EFFECT OF THICK-FILM MATERIALS ON THE MECHANICAL INTEGRITY OF HIGH-STRENGTH CERAMIC SUBSTRATES

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ÉCOLE POLYTECHNIQUE FÉDÉRALE DE LAUSANNE

Need for high-strength substrates

Piezoresistive sensors

- Higher signal / overload capacity
- Simpler fabrication (half bridge)

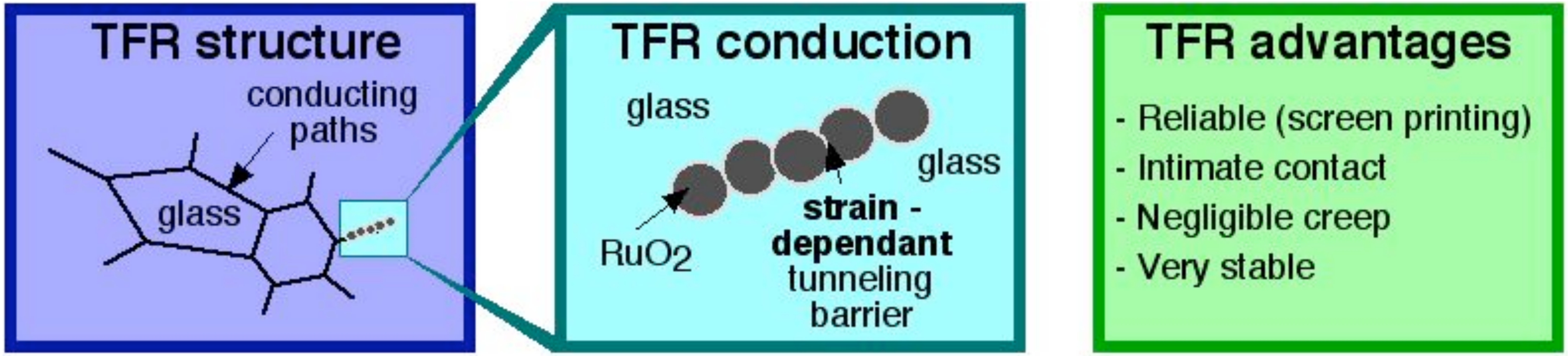
Power electronics / DCB

- High thermal cycling loads
- Thin substrates for high thermal conductivity

Rugged electronics

- Aerospace

Piezoresistive thick-film sensors

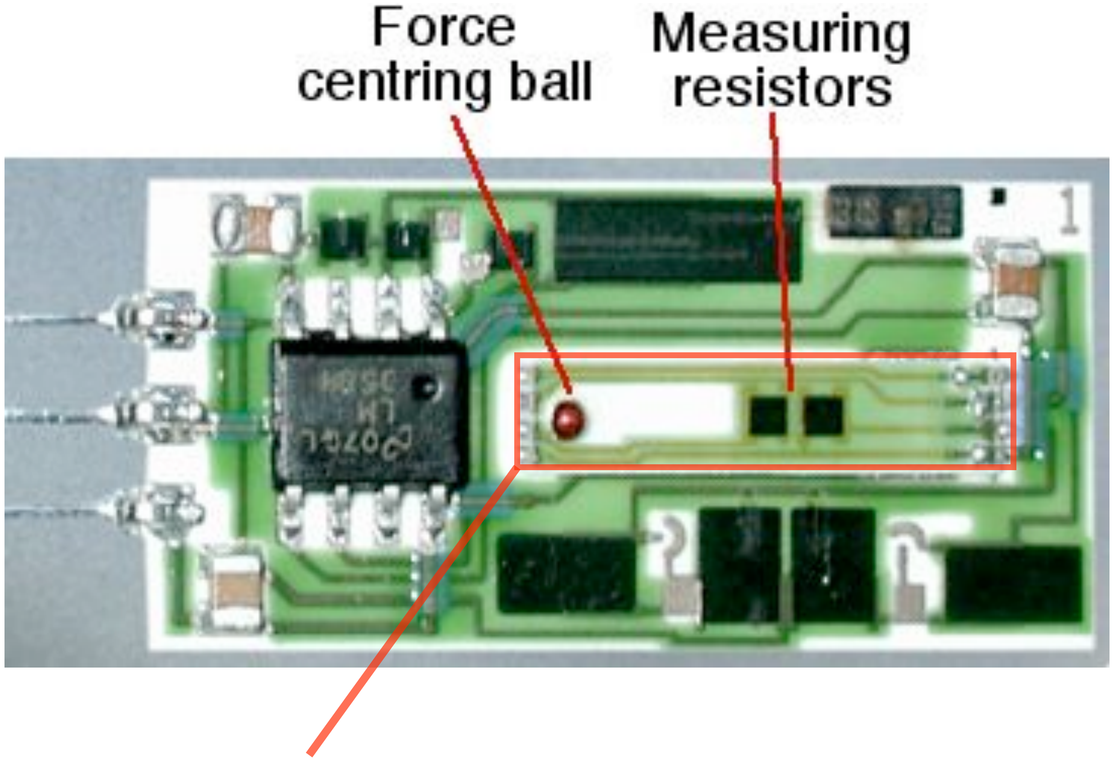


Thick-film resistors posess a **piezoresistive effect**.

Gauge factor = rel. variation / strain = $(\Delta R/R) / \varepsilon$

The **gauge factor** is typ. 12.
(Si : 50 ; metal *DMS - Dehnmeßstreifen* : 2)

Product: force sensor



Soldered alumina cantilever beam

Stressed films

1. Measuring resistors
2. Terminations / conductor lines
3. Protective glass

Candidate ceramic materials

1. **High-purity alumina**
   - \+ Most similar chemistry
   - – Lowest improvement in mechanical properties
2. **Zirconia**
3. **ZTA** (ZrO_2-Toughened Al_2O_3)
4. **LTCC** (Low-Temperature Cofired Ceramic)

Candidate ceramic materials

1. **High-purity alumina**
2. **Zirconia**
   - \+ Potentially the highest strain
   - – Most expensive
   - – Thermal & chemical compatibility problematic
3. **ZTA** (ZrO_2-Toughened Al_2O_3)
4. **LTCC** (Low-Temperature Cofired Ceramic)

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Candidate ceramic materials

1. **High-purity alumina**
2. **Zirconia**
3. **ZTA** (ZrO_2-Toughened Al_2O_3)
   - \+ Good strength
   - ± Medium cost
   - \+ Good thermal & chemical compatibility
4. **LTCC** (Low-Temperature Cofired Ceramic)

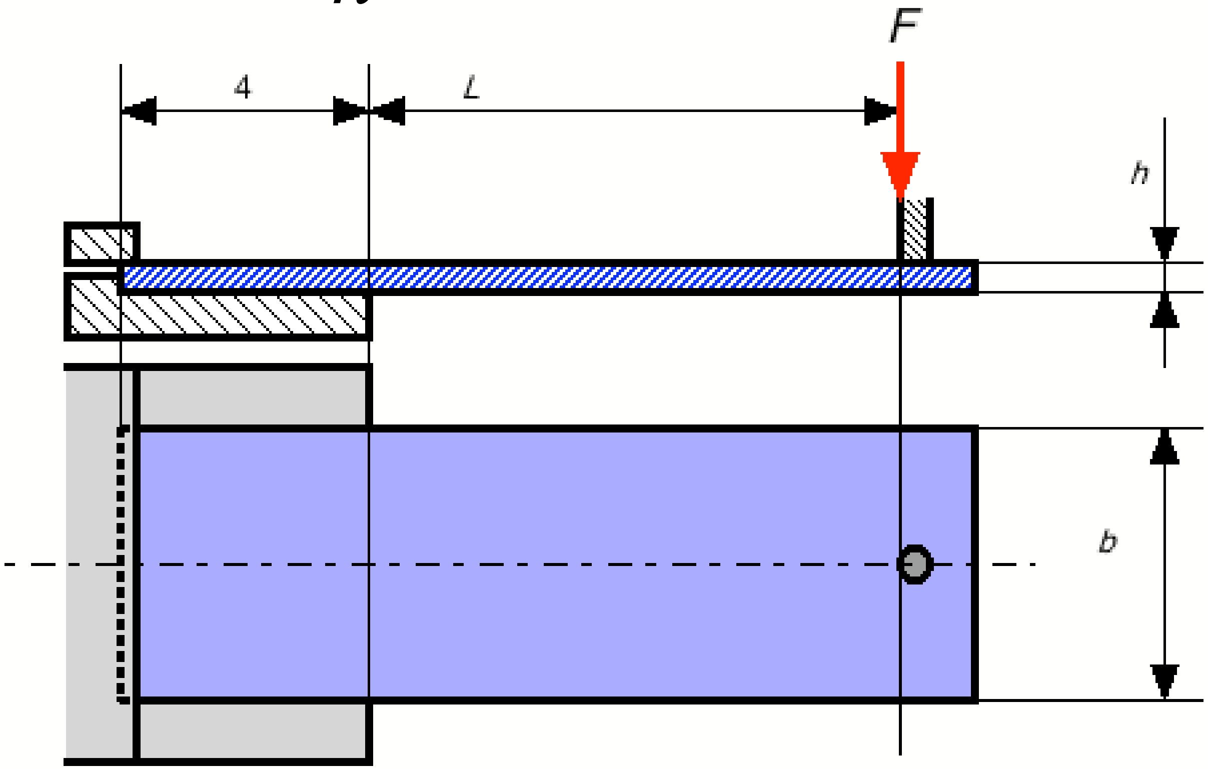
Candidate ceramic materials

1. **High-purity alumina**
2. **Zirconia**
3. **ZTA** (ZrO_2-Toughened Al_2O_3)
4. **LTCC** (Low-Temperature Cofired Ceramic)
   - – Low strength
   - \+ Low Elastic modulus
   - \+ Very sensitive structures attainable
   - \+ 3D structuration can improve properties

Test setup: long & short-term

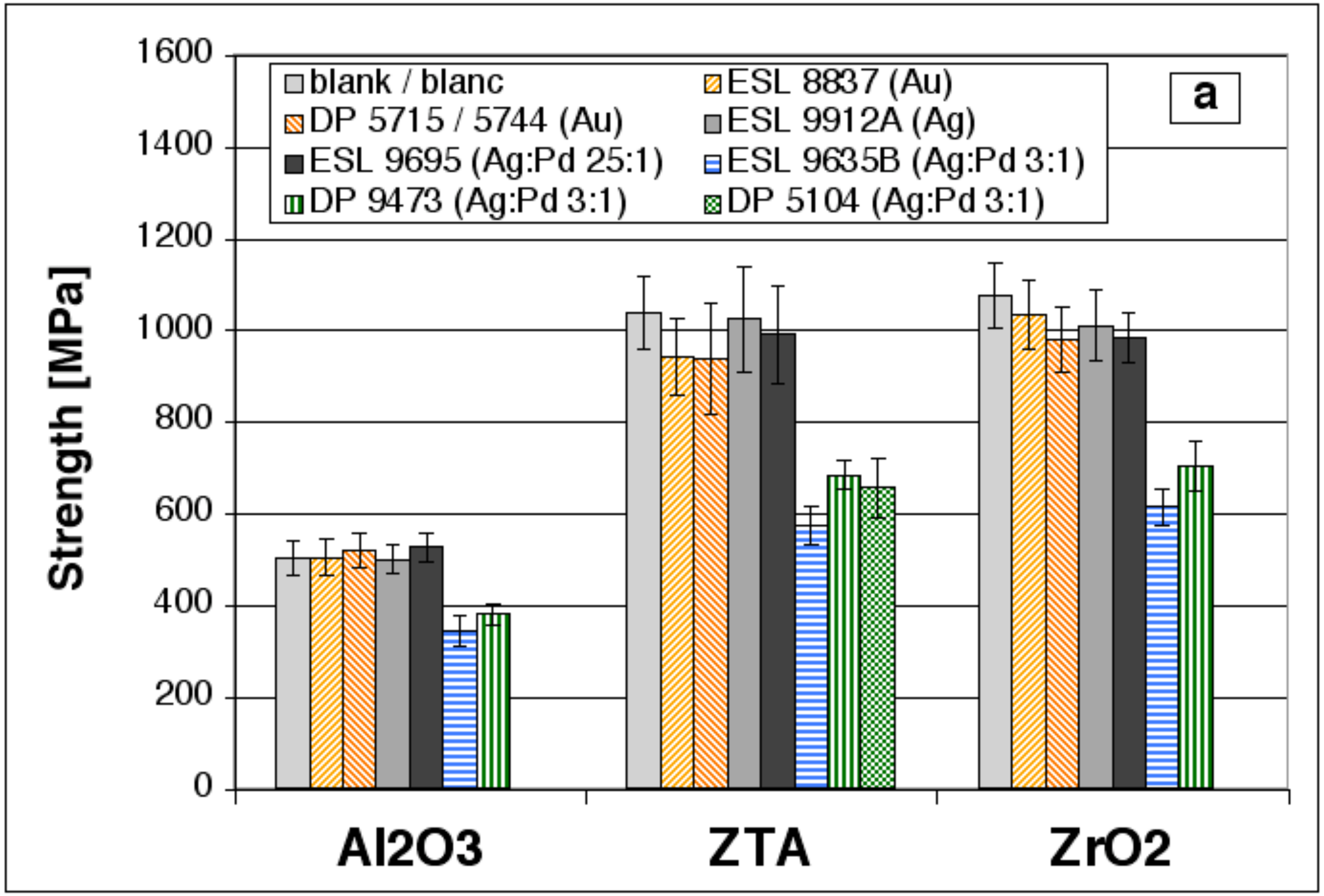
$$\sigma_{nominal} = \frac{6F \cdot L}{h^2}$$

$L \cong 8$; $b \cong 3$; $h \cong 0.25$ mm



Effect of metals on strength

(Short-term, absolute)



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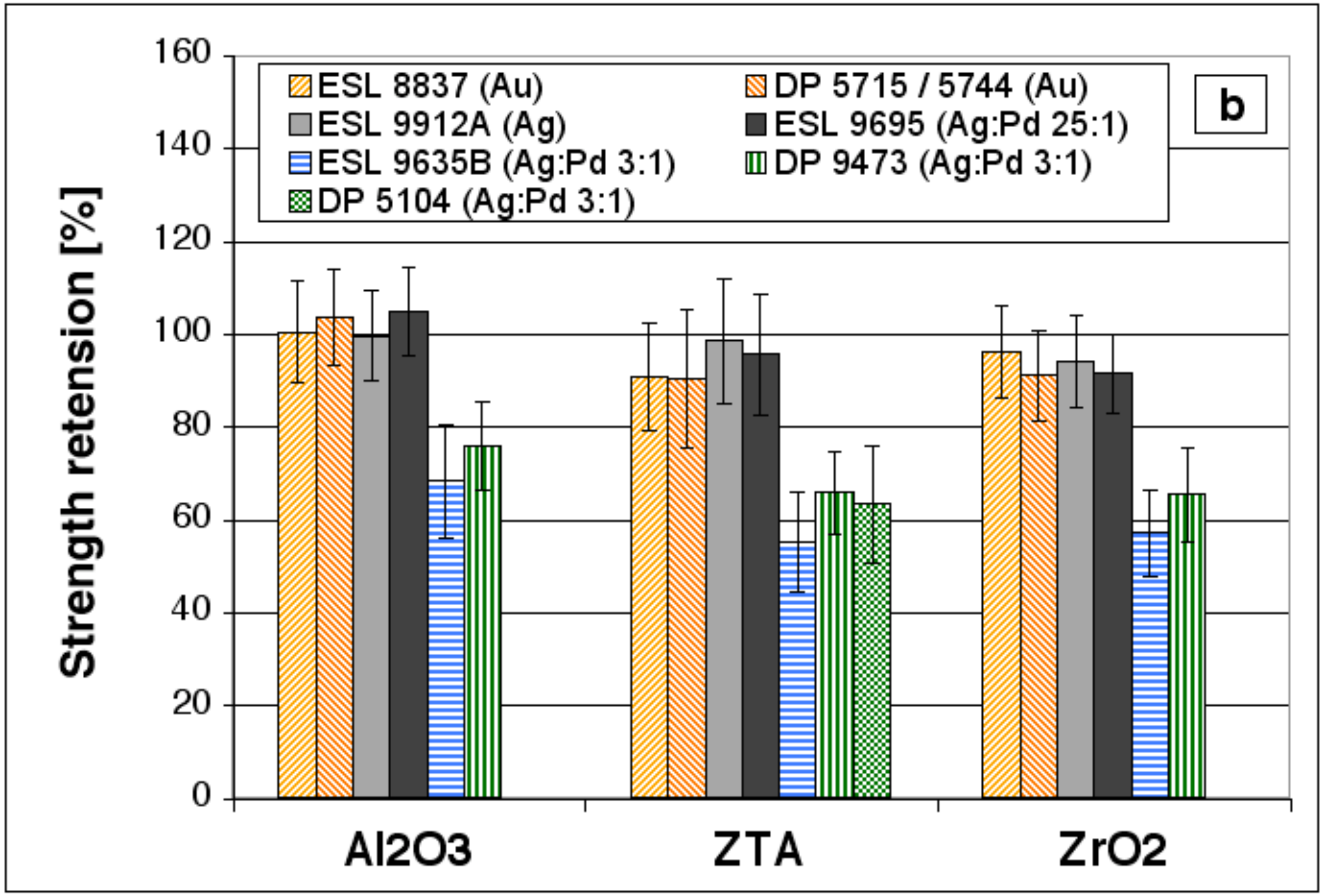
Effect of metals on strength

(Short-term, relative)



Effect of conductors: short term

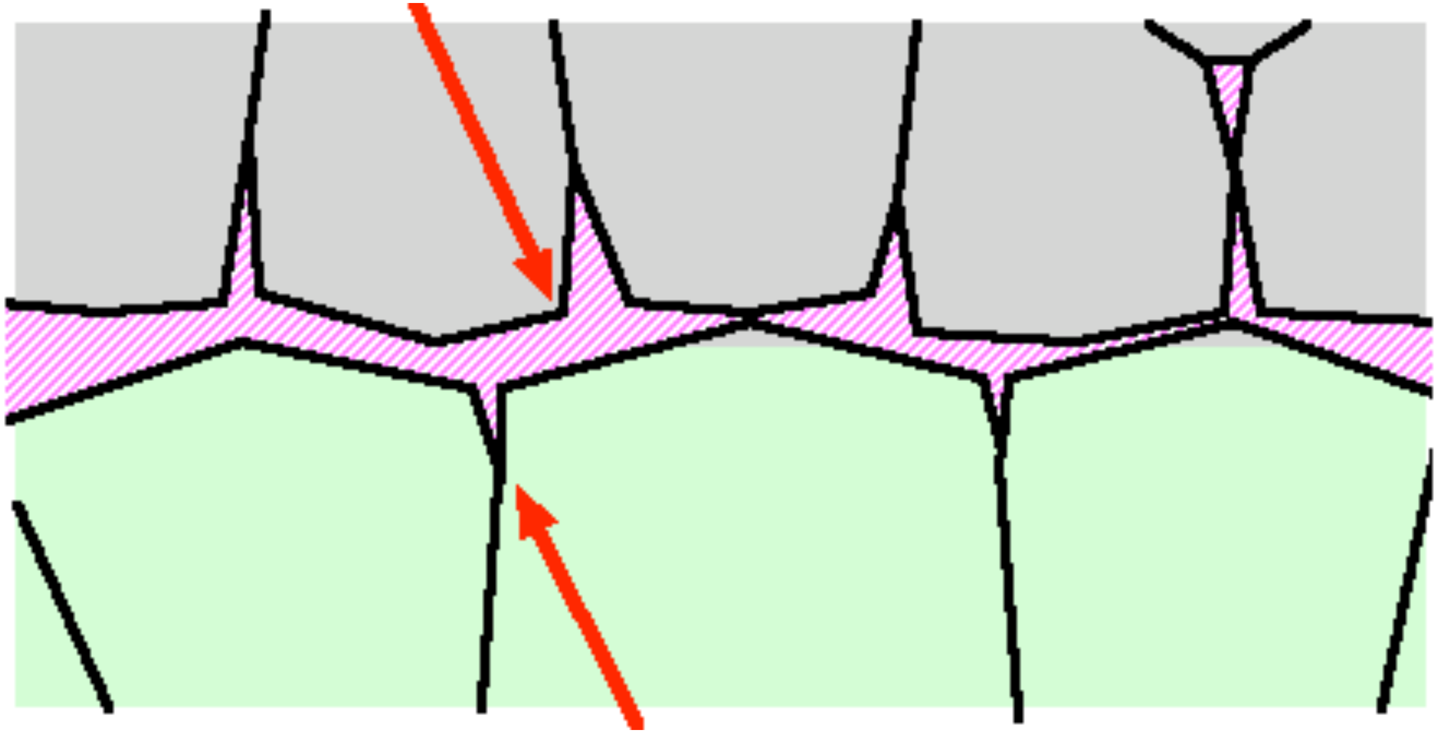
- Conductors with little or no glass frit: retention of original strength

  Ag, Ag:(Pd+Pt) 25:1, Au, thin Au

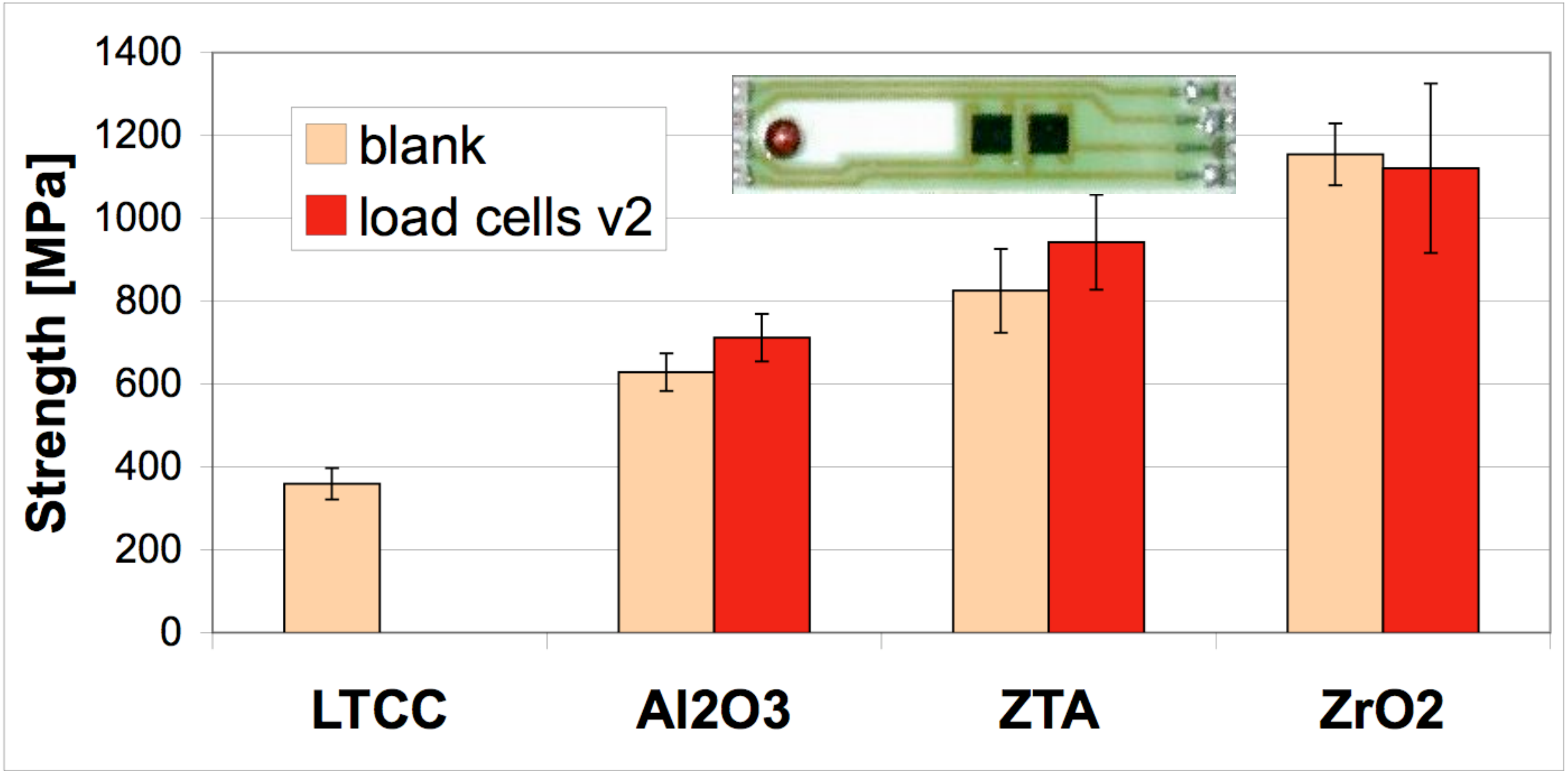
- Conductors with high glass frit: significant loss in strength (25…45%)

  Ag:Pd 2:1…4:1

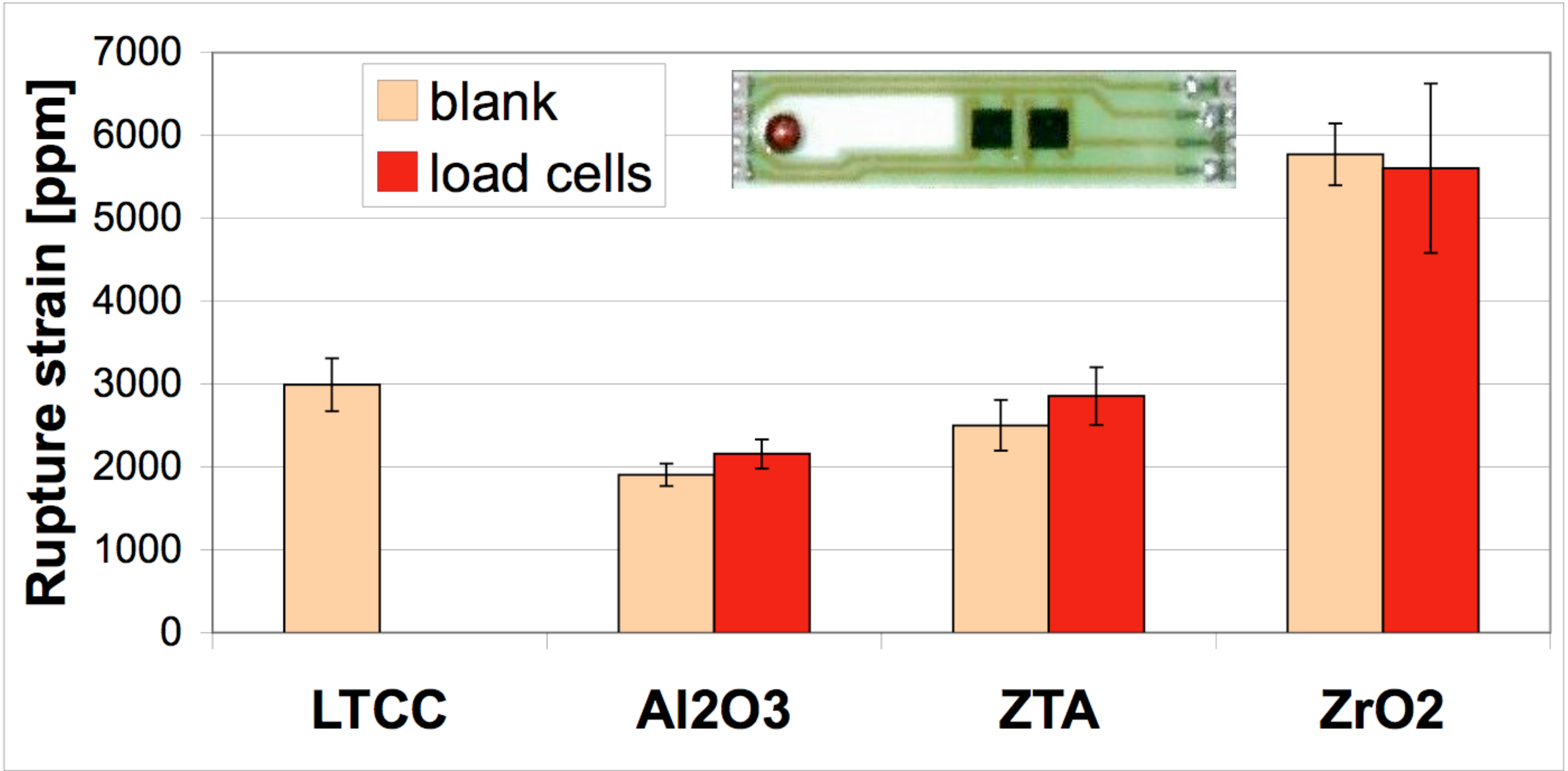
Effect of conductors: glass frit



Blank & load cells: short-term stress



Blank & load cells: short-term strain



Summary: short-term results

ZrO_2

- Potentially the highest signal
- Problems: TCR shift, low thermal conductivity, cost

ZTA

- « Drop-in » improvement over Al_2O_3

LTCC (Du Pont 951)

- Stress: the weakest substrate
- Strain: compares favourably with Al_2O_3 & ZTA

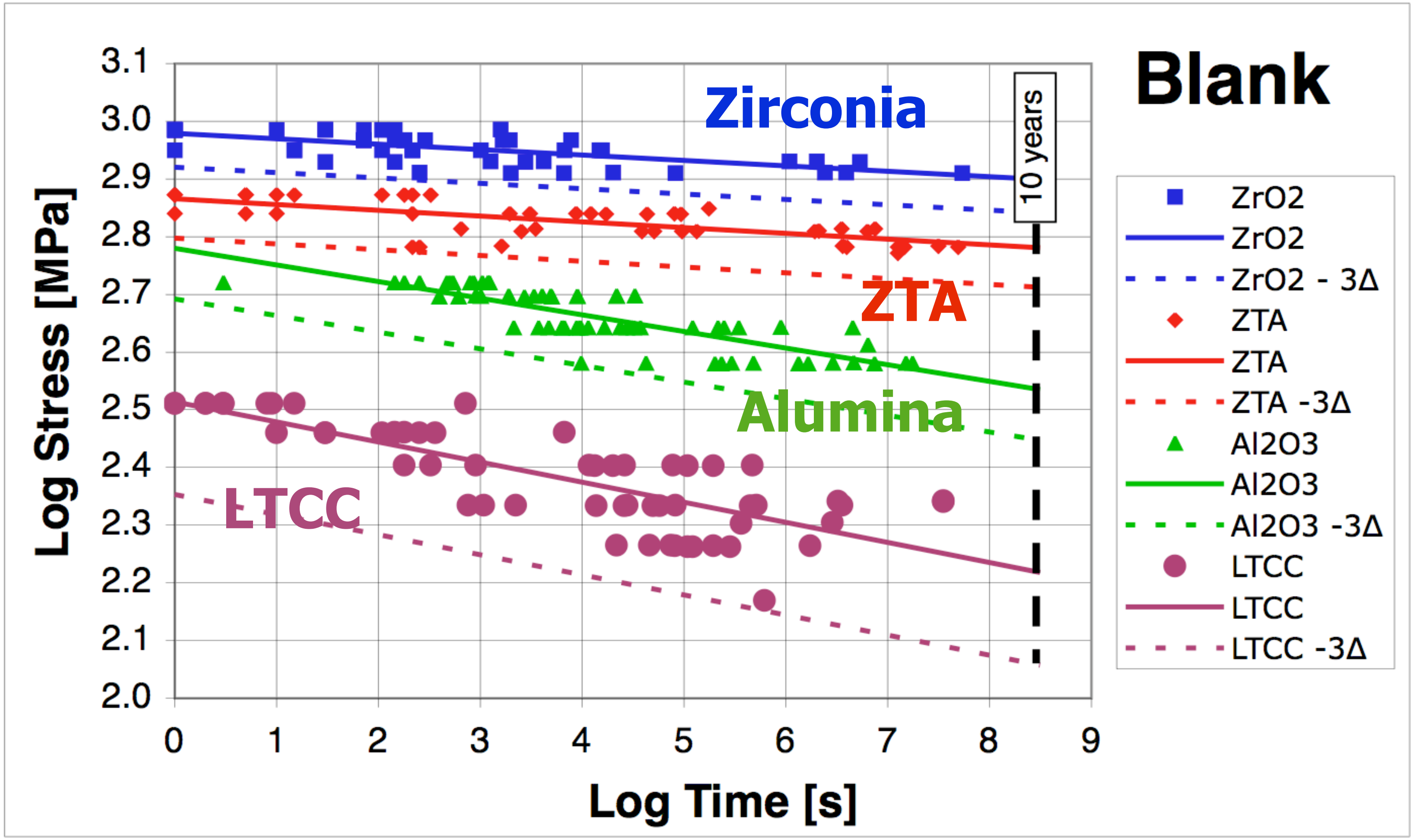
Long-term strength

- Subcritical crack growth occurs until rupture (static fatigue).
- Stress - time to rupture : Paris' law.

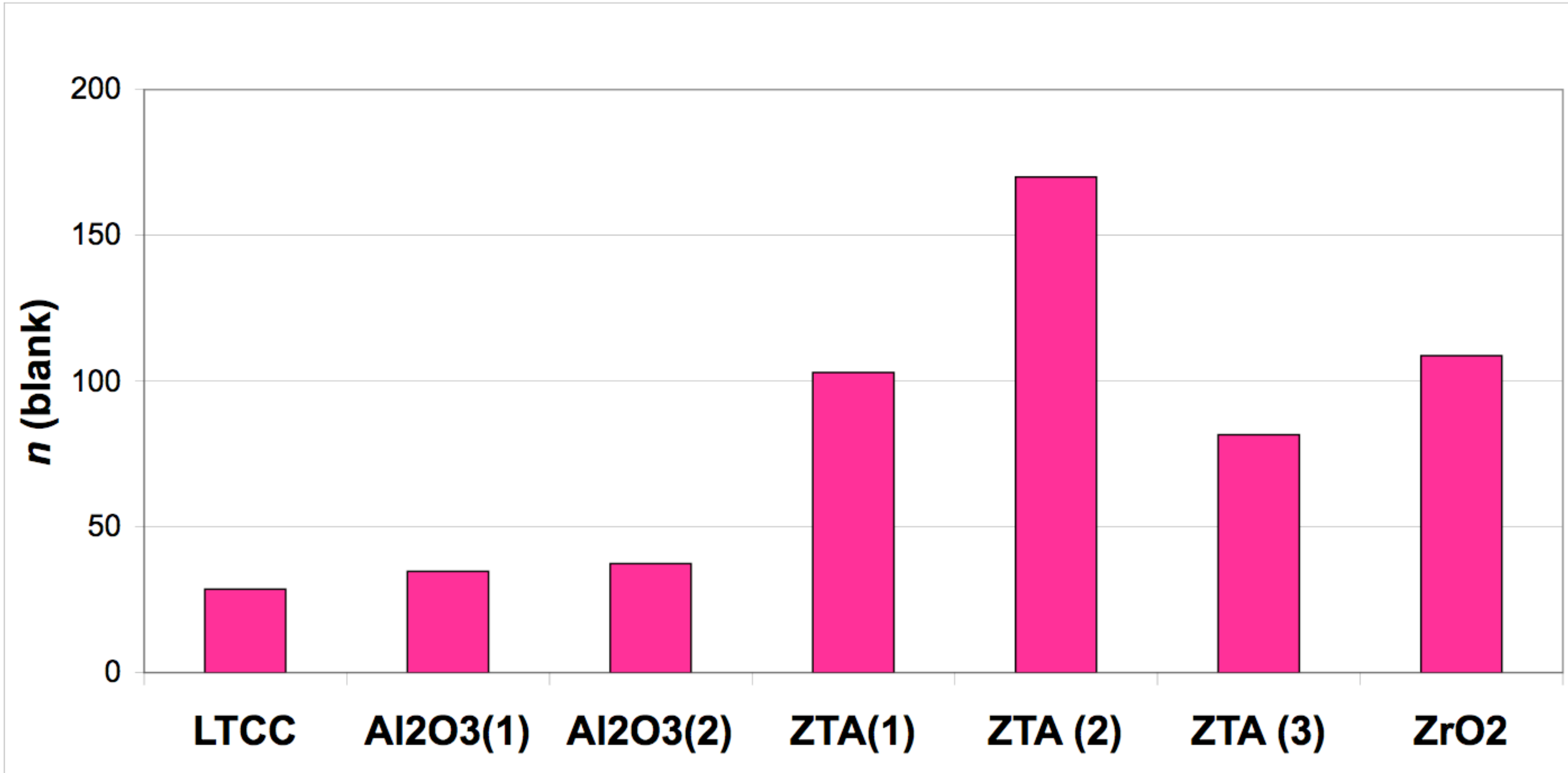
$$\sigma = \sigma_0 \cdot \left(\frac{t}{t_0} \right)^{-1/n} \qquad \log \sigma = \log \sigma_0 - \frac{1}{n} \log \left(\frac{t}{t_0} \right)$$

- The value of *n* is a quality indicator.

Long-term strength - blank



Long-term: *n* values - blank



(several Al_2O_3 & ZTA series)

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Blank substrates - long-term

Two categories:

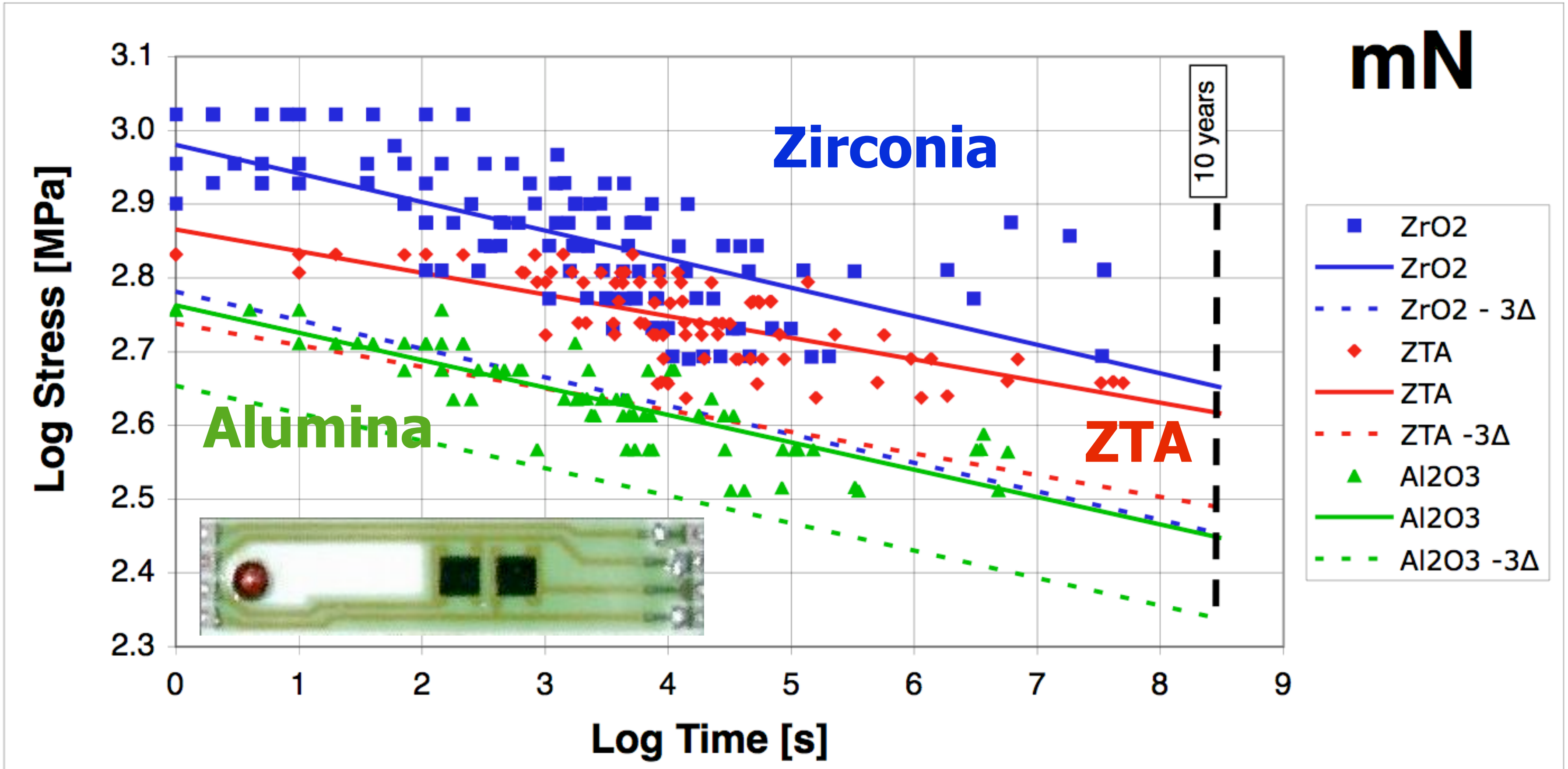
1. ZTA & zirconia

- Little or no glassy phase
- Resistant to static fatigue ; high *n* values, ca. 100

2. Alumina (96%) & LTCC (DP 951)

- Glassy phase (alumina: at grain boundaries)
- Pronounced static fatigue ; low *n* values, ca. 30
- LTCC has lower *n* than alumina, yet still higher design strain for 10 years.

Long-term strength : load cells



⇒ Much of the advantage of ZrO_2 & ZTA is lost!

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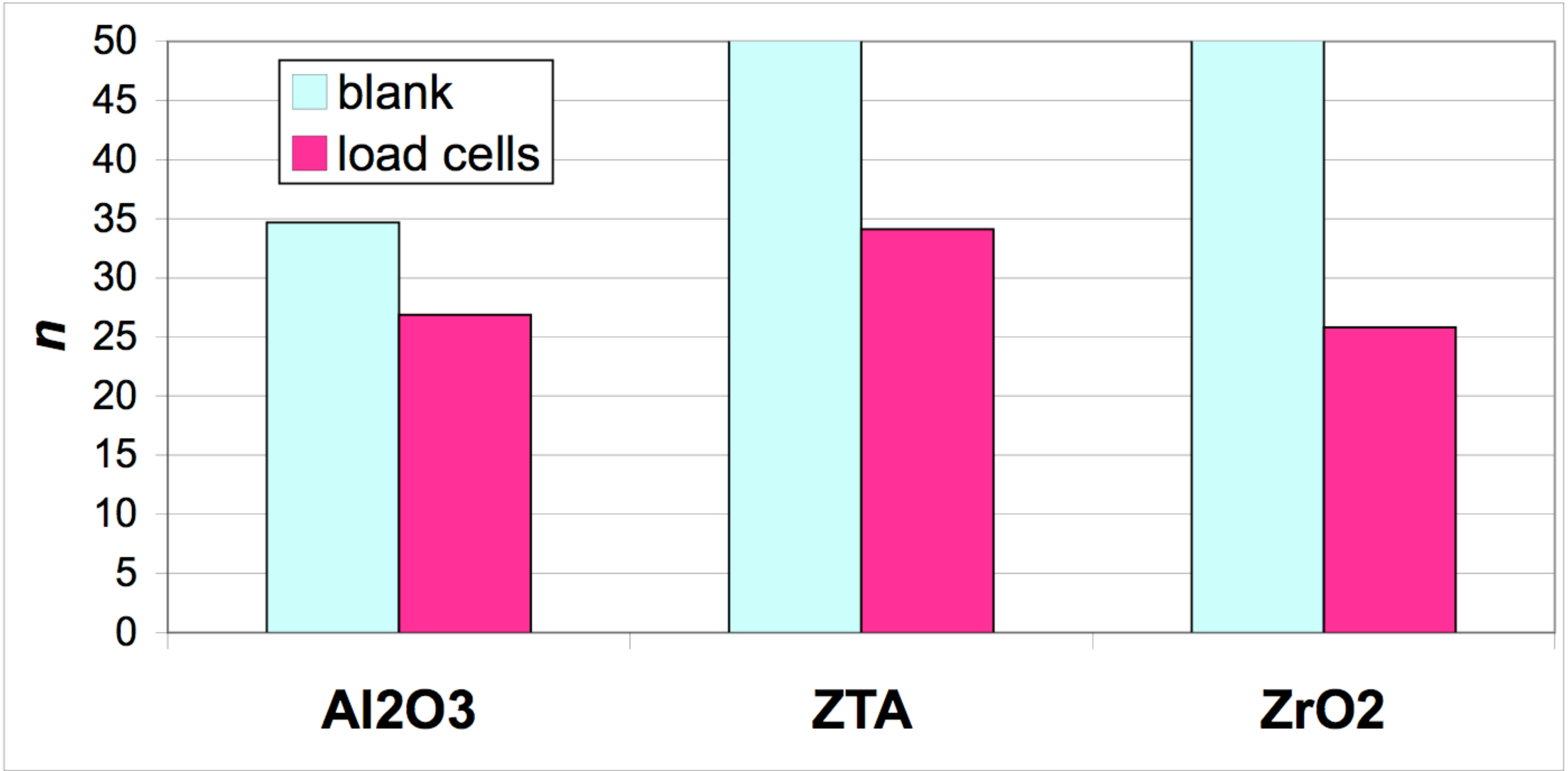
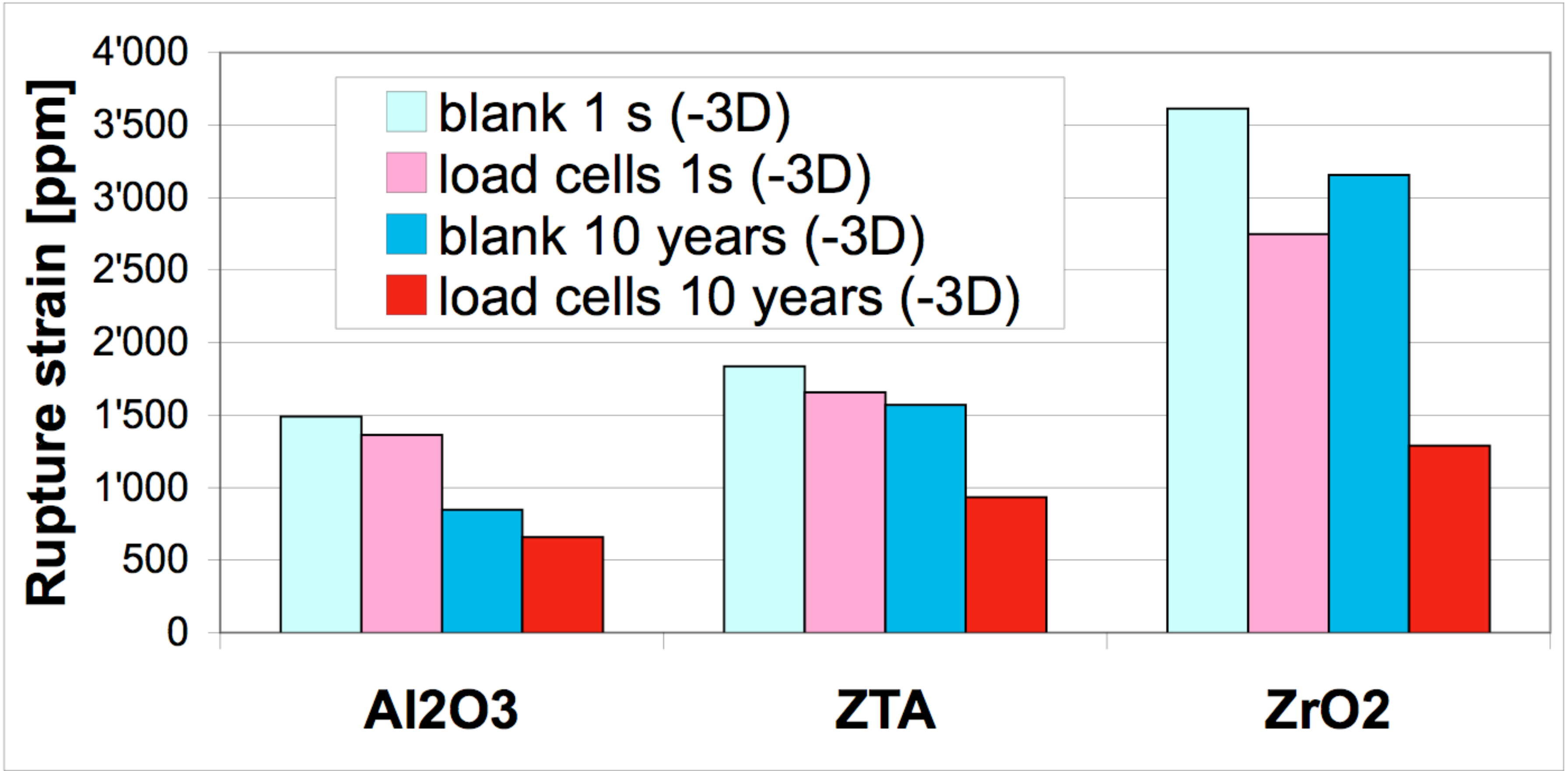
Long-term *n* values: load cells



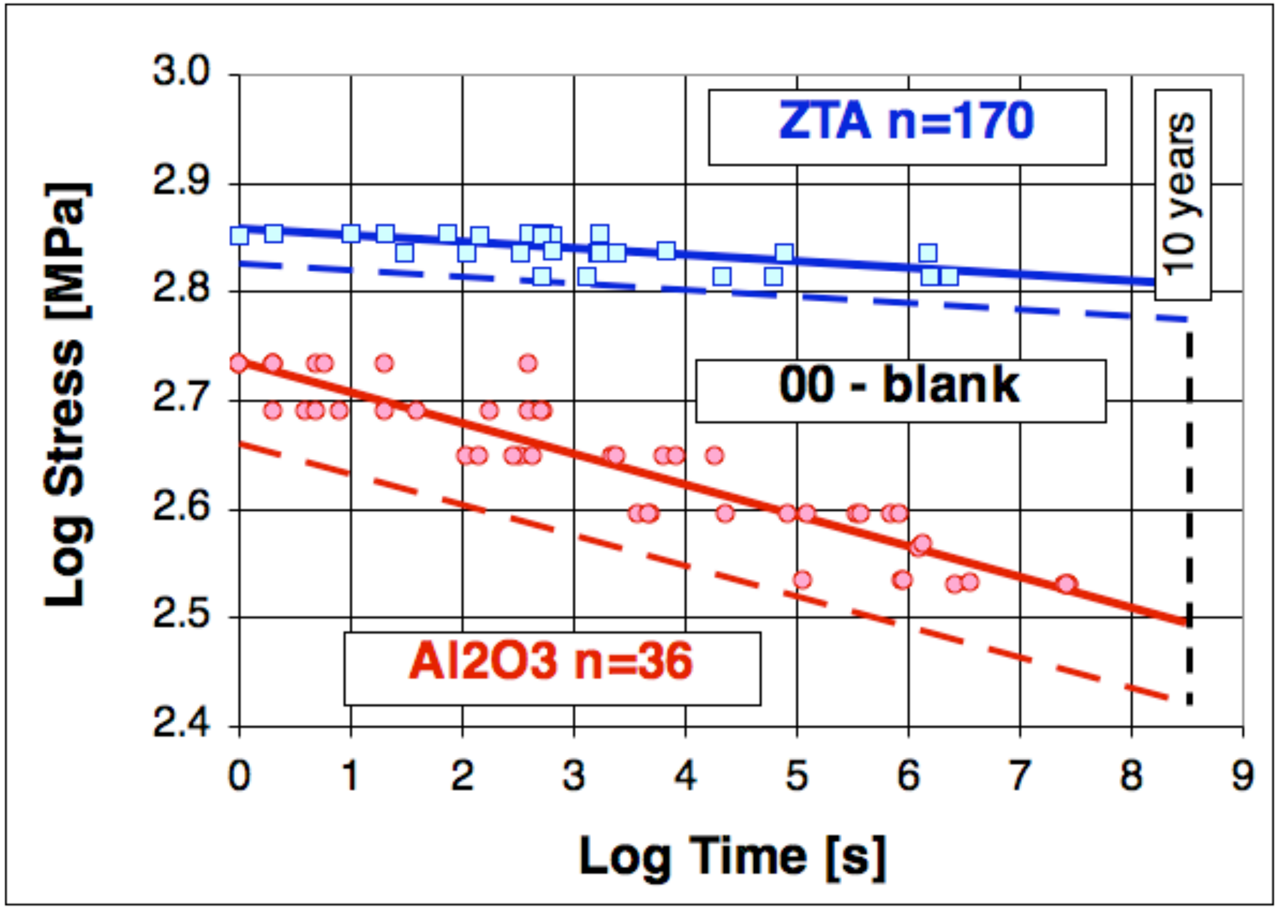
Values of *n* no longer very different!

Long-term strain (load cells, -3D)



High strength substrates more degraded by films!

Static fatigue - blank



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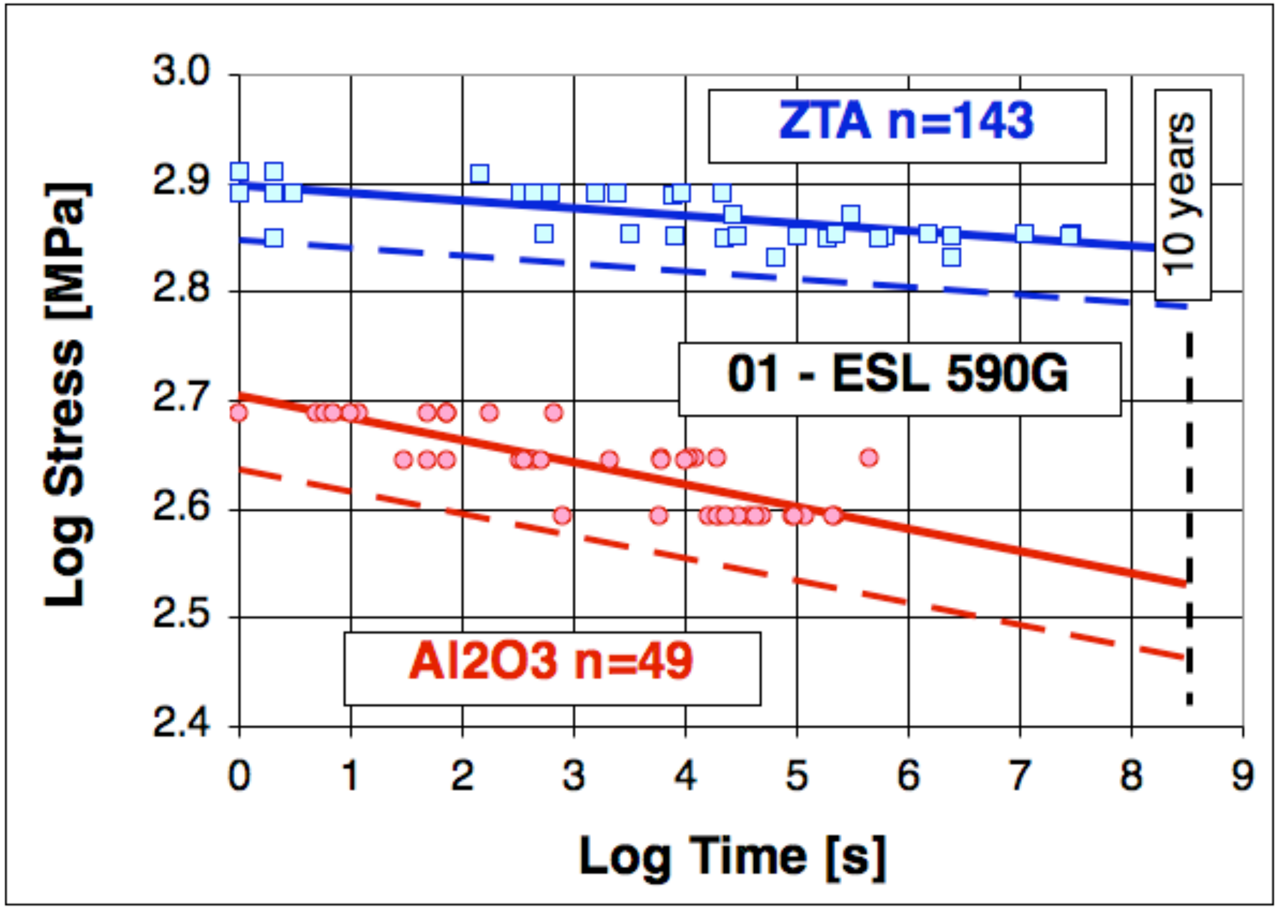
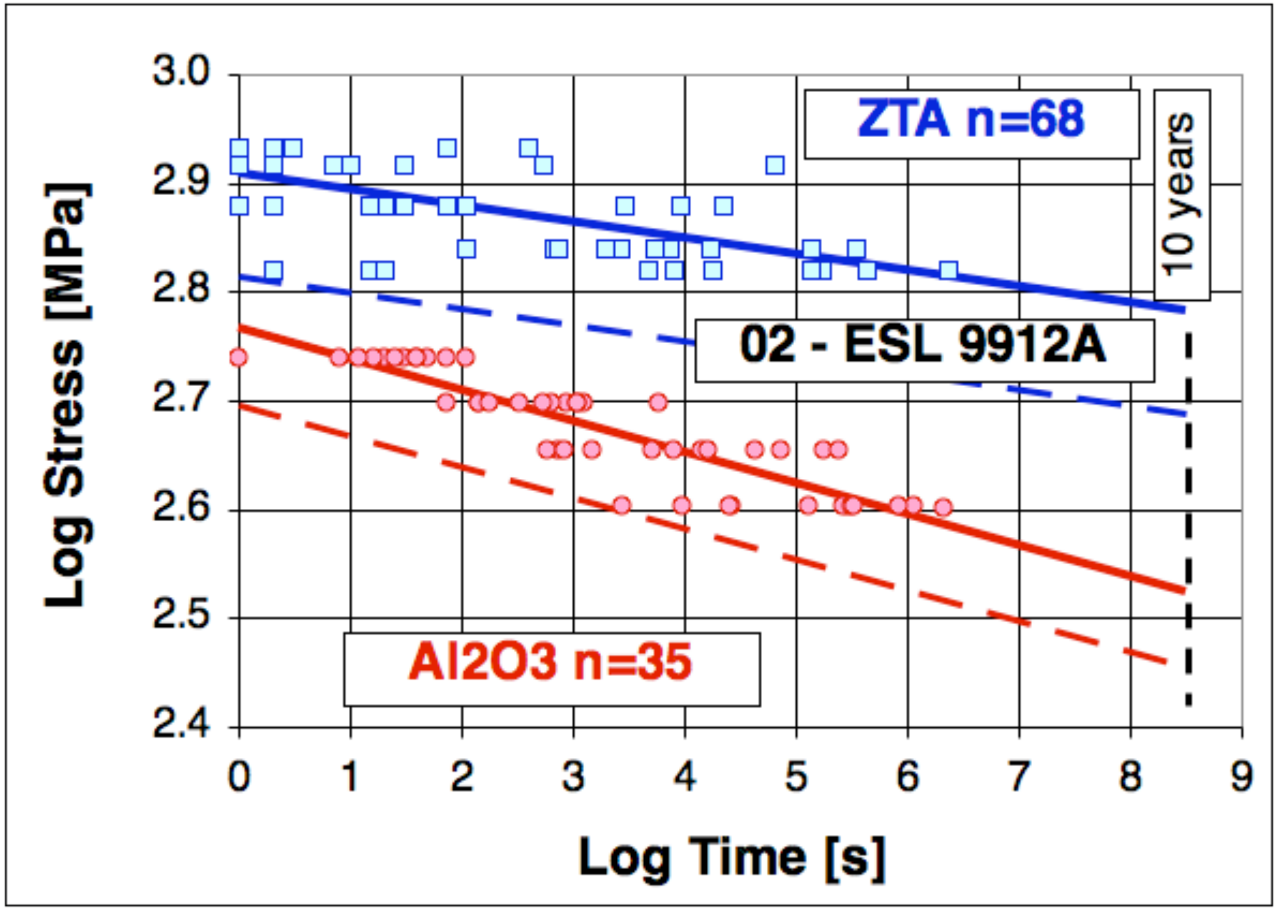
Static fatigue - fritted Ag, low firing



Ag
fritted
500°C firing

Frit seems less deleterious with low firing.

Static fatigue - Ag



Ag
850°C
little glass
(mixed bond)

Moderate degradation of ZTA long-term strength.

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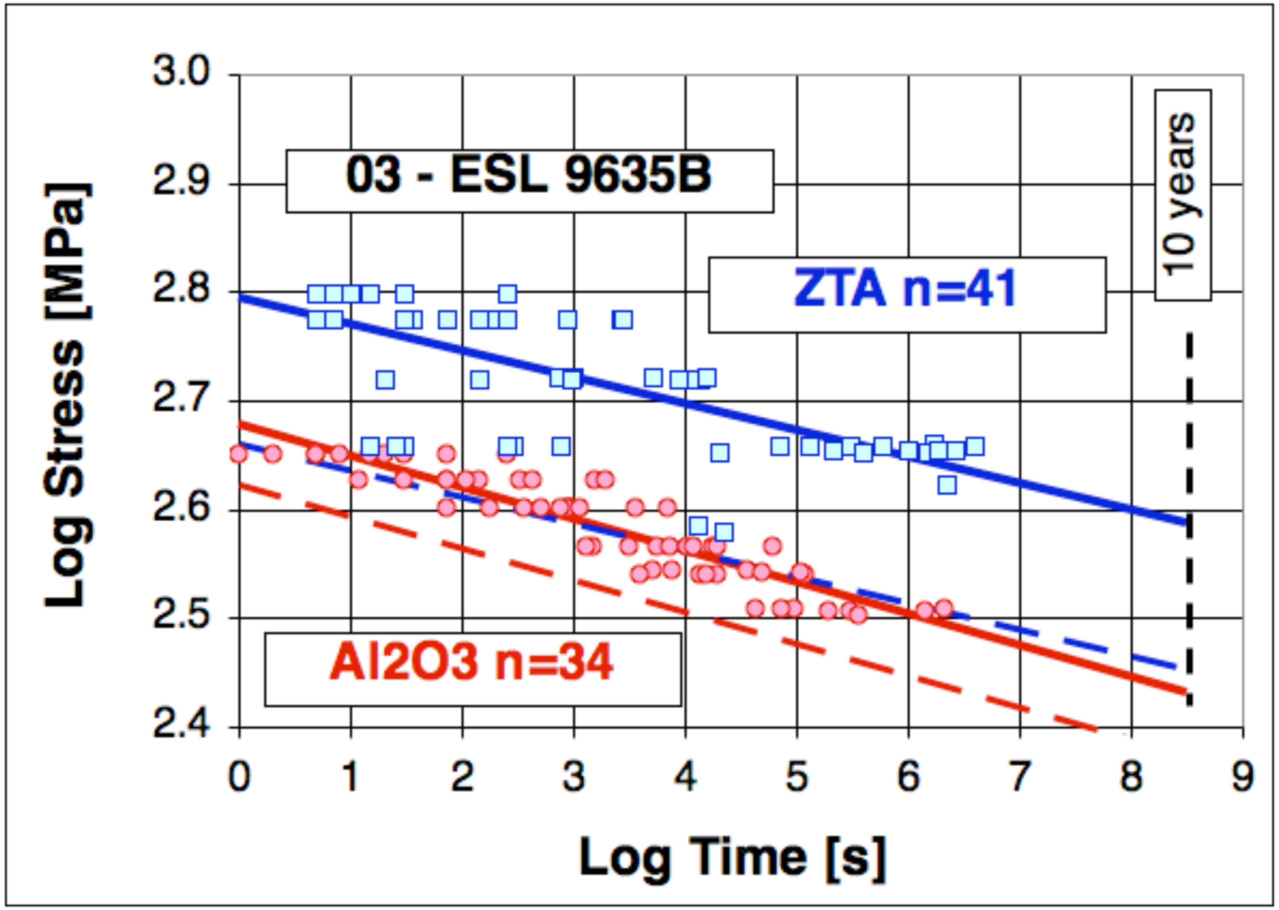
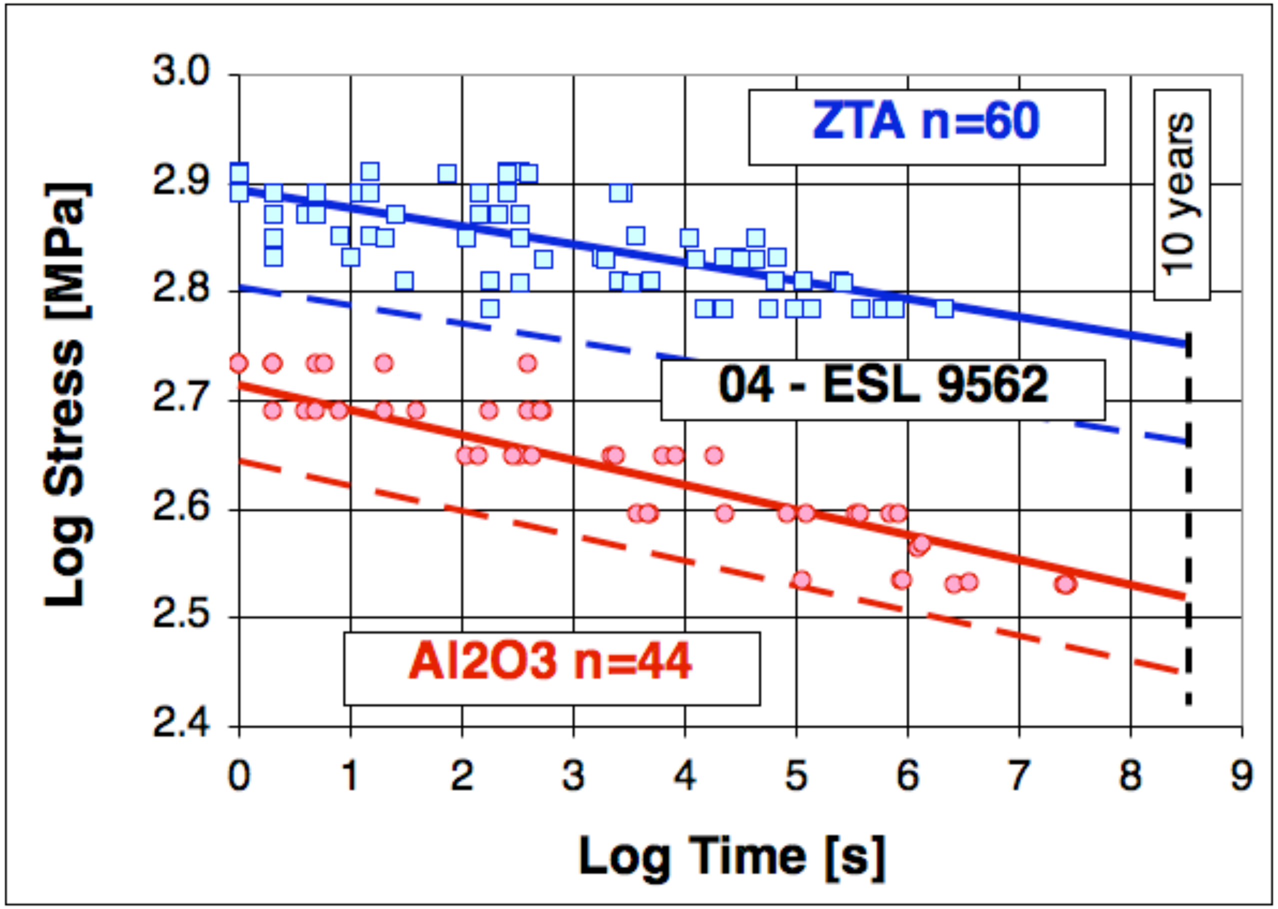
Static fatigue - Ag:Pd 3:1



Ag:Pd 3:1
850°C
fritted

Strong degradation of strength & *n*.

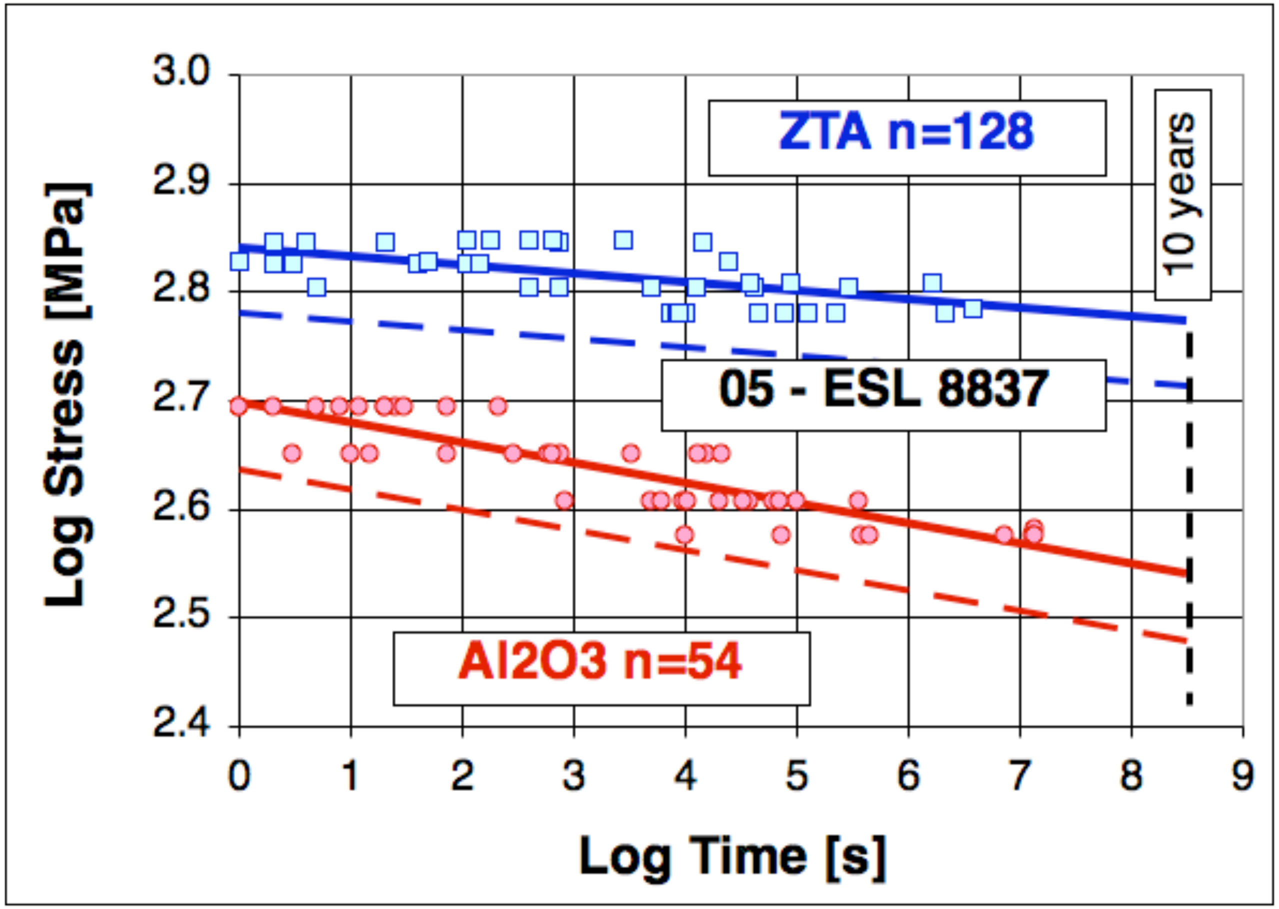
Static fatigue - Ag:(Pd+Pt) 25:1



Ag:(Pd+Pt)
25:1
850°C
fritless

Moderate degradation of long-term strength?

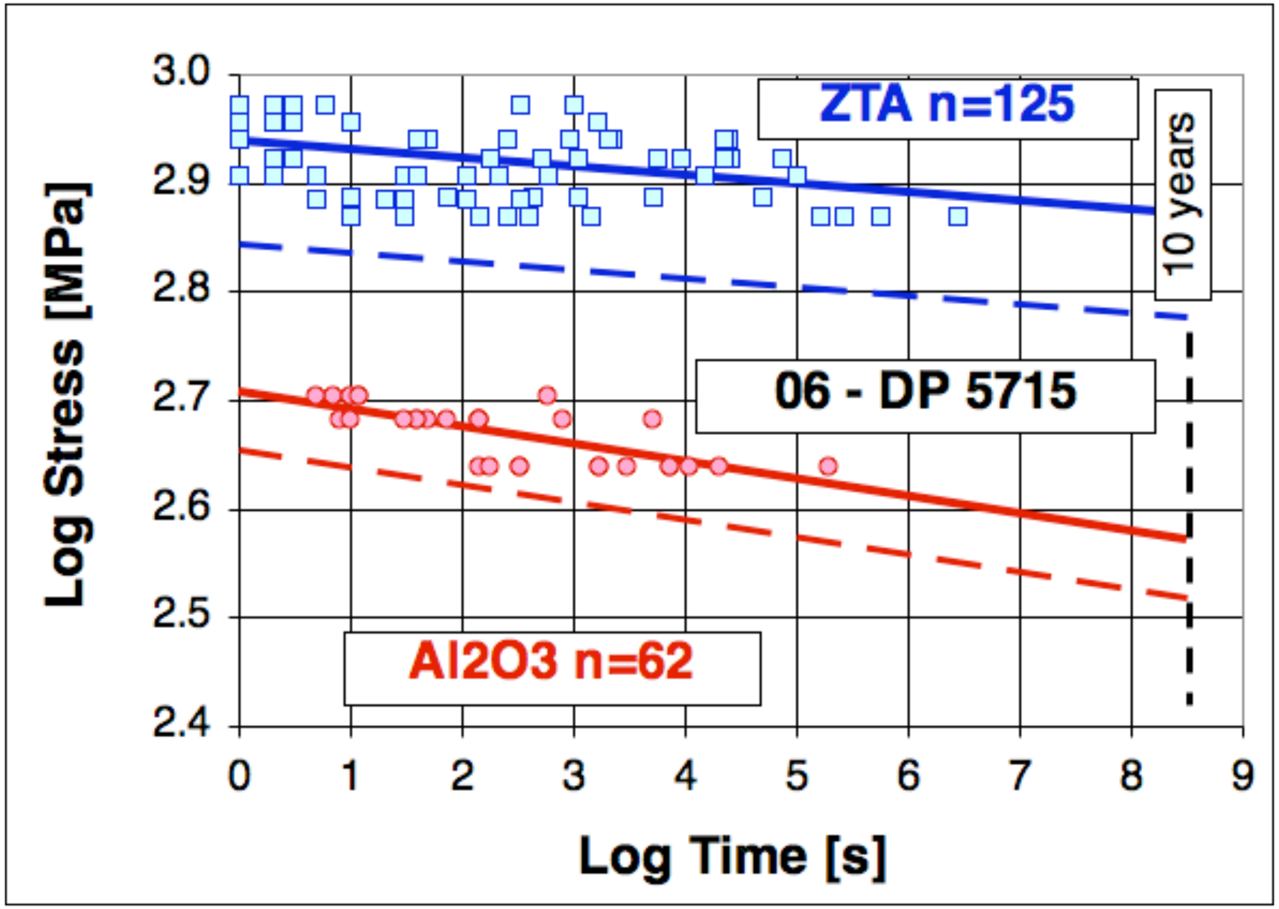
Static fatigue - Au (thin)



Au
850°C
little frit
thin 2µm

No degradation (even increase on alumina)!

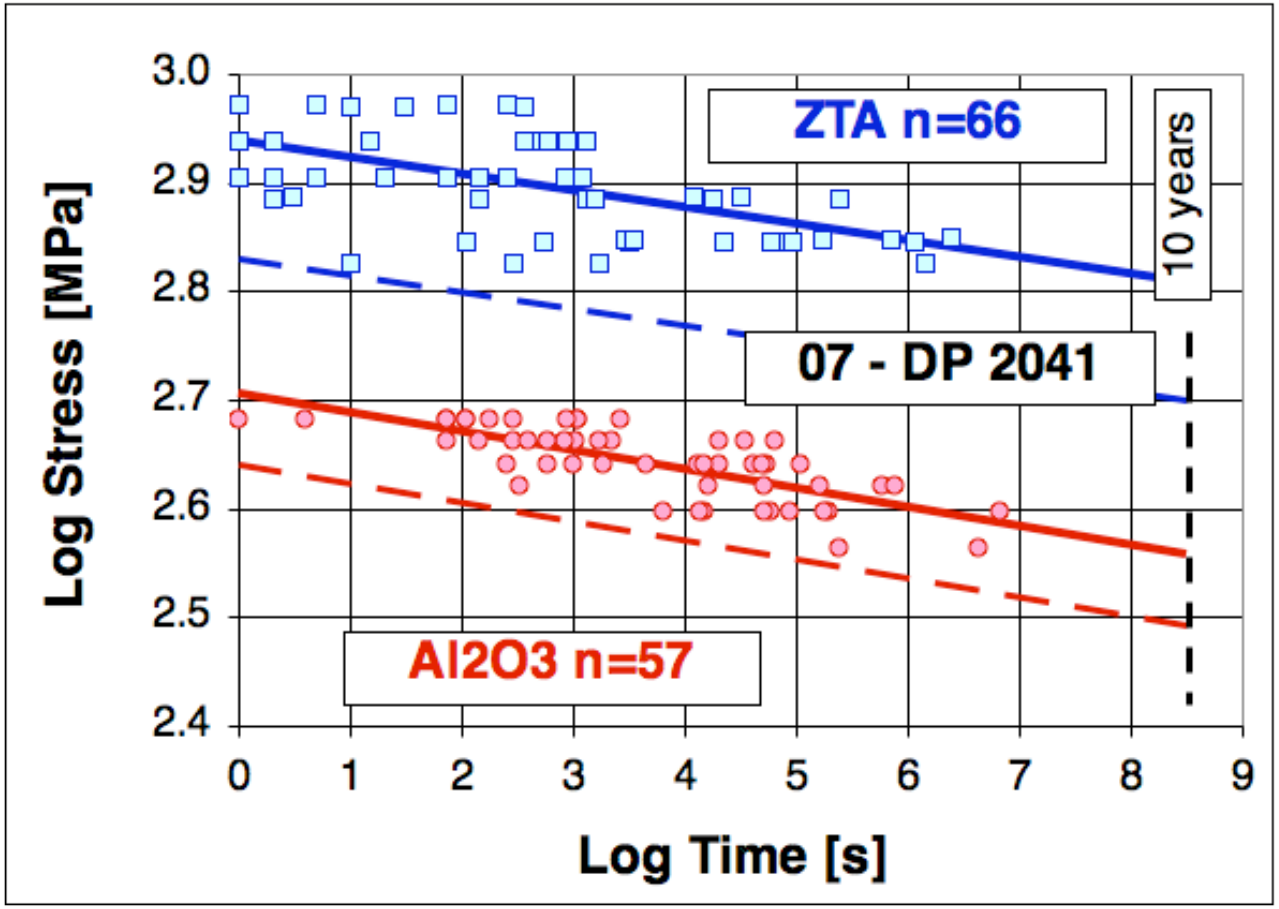
Static fatigue - Au (standard)



Au
850°C
little frit
std. thickness

Moderate degradation of long-term strength?

Static fatigue - DP 2041 resistor



DP 2041
850°C
10 kOhm

Moderate degradation of long-term strength?

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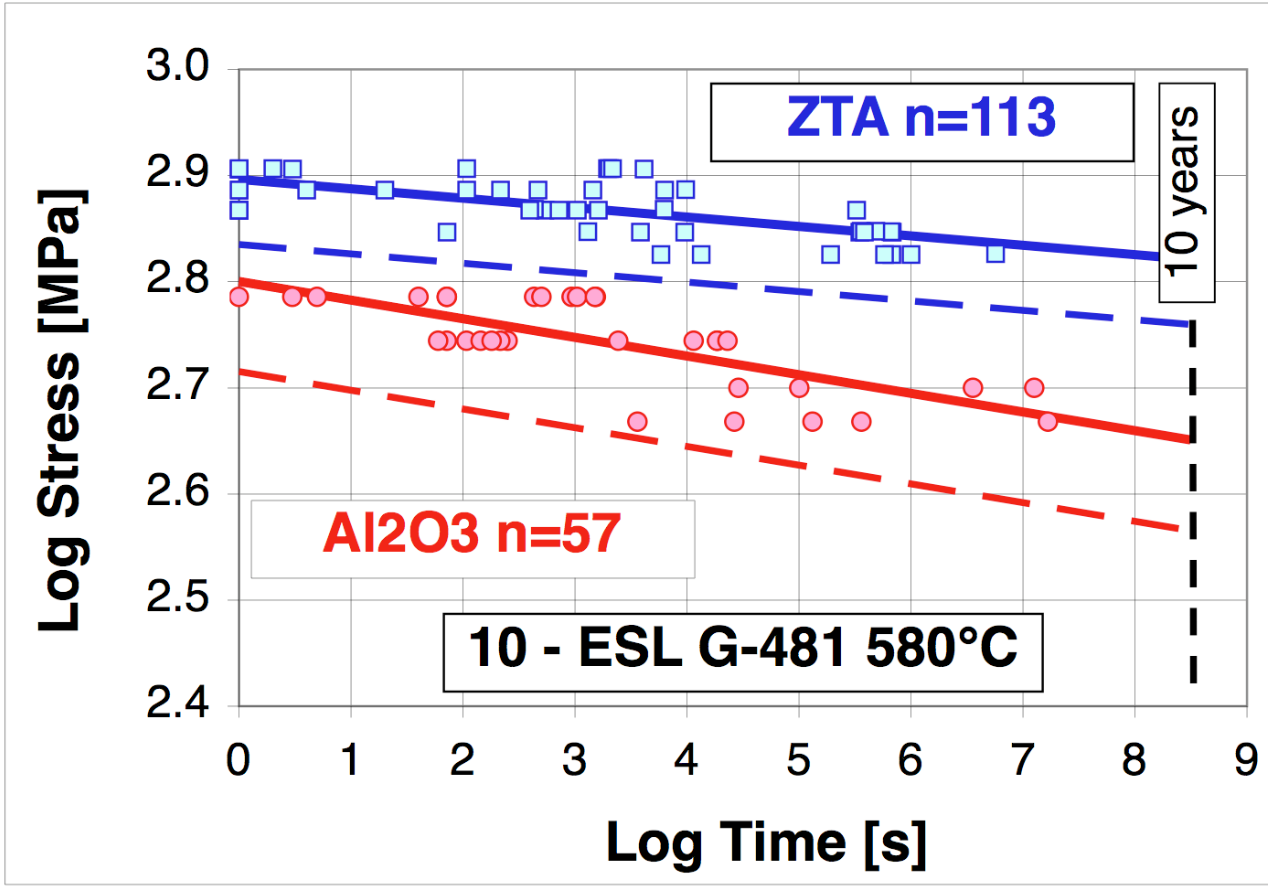
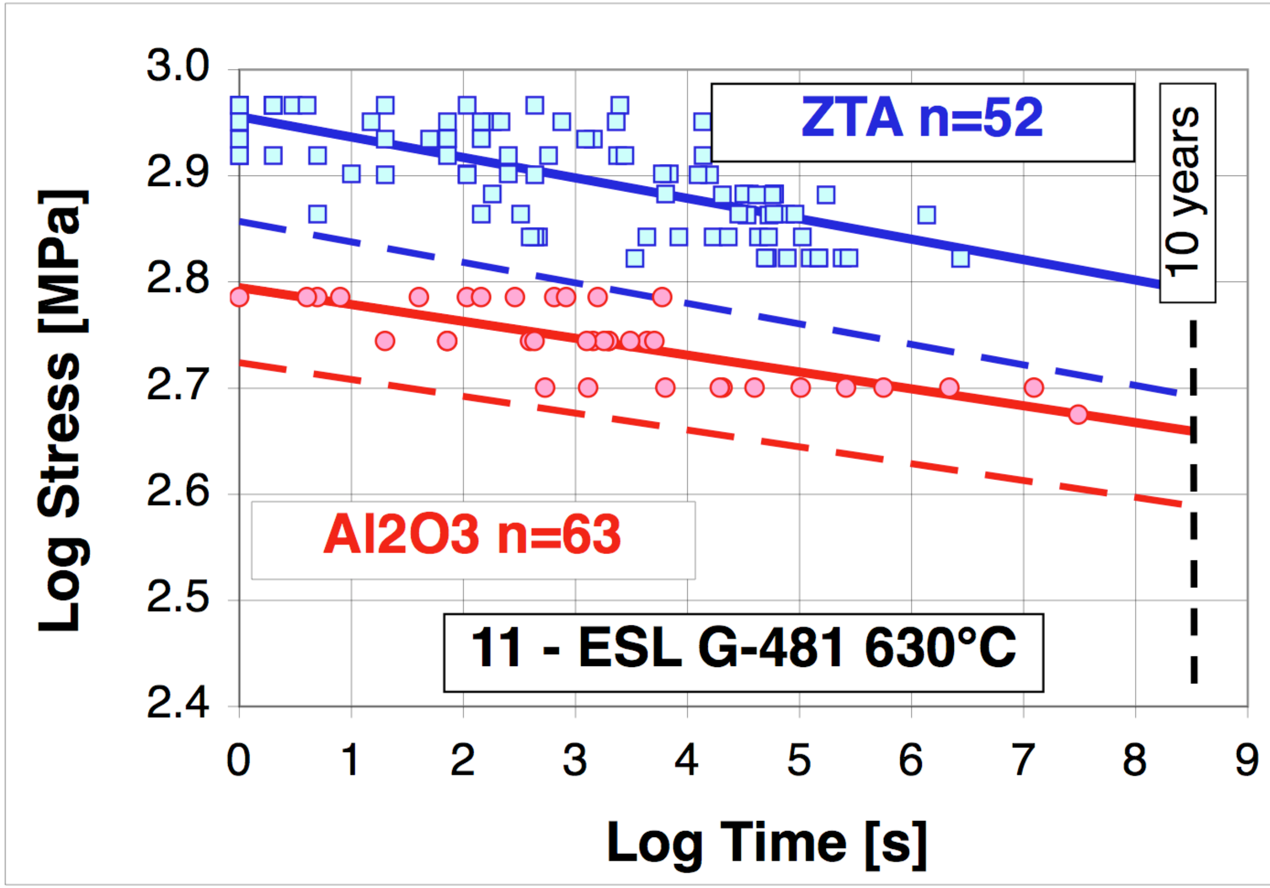
Static fatigue - ESL G-481 @ 580°C



ESL G-481 overglaze 580°C (matt)

Good long-term strength.

Static fatigue - ESL G-481 @ 630°C



ESL G-481
overglaze
630°C
(glossy)

Different behaviour when overglaze is well melted!

Conclusions (1/2)

- Effect of individual layers on strength of ZTA & alumina
- Many conductors & matt fired 600°C overglaze: « no » degradation of long-term strength
- Resistor, some conductors & glossy fired 600°C overglaze: medium degradation

Conclusions (2/2)

- Very deleterious effect of fritted 3:1 Ag:Pd conductors (used for solder & bond pads), even on alumina!

  ⇒ avoid in stressed zones!

- Low-firing fritted Ag conductor: « no » degradation!
- **Synergistic effects - multilayers?**

THANK YOU !