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Reliability Analysis of a Pin-in-Hole Solder Joint by Computational Modeling

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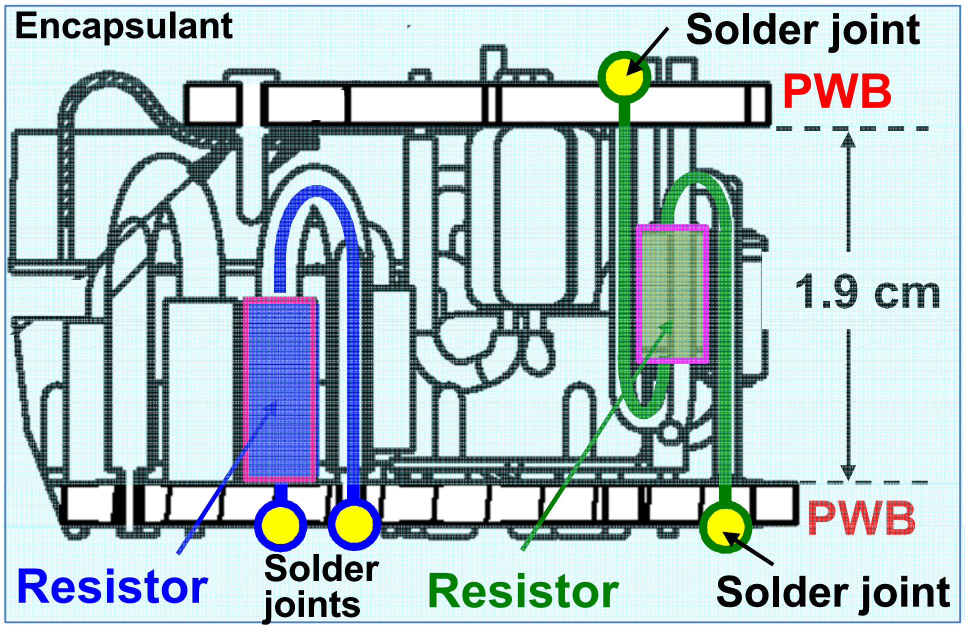
Problem

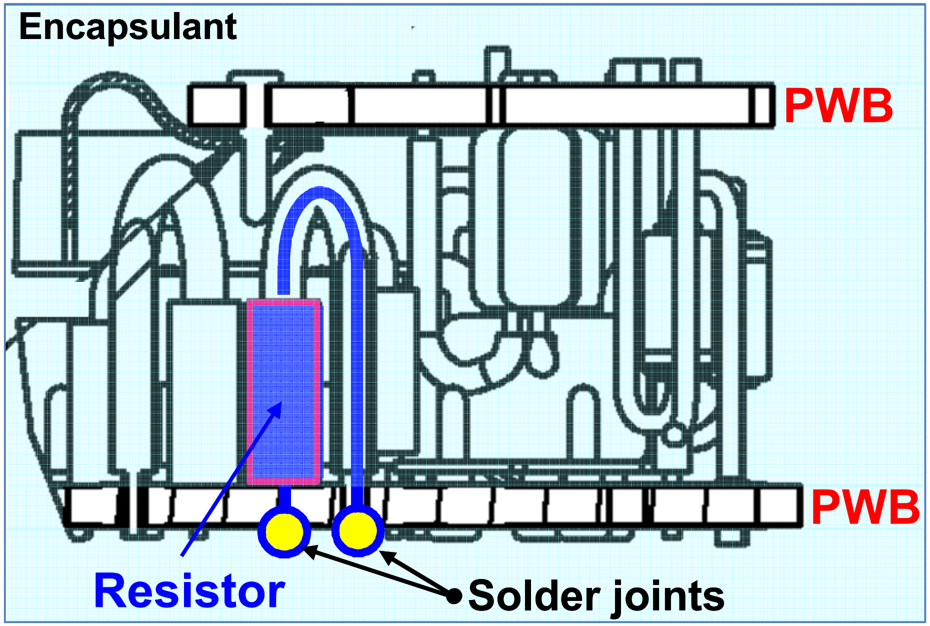
- An electronic assembly was built by soldering *and encapsulating* components between two, printed wiring boards (PWBs).



- During the course of inspection, poor hole fill was observed for several solder joints (red circle).
- The concern arose that the defective solder joints would not meet long-term reliability requirements.

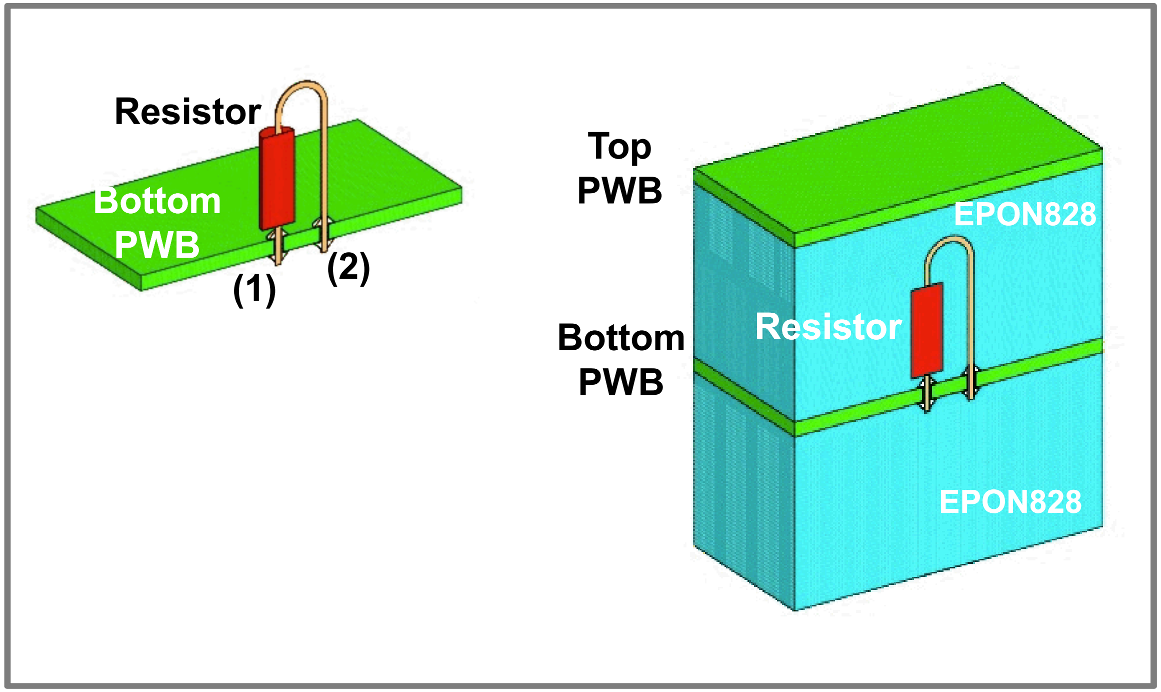
Approach

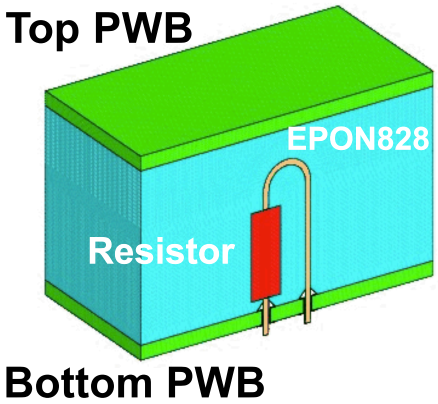
- The primary mode of solder joint degradation was **thermal mechanical fatigue (TMF)** caused by temperatures fluctuations.
- An empirical study was not feasible; therefore, **computational modeling** was used to predict the reliability of the solder joints.
- The **blue resistor configuration** was most susceptible to TMF.



Computational Model

- A finite element model was built-up of the solder joint geometry.

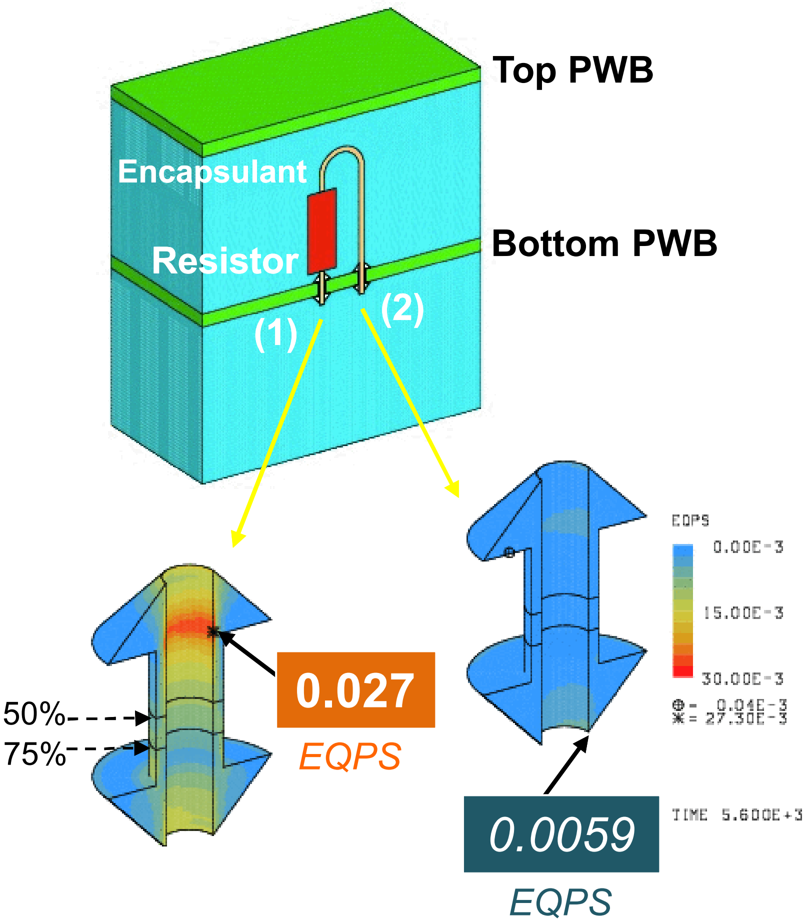


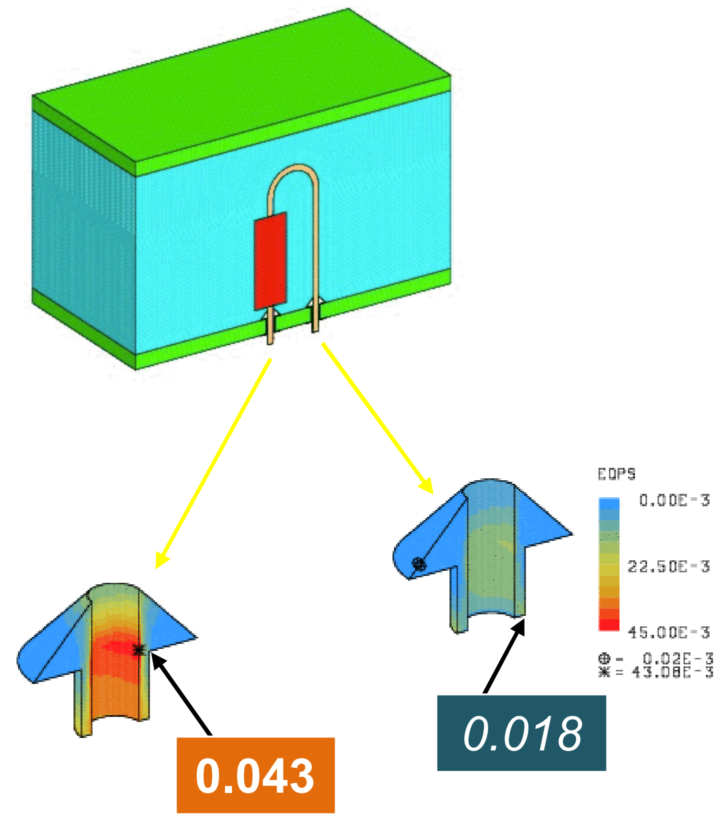


- A special case was evaluated whereby the encapsulant was absent from under the bottom PWB – e.g., instance of a void.

Computational Model

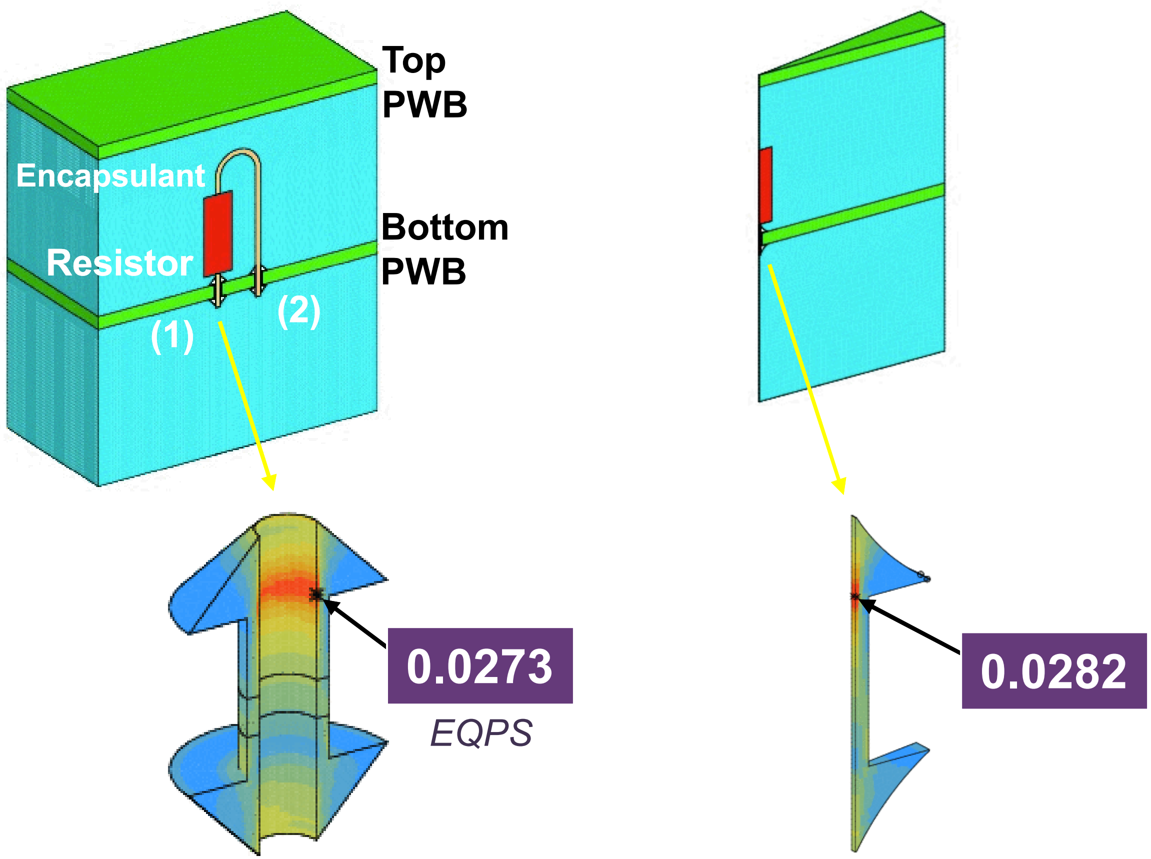
- Scoping analyses determined that solder joint (1) experienced the greater extent of equivalent plastic strain (EQPS) during TMF in both of the limiting cases.





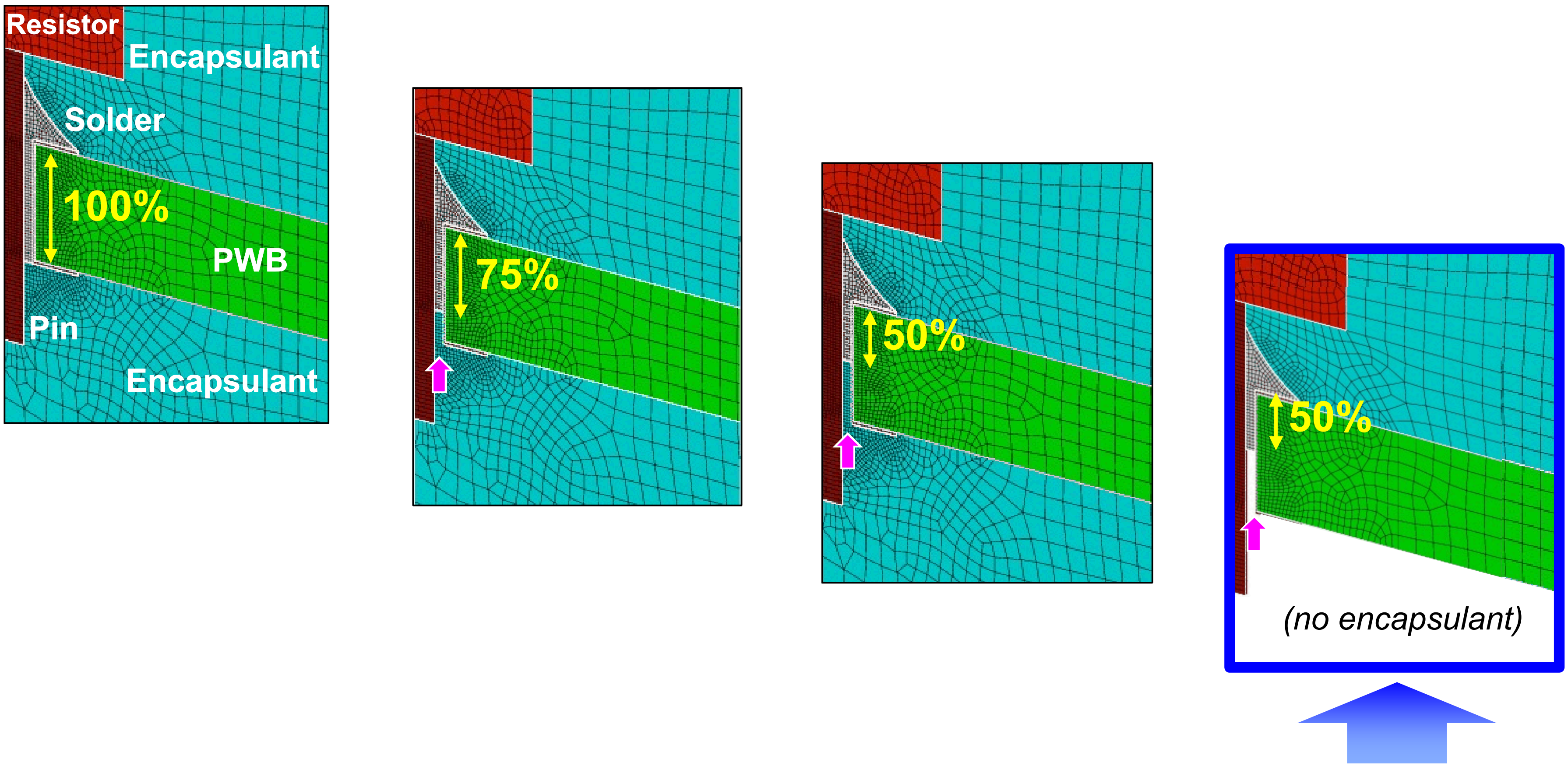
Computational Model

- Cylindrical symmetry of the single joint allowed for reducing the finite element model down to a "10° pie slice" configuration.



Computational Model

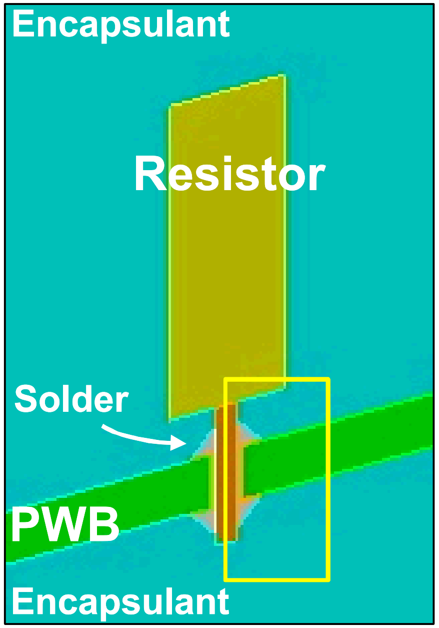
- The four finite element configurations are shown below:

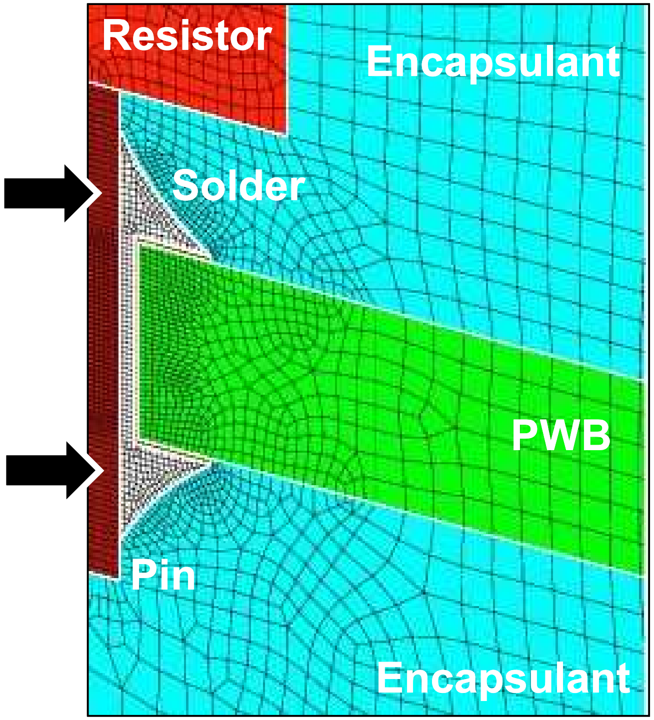


- **The worst-case scenario had 50% hole fill as well as encapsulant missing from underneath the bottom PWB.**

Results

- The baseline condition was **"full fillets, both sides:"**



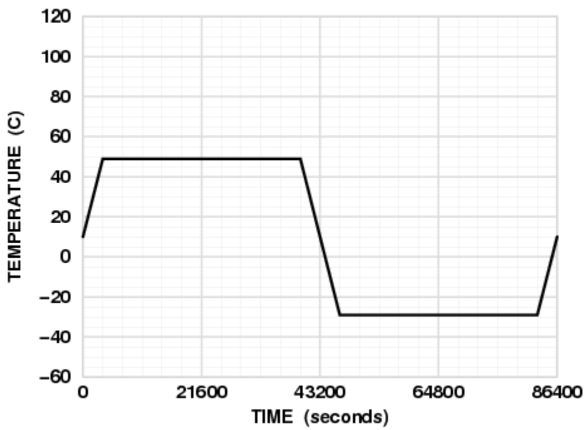


Service Environment

- The **service environment** was comprised of two transportation (and handling) segments #1 and #2, and a (final) use segment:

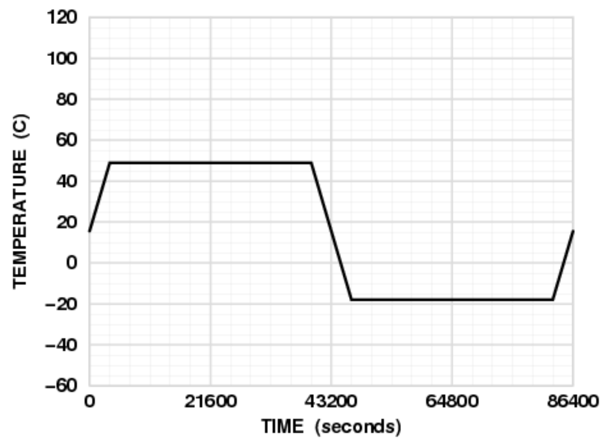
Transport – #1

-29°C/49°C; 15 cycles; 24 hour period



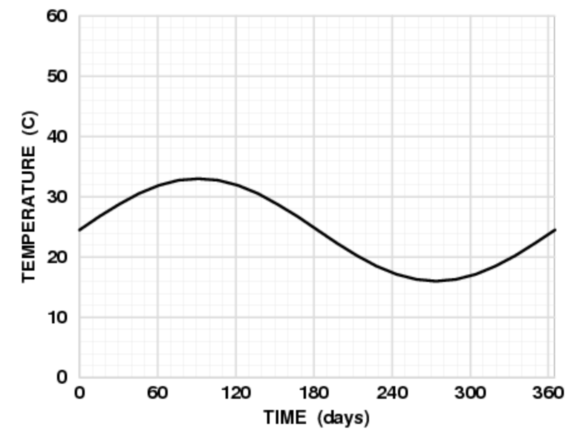
Transport – #2

-18°C/49°C; 15 cycles; 24 hour period



Use

16°C/33°C; 60 cycles 1 year period



- **High-reliability electronics are subjected to acceptance testing prior to being placed into service, *which also consumes TMF life*.**

Acceptance, Environmental, and Destructive Tests

- There were three test-plus-service *thermal cycling* conditions to which the assemblies could experience TMF:

  1. Acceptance test + Service (3 segments)
  2. Acceptance test + Environmental test ("E-test") + Service
  3. Acceptance test + Destructive test ("D-test")

  - The application of the tests vis-à-vis product placed into service:
    - Acceptance test: *100% of product* entering service
    - E-test: *x% of product entering service*
    - D-test: *0% of product that enters service*

- The test parameters are listed below:

  - Acceptance test: -32°C/60°C; 2 cycles; 4 hour holds; 12°C/min max.
  - E-test: -32°C/60°C; 5 cycles; 4 hour holds; 12°C/min max.
  - D-test: -32°C/60°C; 26 cycles; 4 hour holds; 12°C/min max.

Percentage of TMF Life Used-up

- The extent of TMF degradation is expressed as the percentage of **total fatigue life used-up** that is calculated by “Miner’s Rule”.

Number of cycles under the condition #1, $N_{\#1}$

Model predicts cycles to failure, $N_{f,\#1}$

Percentage of fatigue life that is “used-up:” $N_{\#1}/ N_{f,\#1} \times 100$

Percentage of Total Fatigue Life Used-up =

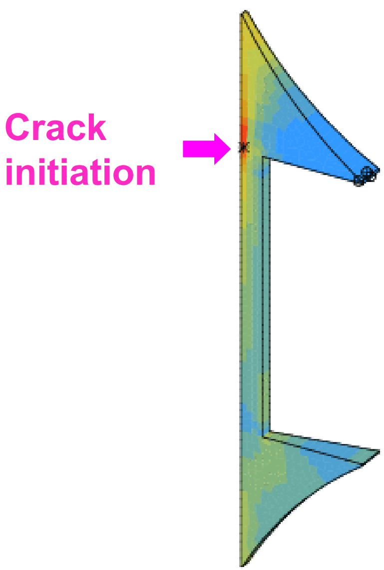
$$\left[(N_{\#1}/ N_{f,\#1}) + (N_{\#2}/ N_{f,\#2}) + (N_{Use} / N_{f,use}) \right] \times 100$$

- The “f” refers to the **failure criterion**.

Failure Criteria

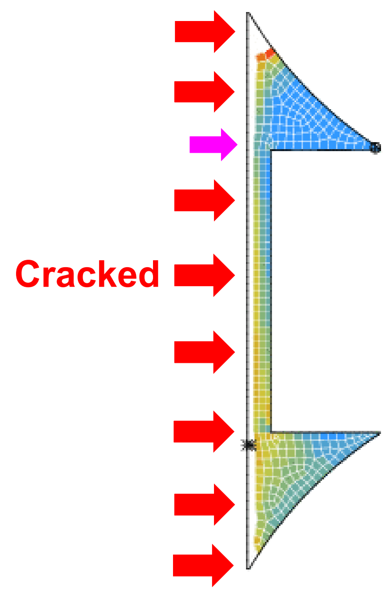
- The extents of TMF deformation and crack propagation were predicted by the "Crack Simulation Model" (CSM).
- The two failure criteria, crack initiation and 100% crack (electrical open) are exemplified by the *use segment: 16° C/33° C; 1 year cycle:*

Cycles to crack initiation



140,000 cycles

Cycles to 100% crack



390,000 cycles

Results

- The percent of TMF life used up by the **Service Conditions**

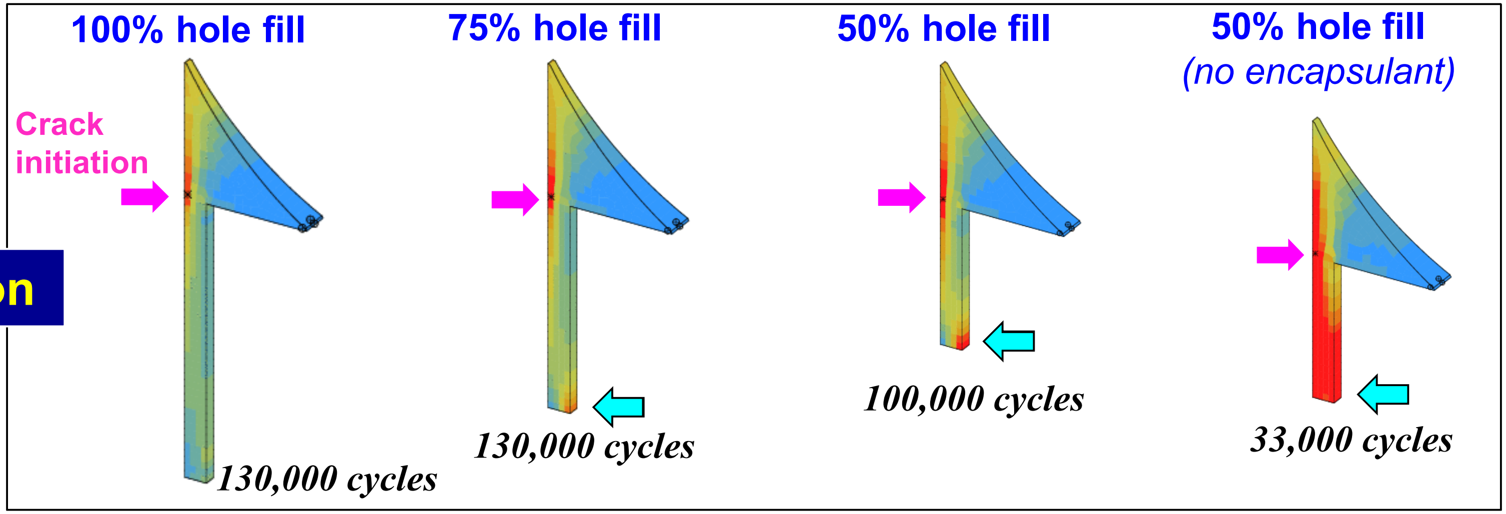
Service = Transp. #1 + Transp. #2 + Use (60 yrs)

Through-Hole Configuration	Percent of Life Used to Crack Initiation (%)	Percent of Life Used to Complete Crack (%)
Full fillet, both sides	*0.66*	*0.18*
100% hole-fill	**0.65**	**0.20**
75% hole-fill	**0.73**	**0.28**
50% hole-fill	**0.94**	**0.33**
50% hole-fill; ***No bottom encapsulant***	**3.9**	**1.7**

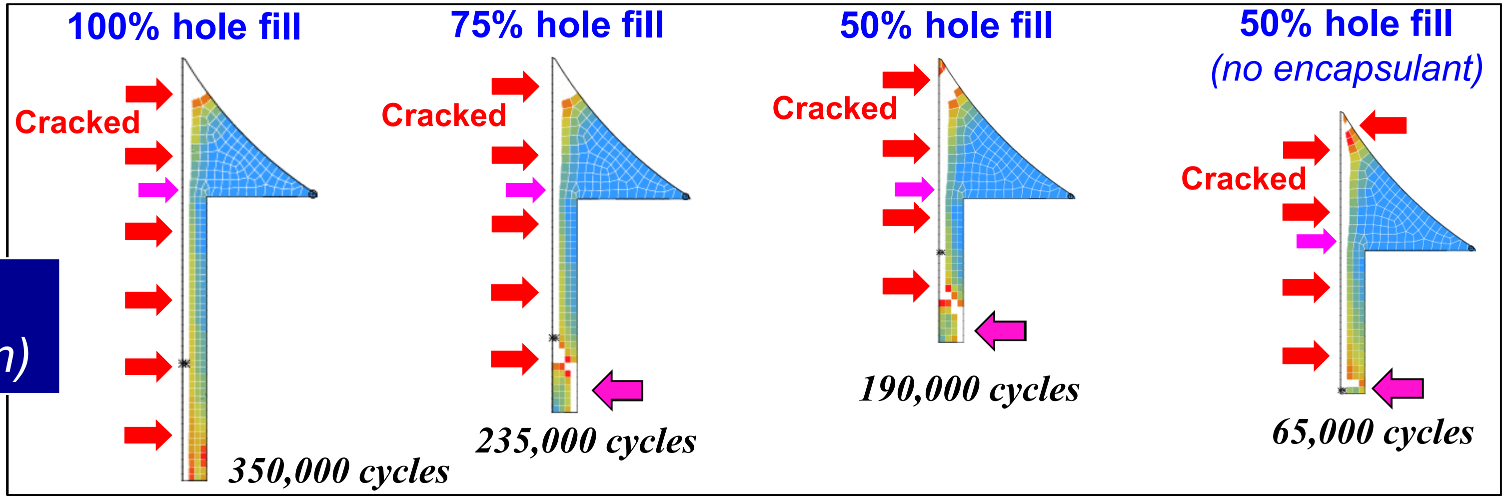
Results

- The model predictions are shown of **TMF deformation** and **crack propagation** for the *use segment: 16° C/33° C; 1 year cycle*.

Crack initiation



100% crack
(Electrical open)



Results

- **The percent of TMF life used up by the worst-case for fielded joints:**

Acceptance test* + *E-test* + *Service *(Transp. #1 + Transp. #2 + Use)*

Through-Hole Configuration	Percent of Life Used to Crack Initiation (%)	Percent of Life Used to Complete Crack (%)
Full fillet, both sides	*1.3*	*0.33*
100% hole-fill	**1.2**	**0.34**
75% hole-fill	**1.4**	**0.47**
50% hole-fill	**1.7**	**0.53**
50% hole-fill; *No bottom encapsulant*	**6.7**	**2.7**

Results

- **The D-test is too benign to represent the long-term reliability of the assembly if the assumed failure mode is solder joint TMF.**

Acceptance test + D-test

Through-Hole Configuration	Percent of Life Used to Crack Initiation (%)	Percent of Life Used to Complete Crack (%)
Full fillet, both sides	*2.5*	*0.61*
100% hole-fill	**2.2**	**0.55**
75% hole-fill	**2.8**	**0.75**
50% hole-fill	**2.9**	**0.78**
50% hole-fill; *No bottom encapsulant*	**11**	**3.7**

Summary

- Built-up printed wiring assemblies were observed to have solder joints that experienced insufficient hole-fill.
- The reliability of these solder joints against thermal mechanical fatigue (TMF) was predicted using a computational model.
- The computational model examined the combined effects of acceptance testing, E-test, transportation, as well as use.
- The failure criteria were:
  - Crack initiation
  - 100% crack (electrical open)
- The model predictions indicated that the defective solder joints would retain more-than-adequate reliability in the field.
- The E-test and D-test were not sufficiently severe to identify defects that could lead to infant mortality or latent failures, respectively, under the TMF failure mode.