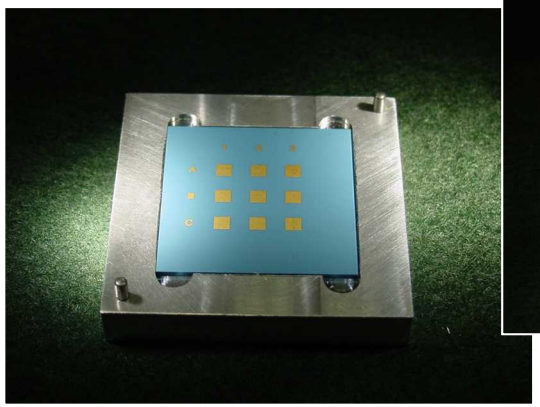


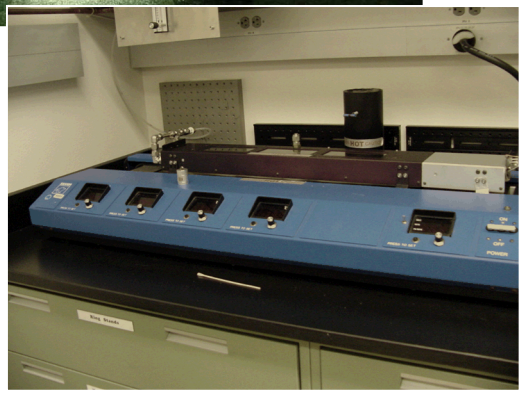


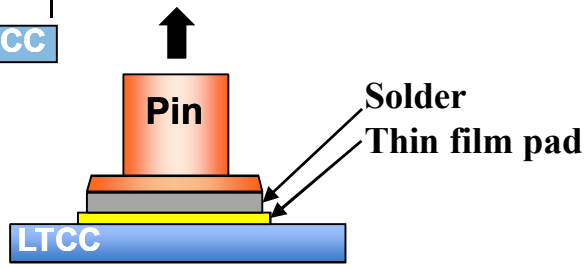
Experimental Procedures

- The pin pull test is a variant of the Sebastion™ pull test used to assess the strength of as-deposited coatings.
- The particular advantage of the new pin pull test is that it *includes the effect of the solder joint.*



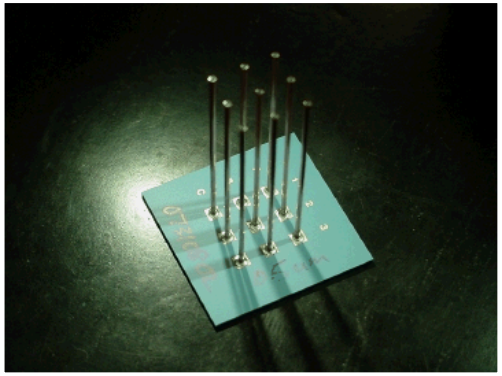




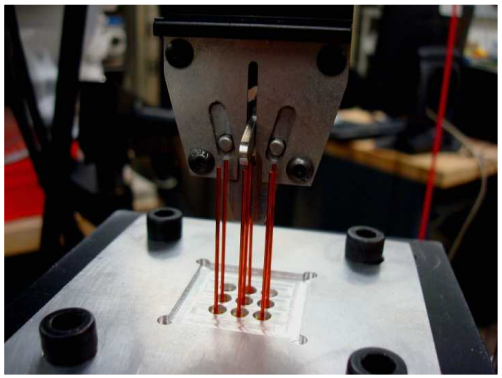


Experimental Procedures

- The procedure pulled 8/9 pins from the specimen at a rate of 10 mm/min, using a table-top test frame.
- The last pin was reserved for a metallographic cross section.

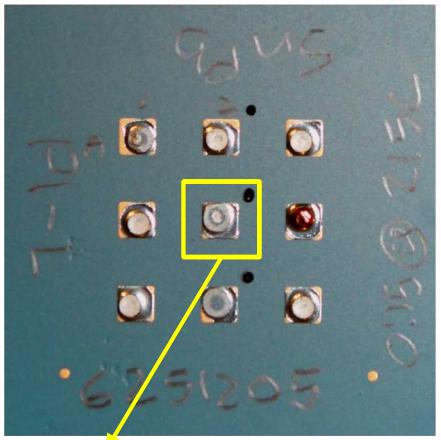


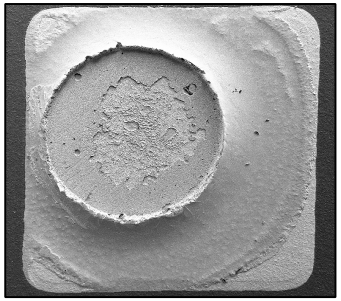
Test specimen



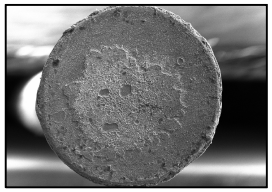
Pull test fixture

Failure mode analysis





Pad



Pin

Fracture surfaces

- **Failure mode analysis** was correlated with the pull strengths to fully describe the performance of the ***thin film solder joints***.

Experimental Procedures

- The Ti - Cu - Pt - Au thin film was the target of this study:

  0.20 Ti - 4.0 Cu - 2.0 Pt - 0.25 Au *(μm)*

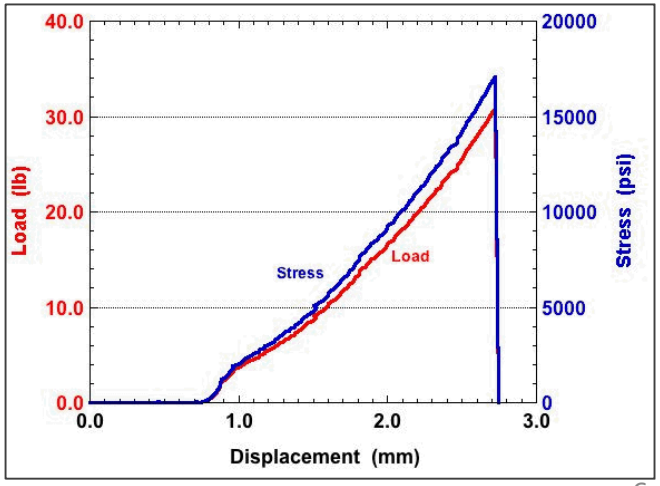
- Solder alloys (wt.%):
  - 63Sn - 37Pb (wt.%)
  - 95.5Sn - 3.9Ag - 0.6Cu *(Pb-free)*

- The liquid-state aging task defined the process margins:
  - Peak temperatures:
    a. Sn-Pb alloy …….. 215°C, 240°C, 260°C, and 290°C
    b. SAC396 alloy ….. 240°C, 260°C, and 290°C
  - Time at peak temperature: 15, 60, and 120 s

Experimental Procedures

- The solid-state (isothermal) aging task examined the long-term stability of the soldered thin film by accelerating interface reactions at elevated temperatures for extended time durations.
  - Aging temperatures:
    a. Sn-Pb alloy …….. 70°C, 100°C, 135°C, and 170°C
    b. SAC396 alloy …... 70°C, 100°C, 135°C, 170°C, and 205°C
  - Time periods: 10, 25, 50, 100, and 200 days

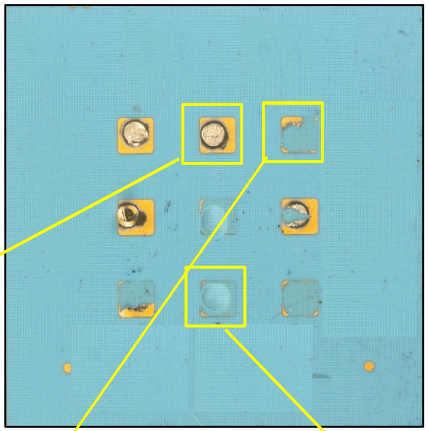
- The pull strengths were expressed as the mean of the maximum loads obtained from sixteen (16) test sites and an error term that was ± one standard deviation.

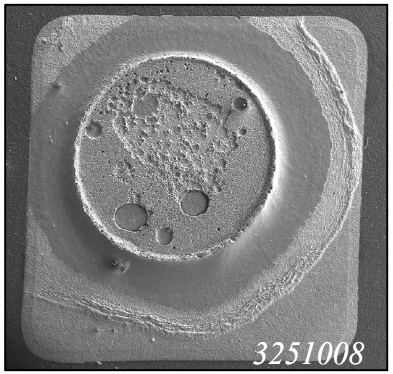


5171001 240C, 1 min, SnPb Site A1

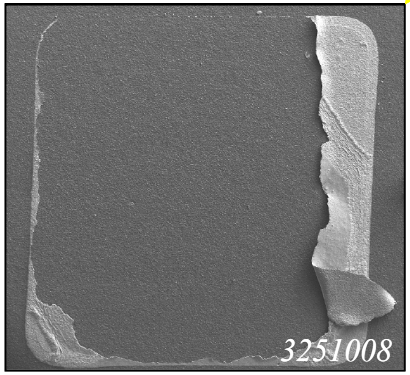
Experimental Procedures

- Documentation was made of the fracture surface morphology.
- Three (3) fracture surface morphologies were identified amongst the pull test sites:
  - Solder failure
  - Thin film delamination
  - LTCC divot

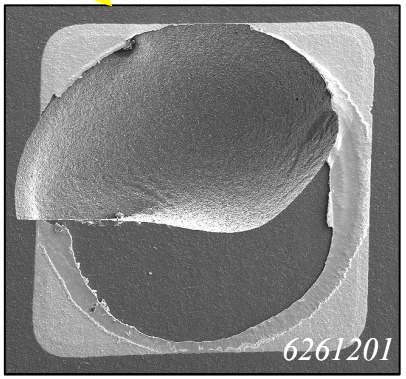




Solder failure



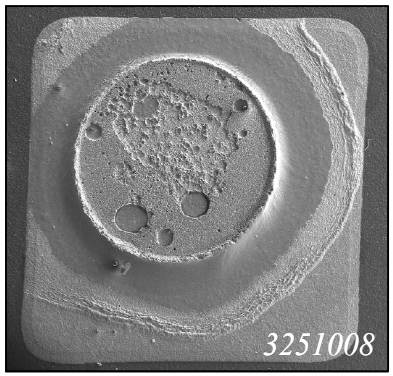
Thin film delamination



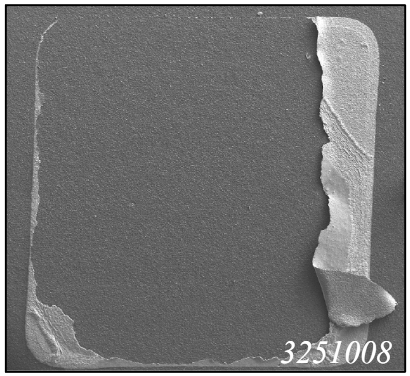
LTCC divot

Experimental Procedures

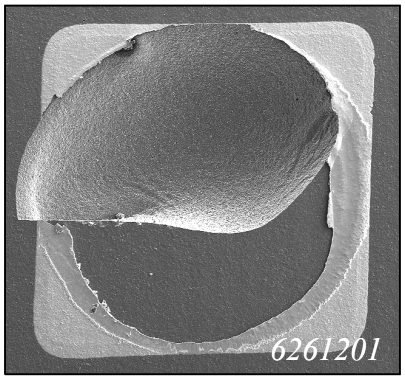
- Schematic diagrams illustrate the fracture surface morphologies:



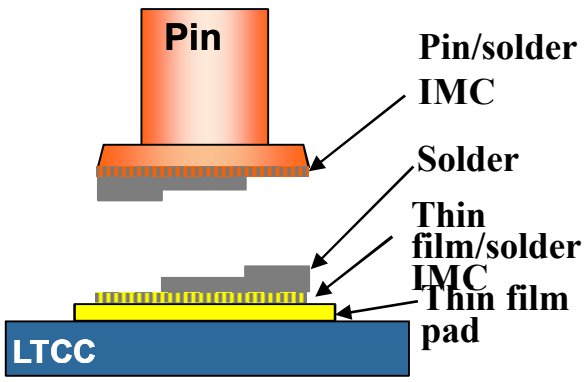
Solder failure

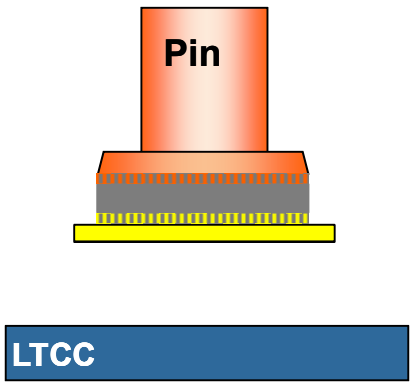


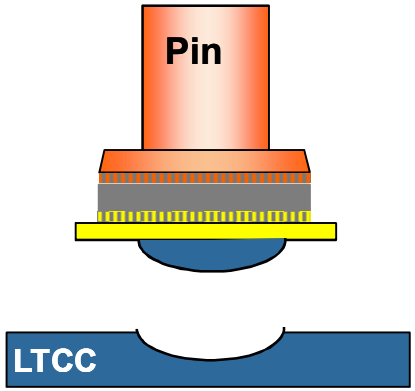
Thin film delamination



LTCC divot



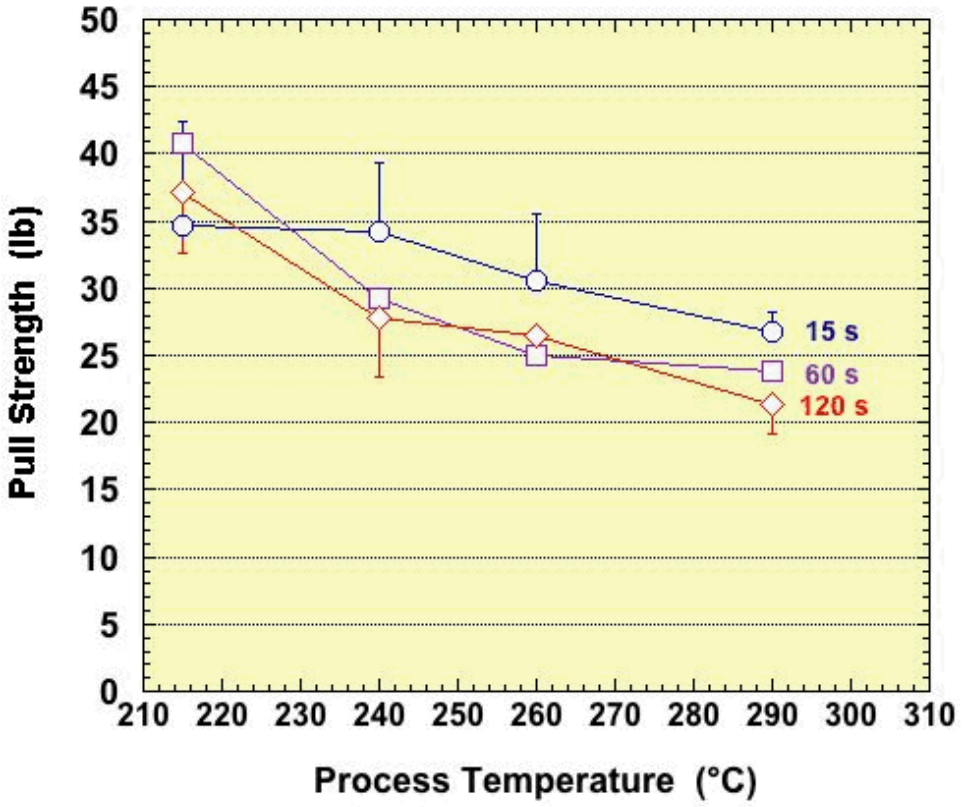




- Pull test sites were assigned one of three failure modes.
- The percentage of each failure mode was documented per test condition.

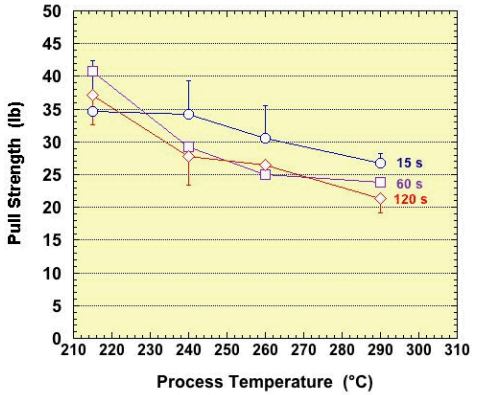
Results and Discussion

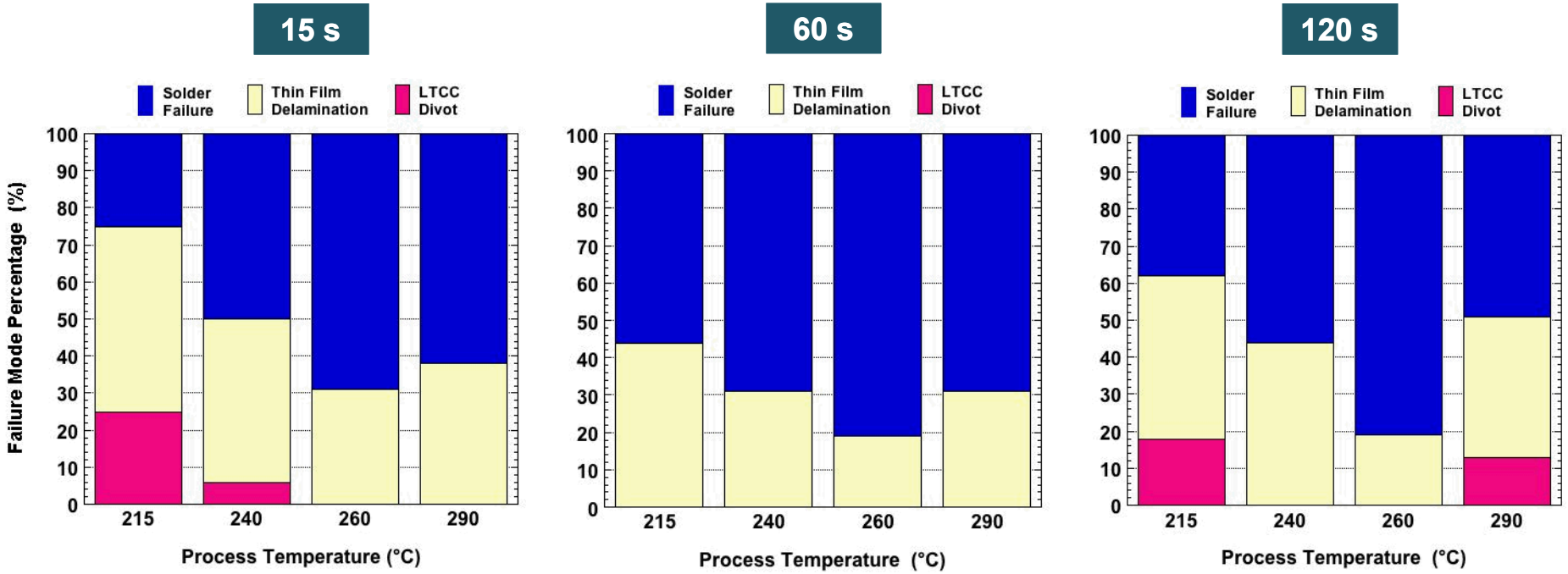
- **Liquid-state aging (process margins) analysis began by examining the strength of 63Sn-37Pb solder joints:**
  - **The strength decreased with increasing process temperature.**
    - **Even the lowest strength value indicated adequate mechanical integrity.**
  - **Mean strengths were generally higher after 15 s when compared to 60 s and 120 s.**
    - **The pull strengths were very similar after the 60 s and 120 s process times.**



Results and Discussion

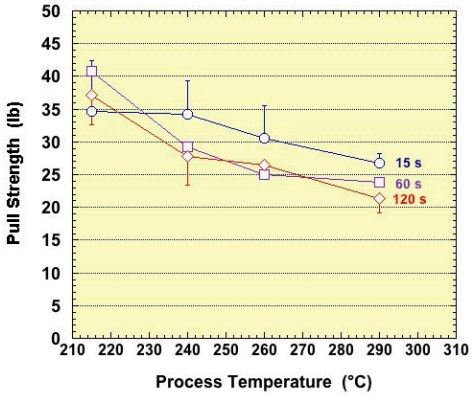
- The failure mode analysis (FMA) was initially compiled using all three fracture surface types:
  - Solder failure
  - Thin film delamination
  - LTCC divot



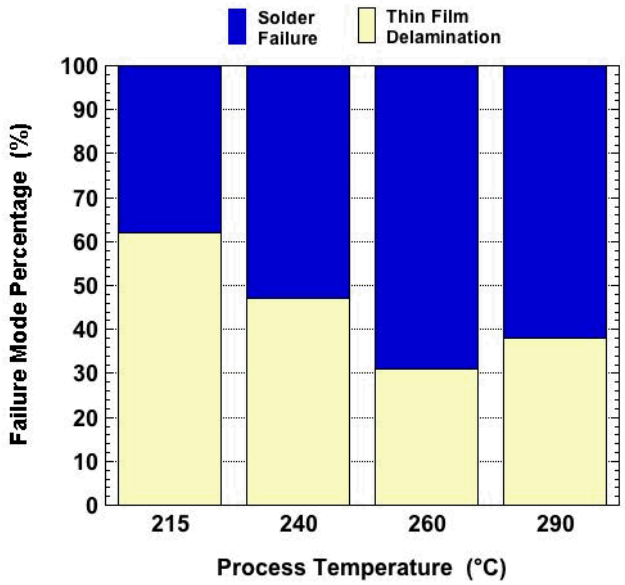


Results and Discussion

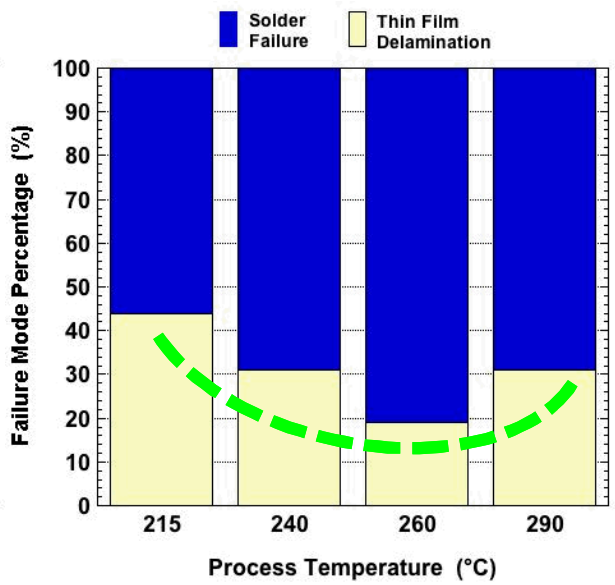
- **The LTCC divot failures appeared to be a random occurrence.**
  - **The LTCC divot failures were equally divided between the other two modes.**
  - **A similar trend was observed for all three process times.**



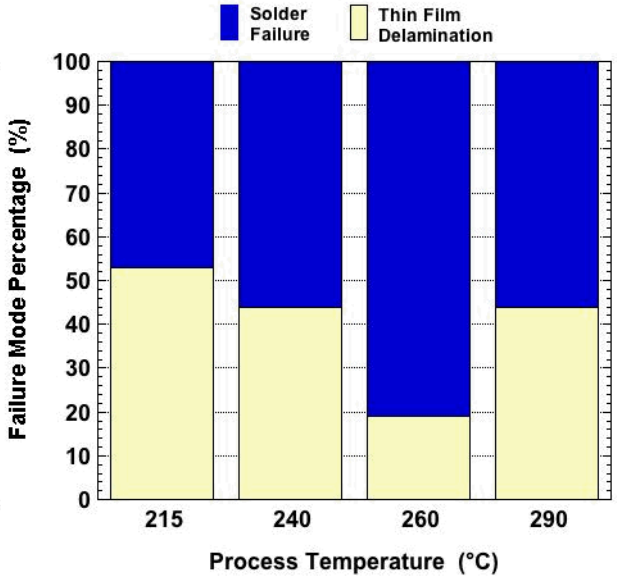
15 s



60 s

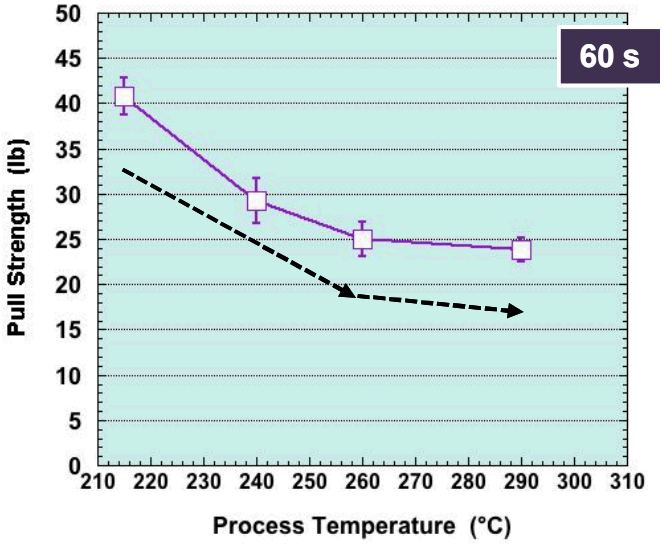


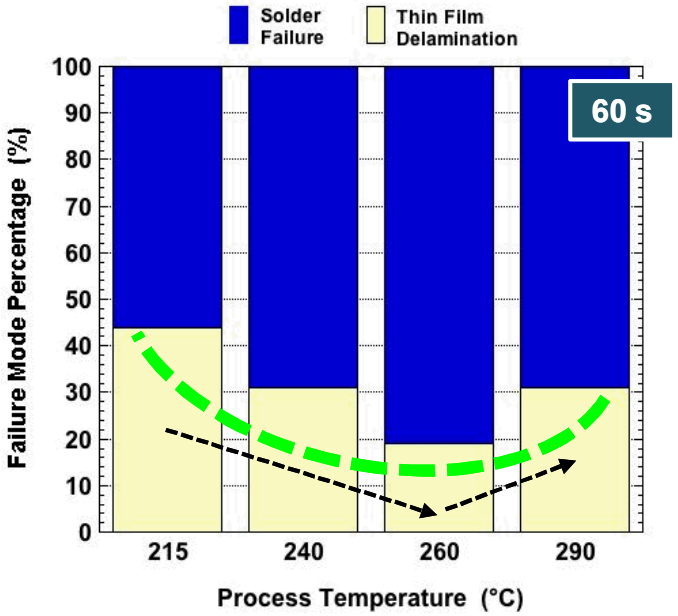
120 s



Results and Discussion

- **A correlation appeared between pull strength and failure mode frequency for 215°C – 260°C; *it broke down for 260°C – 290°C*.**





- **215°C – 260°C: Strength decrease … solder failures increase.**

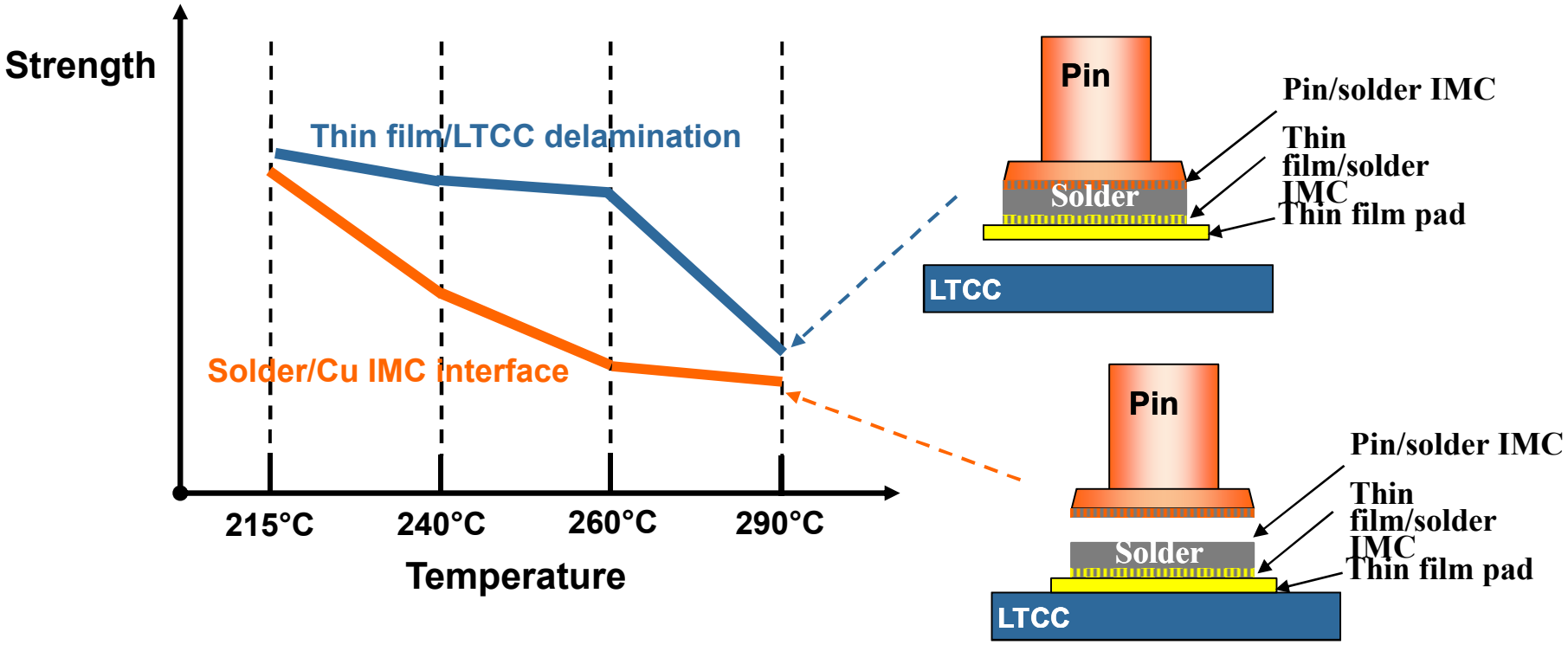
  Weakening of one or more of these individual structure(s):
  (a) solder/Cu IMC; … (b) solder/Pt IMC; or … (c) bulk solder

- **260°C – 290°C: Strength decreased *slightly* … delamination failures increase.**

  Higher process temperature potentially weakened the Ti / LTCC interface.

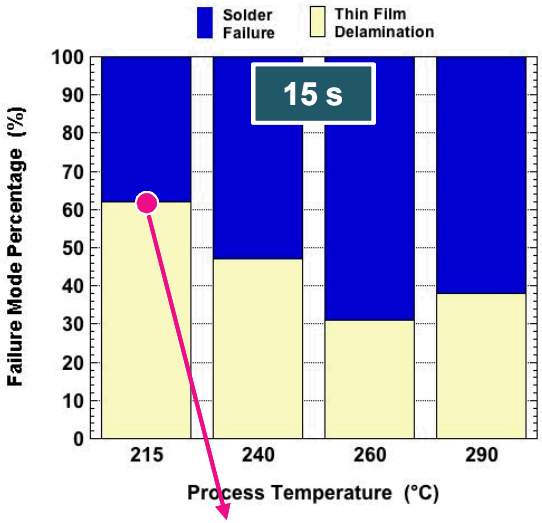
Results and Discussion

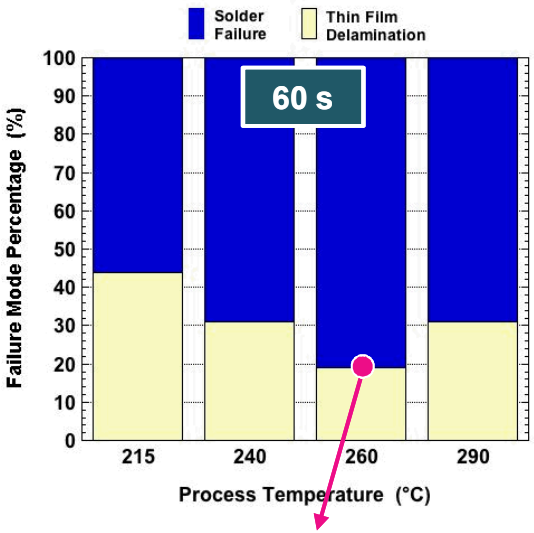
- The FMA begins by understanding that the solder joint is a multi-component system of several potential failure points.

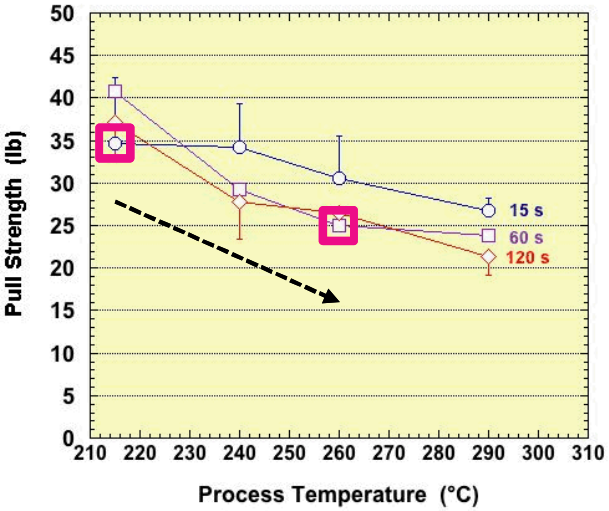


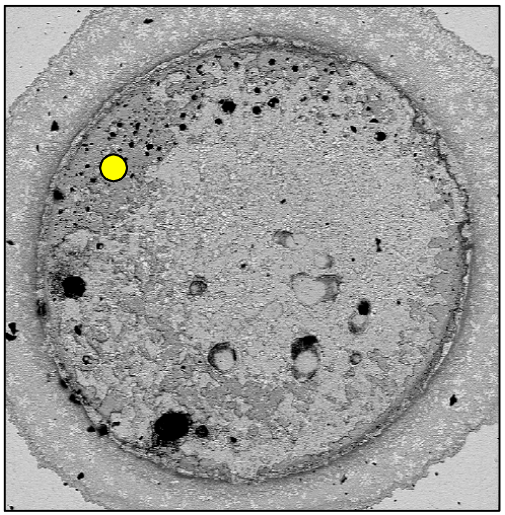
- The increase of thin film delaminations between 260°C and 290°C was due to a weakening of the Ti / LTCC interface *relative to* the solder / Cu IMC interface.
- The Ti / LTCC interface started to impact strength between 260 – 290°C.

Results and Discussion

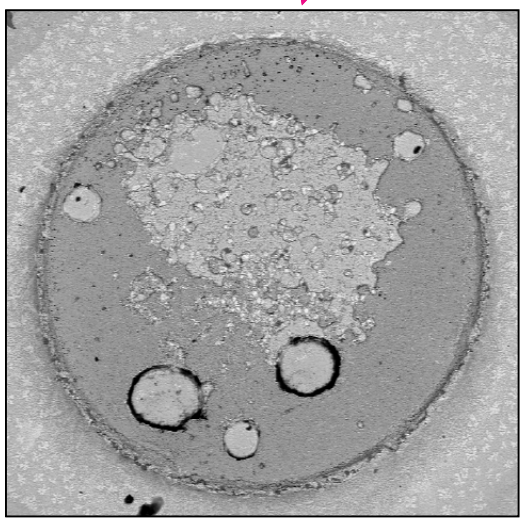








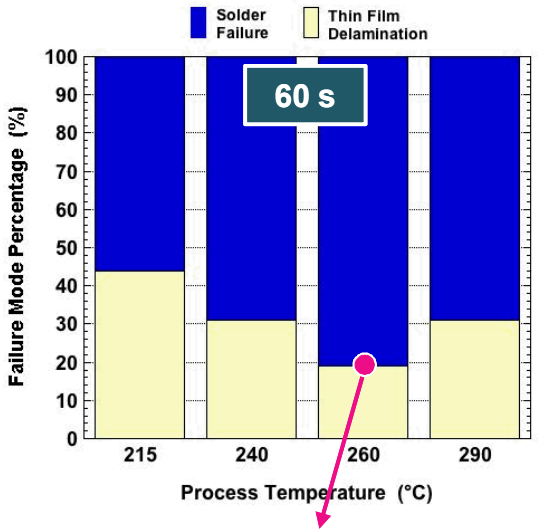
3291002; 215°C, 15 s

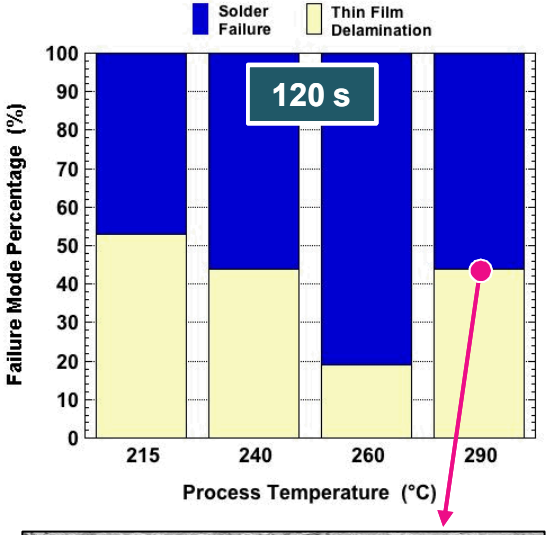


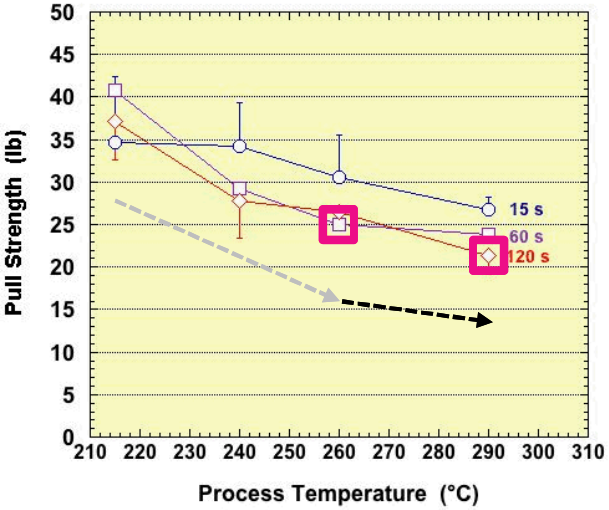
3251008; 260°C, 60 s

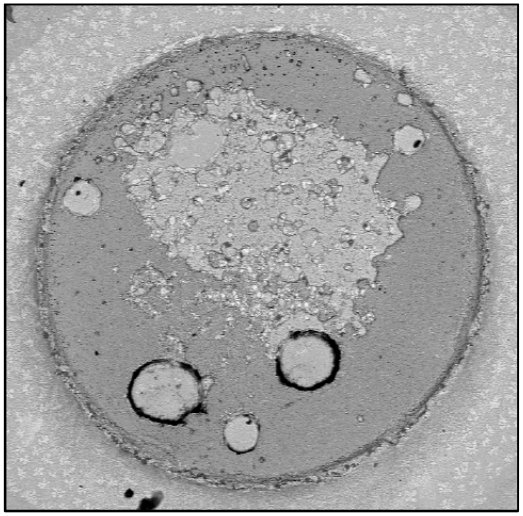
The decrease of pull strength was caused by the increased presence of failure associated with the solder / Cu IMC layer (yellow circle).

Results and Discussion

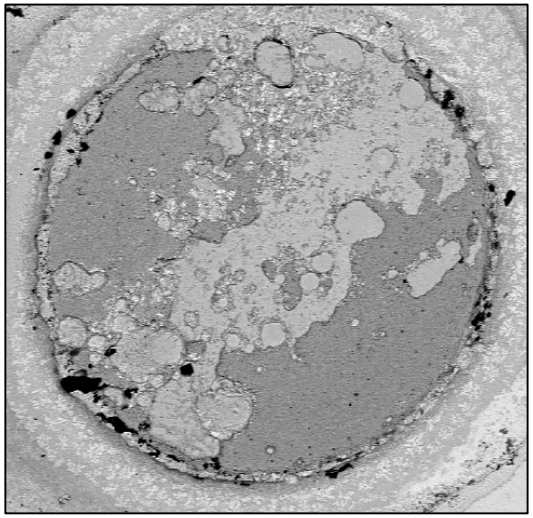








3251008; 260°C, 60 s



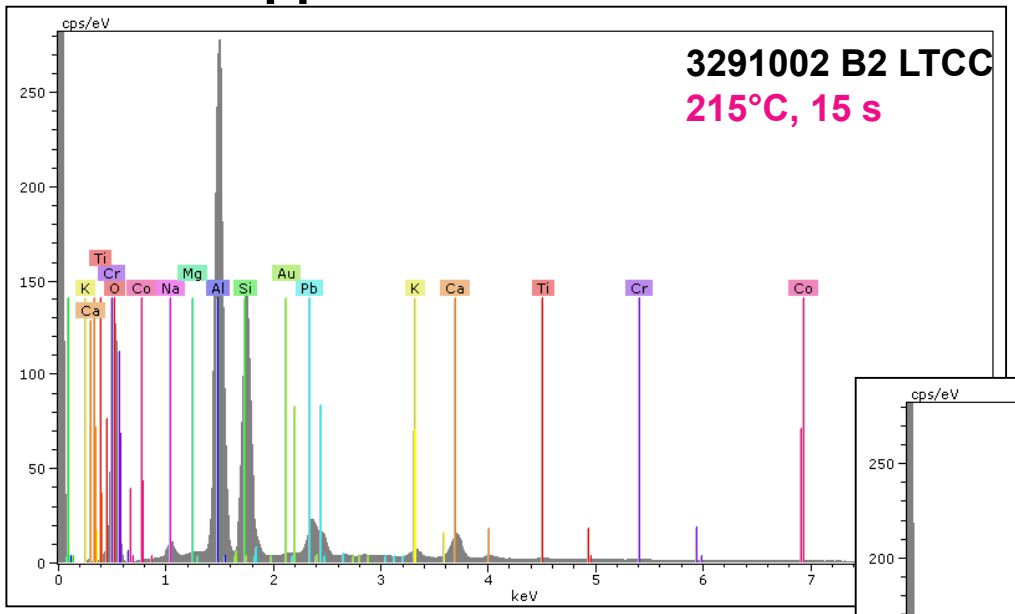
3291010; 290°C, 120 s

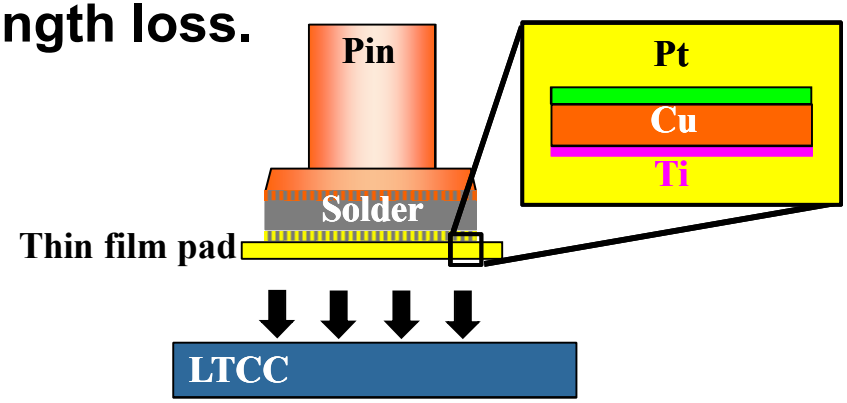
The area extent of the solder/Cu IMC failure stayed-the-same, or decreased slightly, as the pull strength decreased, slightly.

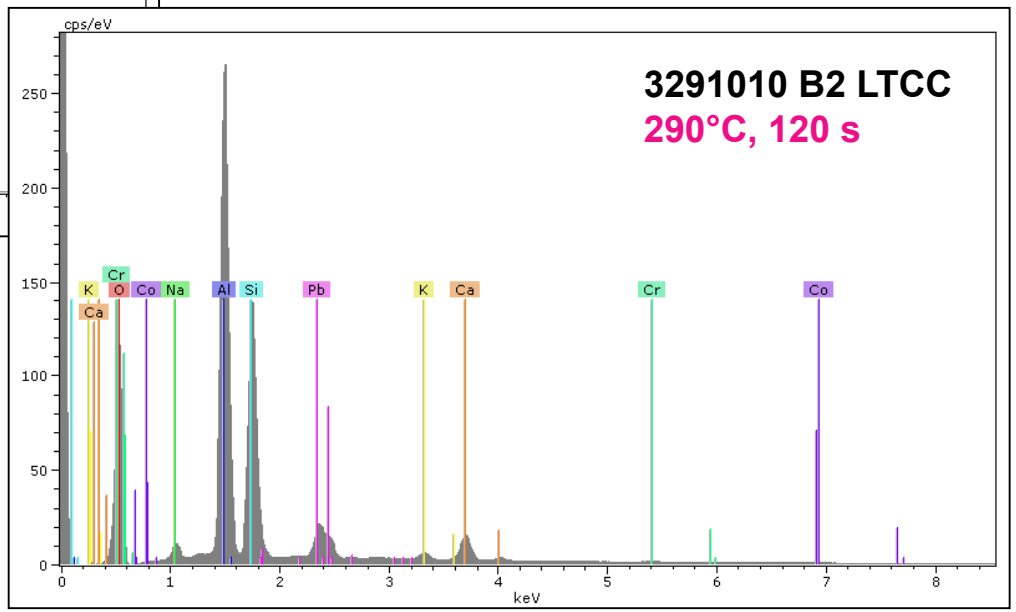
Thus, it appeared that the weakening of the Ti / LTCC interface, *relative to* the strength of the solder / Cu IMC interface, was beginning to impact overall joint strength.

Results and Discussion

- SEM and EDX techniques were used to identify a root-cause of the apparent Ti/LTCC interface strength loss.





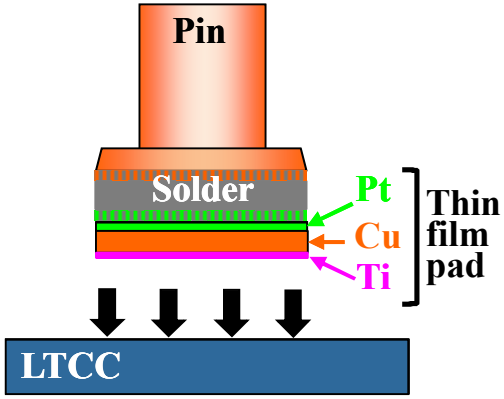


There were no distinguishable differences between the chemistries of the LTCC fracture surfaces.

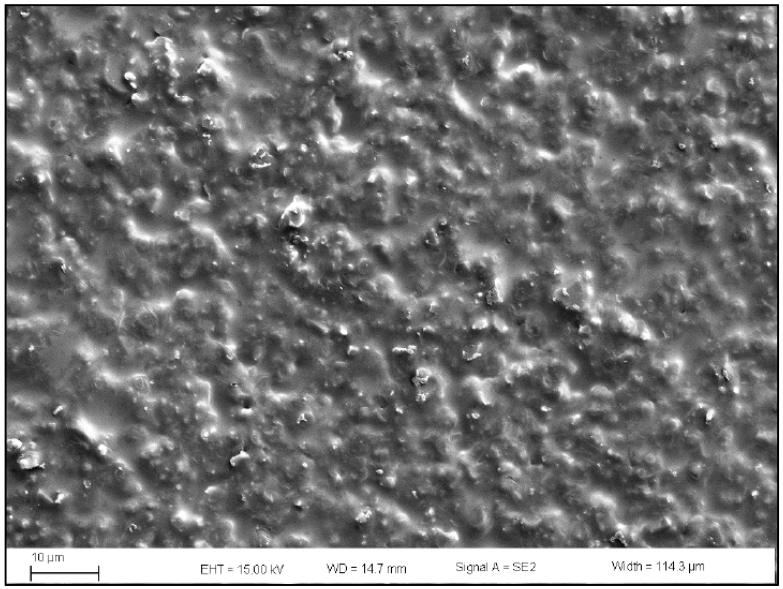
A EDX analysis was not performed on the surface of the 260°C, 60s sample.

Results and Discussion

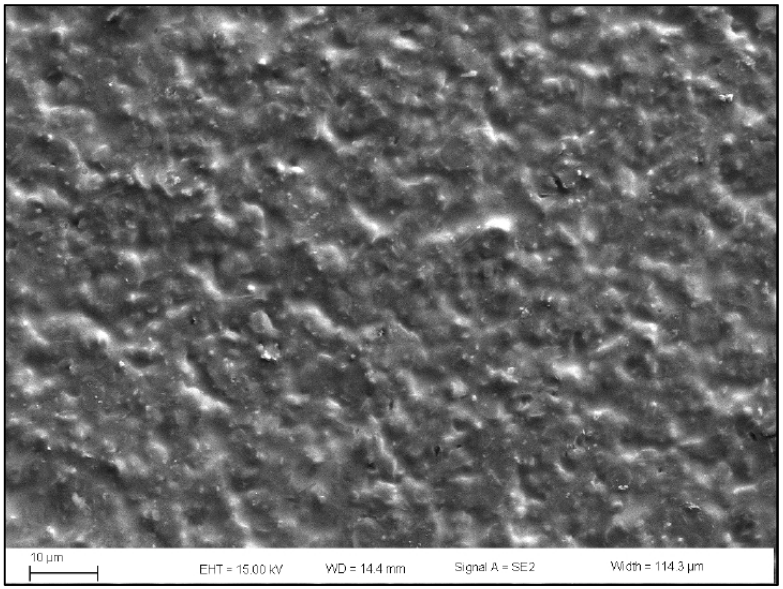
- The LTCC fracture surface created by the thin film delamination was examined by SEM for changes that would correlate with the pull strength behavior.
  - No distinguishable differences were identified between the two conditions.



3291002 B2 LTCC: 215°C, 15 s

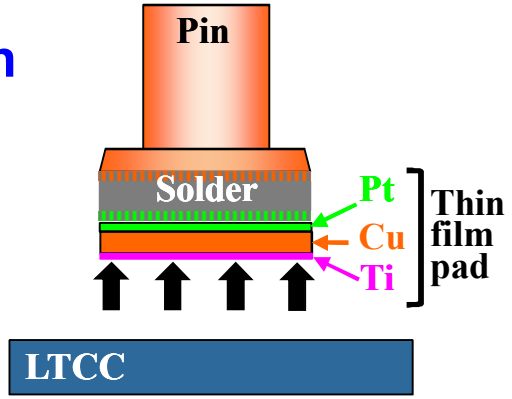


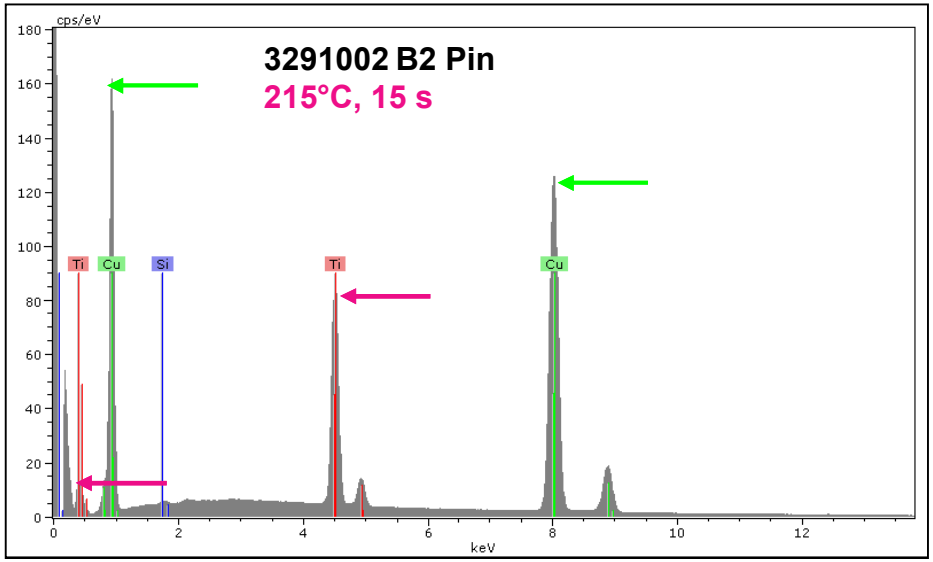
3291010 B2 LTCC: 290°C, 120 s

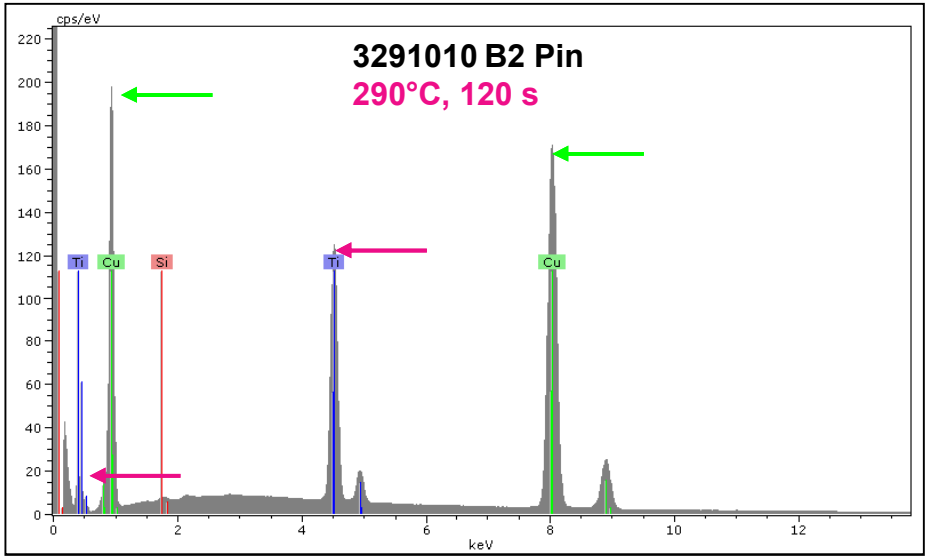


Results and Discussion

- The EDX analysis spectra that were obtained from the pin side of the thin film delamination failure mode could not detect a difference in the fracture surface chemistry.

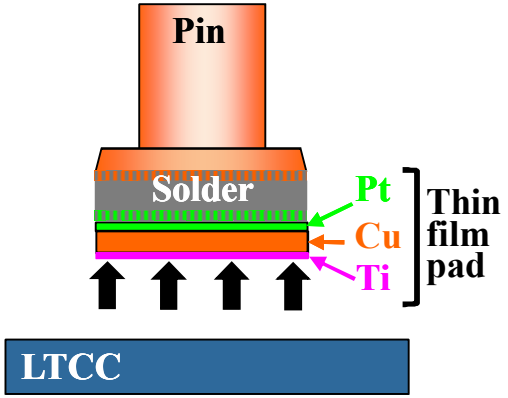




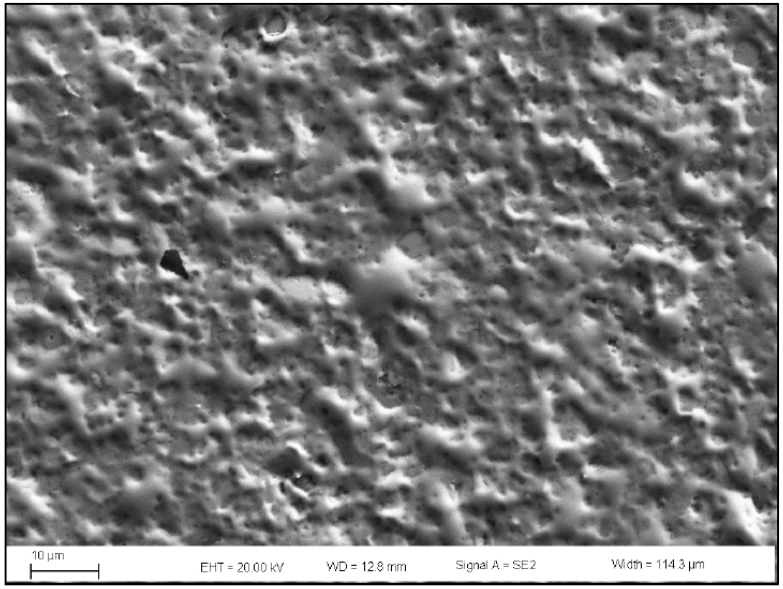


Results and Discussion

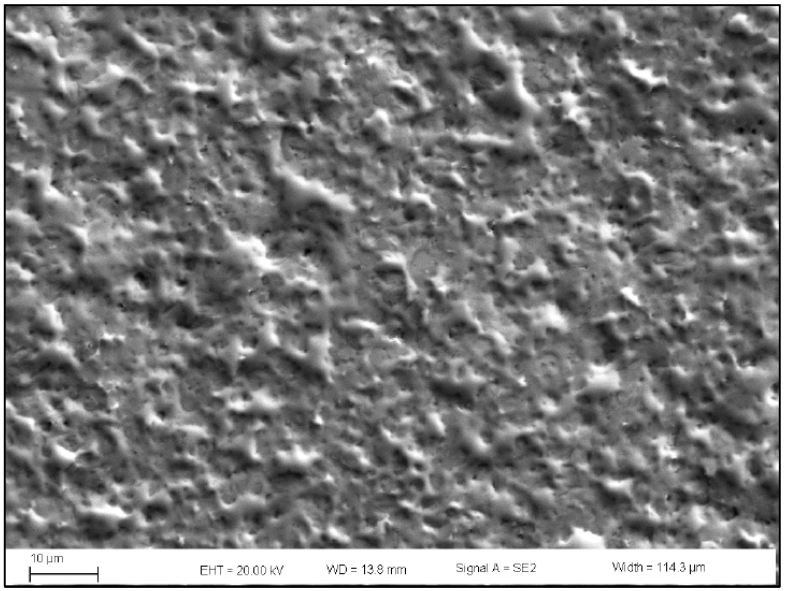
- The SEM analyses of the fracture surfaces were likewise inconclusive with respect to identifying difference in the fracture surface morphology between the two conditions.



3291002 B2 LTCC: 215°C, 15 s

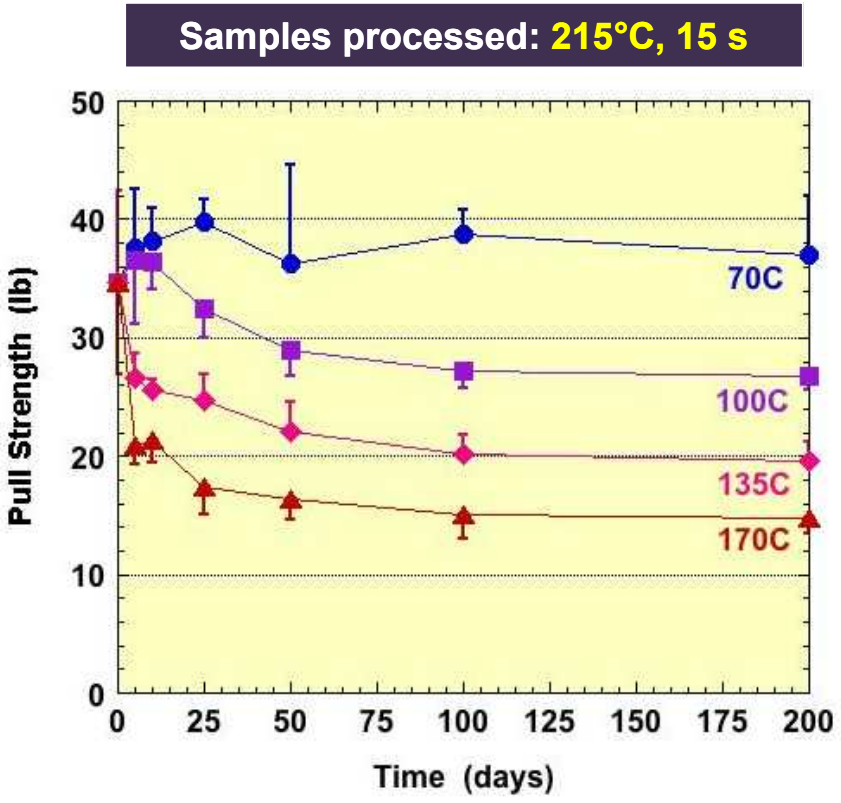


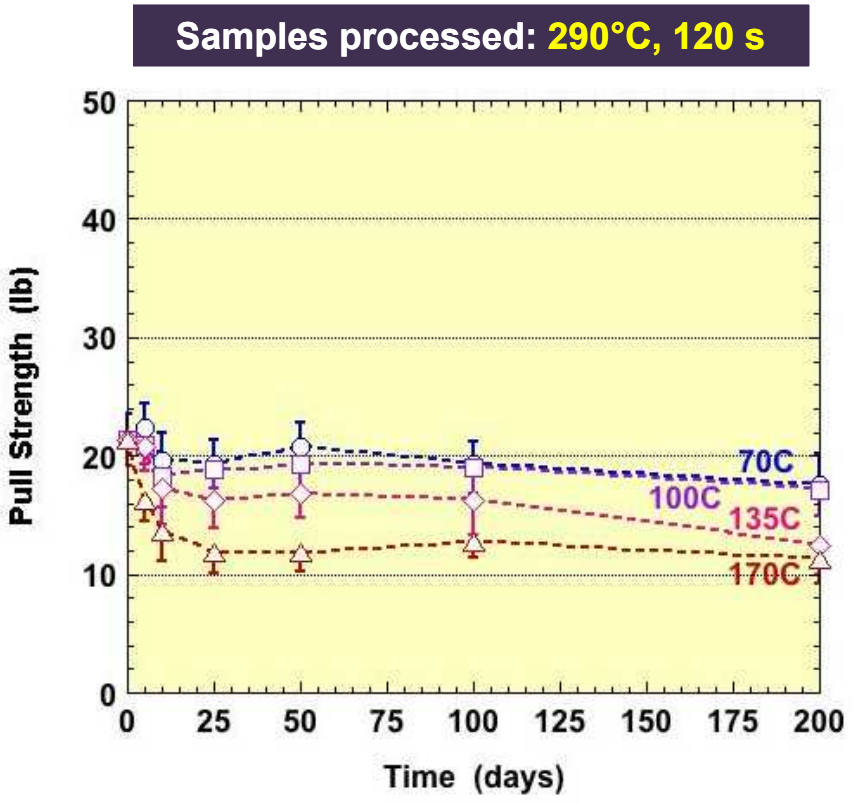
3291010 B2 LTCC: 290°C, 120 s



Results and Discussion

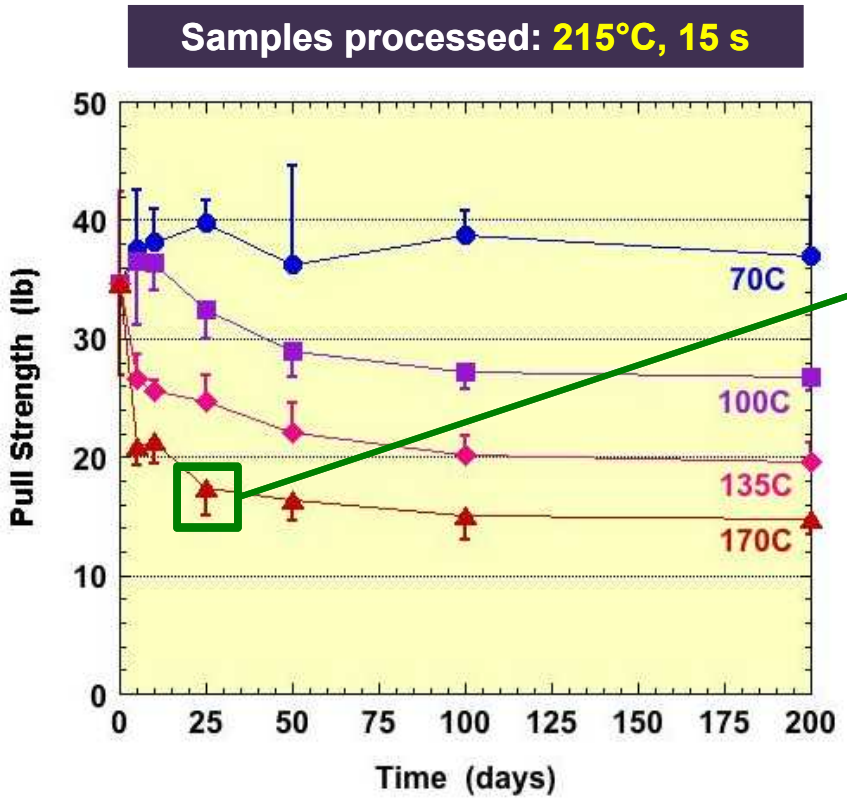
- **The pull test data were analyzed for the Sn-Pb solder joints that were subjected to the solid-state aging heat treatments.**

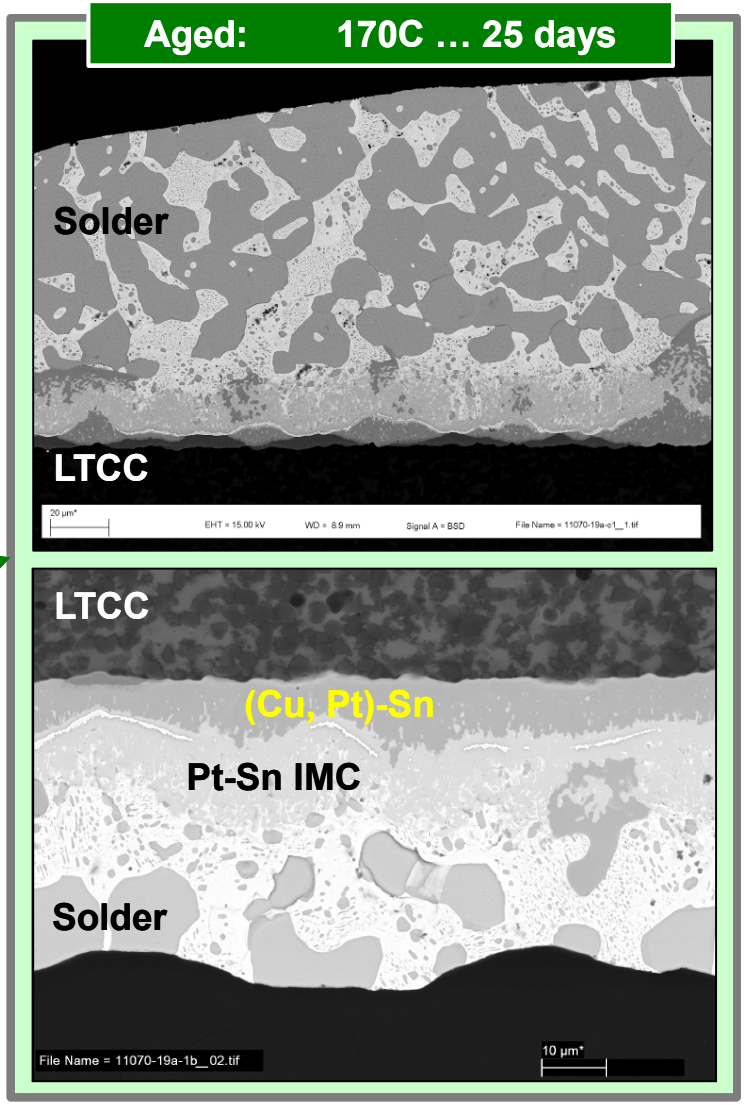




Results and Discussion

- In spite of, what is predicted to be a complete conversion of Cu to (Cu, Pt)-Sn IMC, the joint retained adequate strength.





Summary

- A pin pull test was developed to support the implementation of thin film conductors for hybrid microcircuit (HMC) products.

- The present investigation examined the thin film system …

  0.20 Ti - 4.0 Cu - 2.0 Pt - 0.25 Au *(μm)*

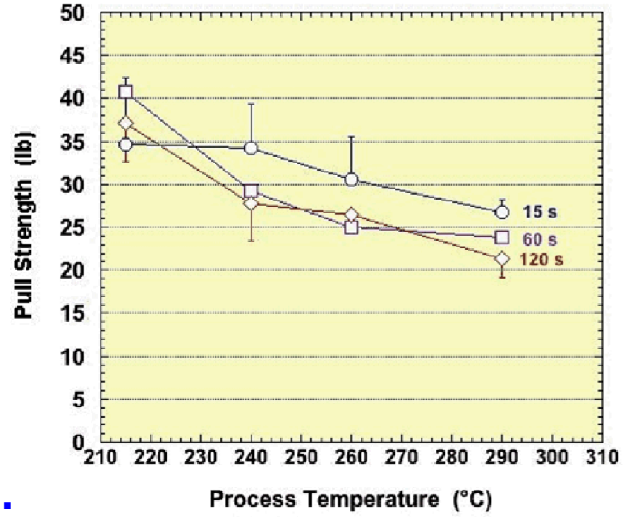
  … on low-temperature, co-fired ceramic (LTCC) substrates.

- The test was used to evaluate the process margins associated with making 63Sn-37Sn solder joints to the Ti-Cu-Pt-Au film.
  - Peak temperatures: 215°C, 240°C, 260°C, and 290°C
  - Time at peak temperature: 15, 60, and 120 s

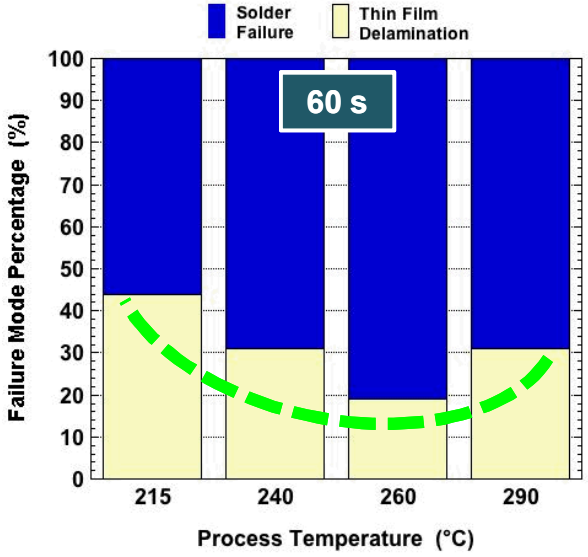
(con't)

Summary

- **There was a general degradation of pull strength with the severity of the process conditions.**
  - **Process temperatures: The pull strength decreased with increasing process temperature.**
  - **Process time: Pull strength declined the most between 15 s and either 60 s or 120 s.**



- **The failure mode analysis was comprised of two serial processes:**
  - **215 C – 260 C: An increased presence of the solder / Cu IMC layer failure mode correlated with a loss of pull strength.**
  - **260 C – 290 C: The increased presence of the thin film delamination mode, *although not affecting pull strength,* signaled the start of degradation to thin film adhesion.**



Thin Film Systems: Studies Underway

- **The following systems are under study. The objective of these investigations was to examine alternative adhesion layers.**
  - **0.1 Si – 0.1 Ti – 4.0 Cu – 2.0 Pt – 0.375 Au (μm)**
    - **Liquid-state aging (process window) for the 63Sn-37Pb and Pb-free (SAC305) solders.**
    - **Solid-state aging for the 63Sn-37Pb alloy, only.**
  - **0.2 Zr – 4.0 Cu – 2.0 Pt – 0.250 Au (μm)**
    - **Liquid-state aging (process window) for the 63Sn-37Pb and Pb-free (SAC305) solders.**
  - **0.2 $Ti_{0.3}W_{0.7}$ – 4.0 Cu – 2.0 Pt – 0.375 Au (μm)**
    - **Liquid-state aging (process window) for the 63Sn-37Pb solder.**
    - **Solid-state aging for the 63Sn-37Pb alloy.**

Thin Film Systems: Studies Underway

- 0.2 Cr – 4.0 Cu – 2.0 Pt – 0.250 Au (μm)
  - Liquid-state aging (process window) for the 63Sn-37Pb and Pb-free (SAC305) solders.

- The sample fabrication and pull tests are completed for the Si – Ti – Cu – Pt – Au and Cr – Cu – Pt – Au systems.
- The sample fabrication is competed; pull tests are underway for the Zr – Cu – Pt – Au system.
- The Ti/W – Cu – Pt – Au LTCC substrates were recently received (July 2013) are are being staged for pull test sample fabrication.