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Experimental Validation of FE Combined Lifetime Modeling for Power Cycling Capability of a SiC Power Module

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Motivation

- Empirical lifetime models (e.g., LESIT, CIPS2008, etc.) may not suit for description lifetime of packaging technology in state-of-art.
- Analytic approach cannot explicitly consider complexity of the real power module (geometry, material, test condition…)
- Finite-Element-Analysis (FEA) of power cycling test (PCT) enables calculating the mechanical indicators for end-of-life with more detailed physical information

Goal

- Benchmark of extrapolation accuracy for empirical lifetime models vs. Combined FE lifetime models validated by power cycling test results.

Power Cycling Test

Setup

- Power module with sintered DTS and Cu-clips (manufactured by Schaeffler AG, former Vitesco)
- Dynamic calibration during PCT
- Three Runs in total:
  - Run I, Run II for modeling
  - Run III for validation

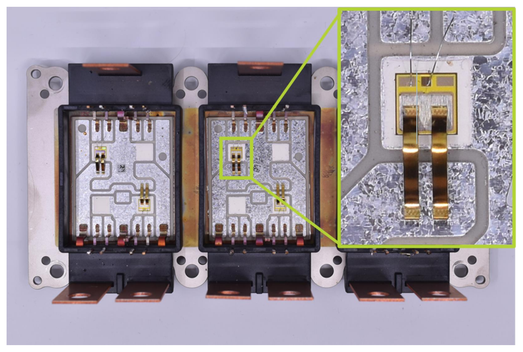


Figure 1

Power Cycling Test Conditions

Parameters	Run I	Run II	Run III
ΔT in °C	**130**	**120**	**95**
T_{mean} in °C (**constant**)	110	110	110
T_{max} in °C	175	170	155
T_{min} in °C	45	50	65
t_{on}/t_{off} in s (**constant**)	3/6	3/6	3/6
Remark	for modeling	for modeling	for evaluation

Table 1

Experimental Results

- Run III has the largest deviation of ΔT
- Hybrid failure mode is confirmed:
  - Top-side sinter degradation
  - Thin film delamination
- Almost complete top-side degradation only leads to 5% increase of forward voltage
  → redistribution of current

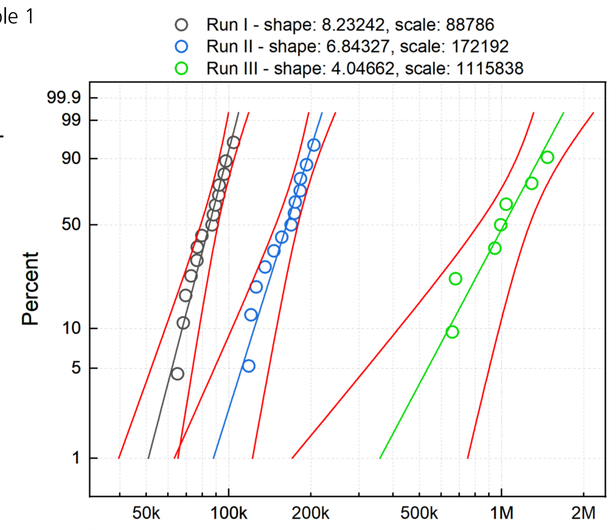


Figure 2

Lifetime Modeling and Prediction

Type	Approach	Equation
empiric	■ LESIT	$N_f = A \cdot \Delta T_j^{\alpha} e^{\frac{E_a}{R \cdot (T_{j,mean}+273.15)}}$
Combined FE	■ Coffin-Manson (plastic strain)	$N_f = C_1 (\Delta \varepsilon_{acc,pl})^{C_2}$
	■ Energy-based (plastic work)	$N_f = D_1 (\Delta W_{pl})^{D_2}$
	■ Critical Damage (CD) Hypothesis	$W_{cd} = N_f \cdot \Delta W_{pl} = f(T)$
	– Linear	$W_{cd} = a \cdot \Delta T + b$
	– Arrhenius-like	$W_{cd} = W_0 \cdot e^{\frac{E_a}{R \cdot (T_{j,max}+273.15)}}$

Table 2

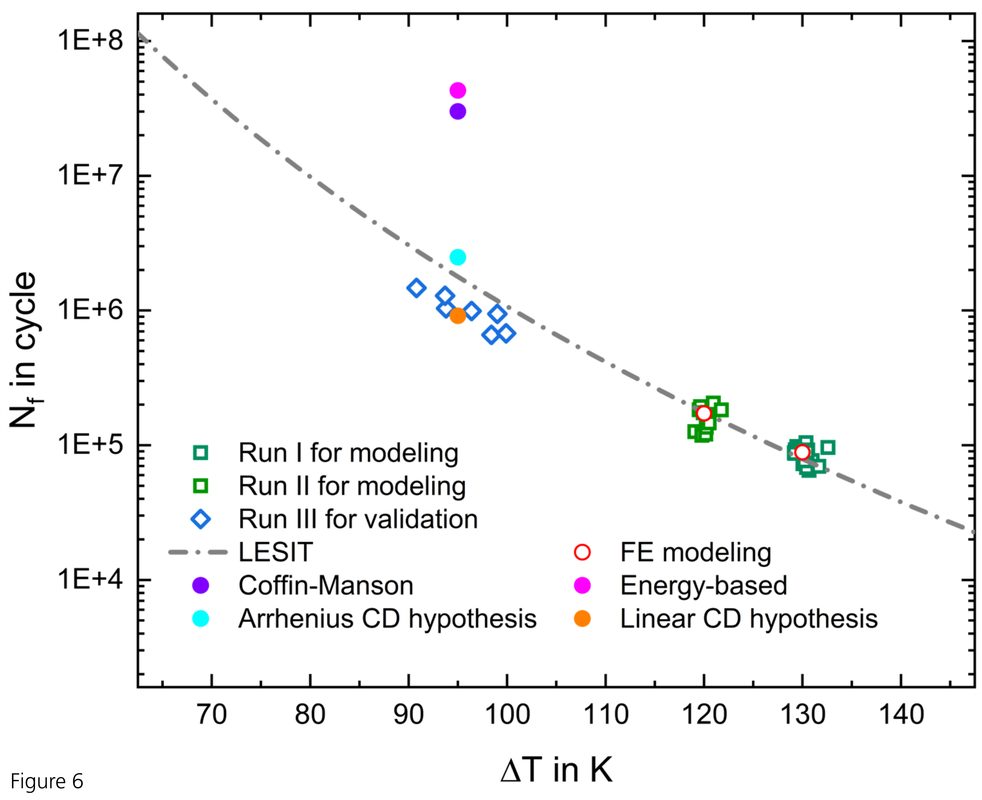


Figure 6

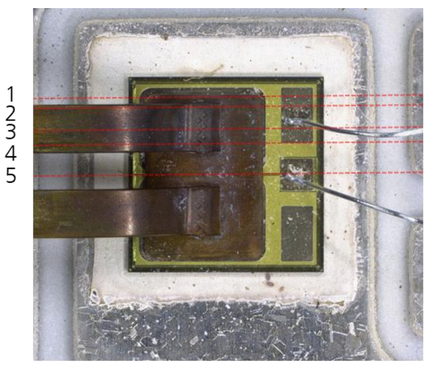
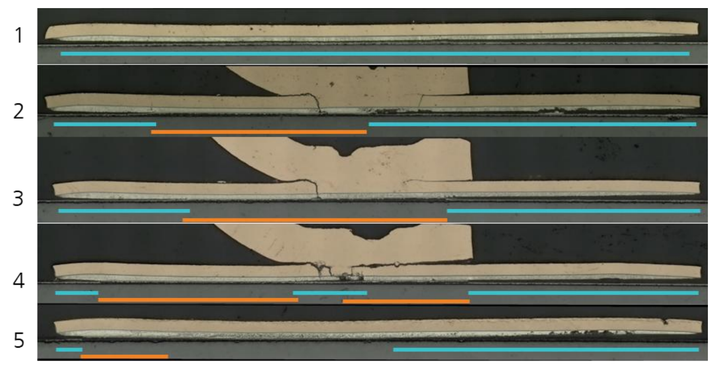


Figure 3



FE Modeling

- Detailed FE-modeling (electro-thermo-mechanical)
- Thermal calibration using cooling curve extracted from PCT experiment
- Parameterizing thermal properties
- Deviation within the error specified by AQG324
- Post-processing of FE model considers the hybrid failure mode
  - Acc. plastic strain increment
  - Acc. plastic work increment

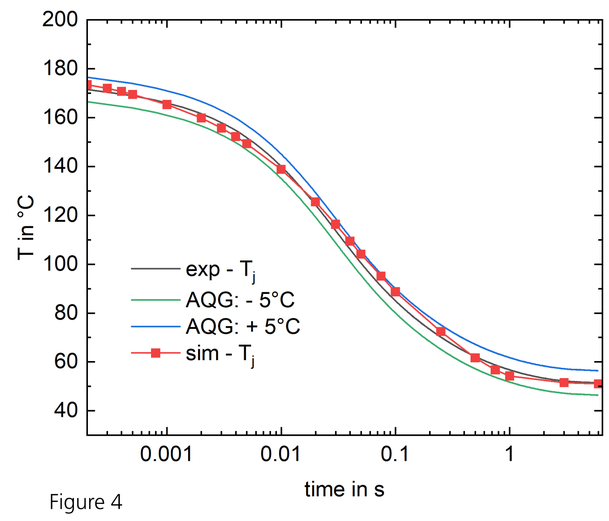


Figure 4

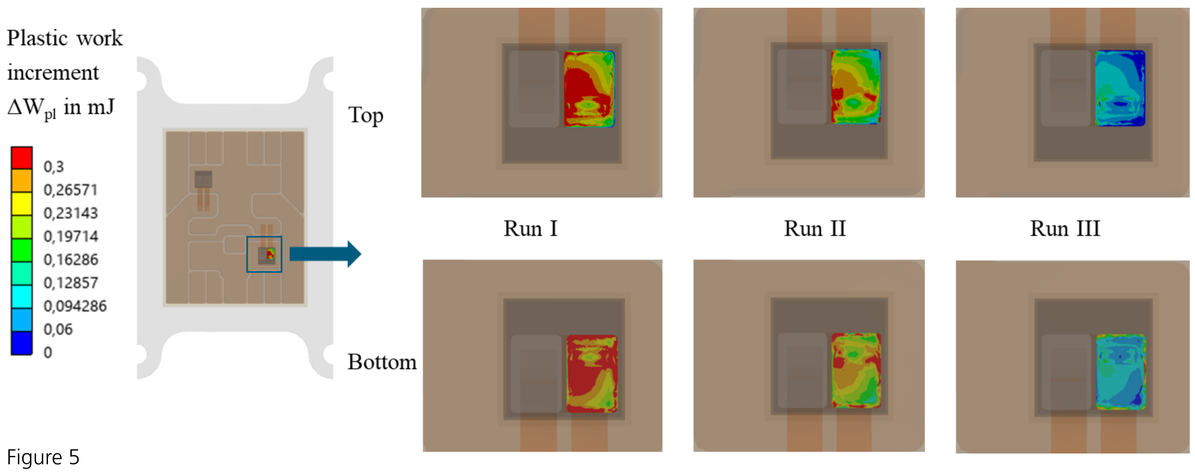


Figure 5

Figure 1 Test vehicle manufactured by Schaeffler AG (former Vitesco Technologies Group AG, Sintering + Cu-clip + Die Top System)

Figure 2 Weibull distributions of power cycling results

Figure 3 Microscopic analysis for hybrid failure mode (Degradation of sinter layer + delamination of thin film)

Figure 4 Thermal calibration based on cooling curve of PCT: experiment vs. simulation

Figure 5 Distribution of plastic work increment of chip top-side interconnection for different PCT runs in top view (upper) in bottom view (lower)

Figure 6 All raw experimental data, the empirical LESIT lifetime modeling and the combined FE lifetime modeling

Table 1 Test parameters of power cycling experiments

Table 2 Approaches applied for lifetime modeling