# THERMO-MECHANICAL TESTING OF OXIDATION PROTECTION SYSTEM FOR RE-ENTRY APPLICATIONS

**Inmaculada Huertas Olivares[1], Volker Liedtke[1], Markus Langer[1], Ulrich Trabandt[2], Karin E. Handrick[3], Yaara F. Haruvy[1]**

*(1) ARC Seibersdorf Research GmbH, A- 2444, Seibersdorf, Austria*
*(2) EADS Space Transportation, Huenefeldstrasse 1-5, D-28199, Bremen, Germany*
*(3) MT Aerospace AG, Franz-Josef Strauss Strasse 5, D- 86153, Augsburg, Germany*

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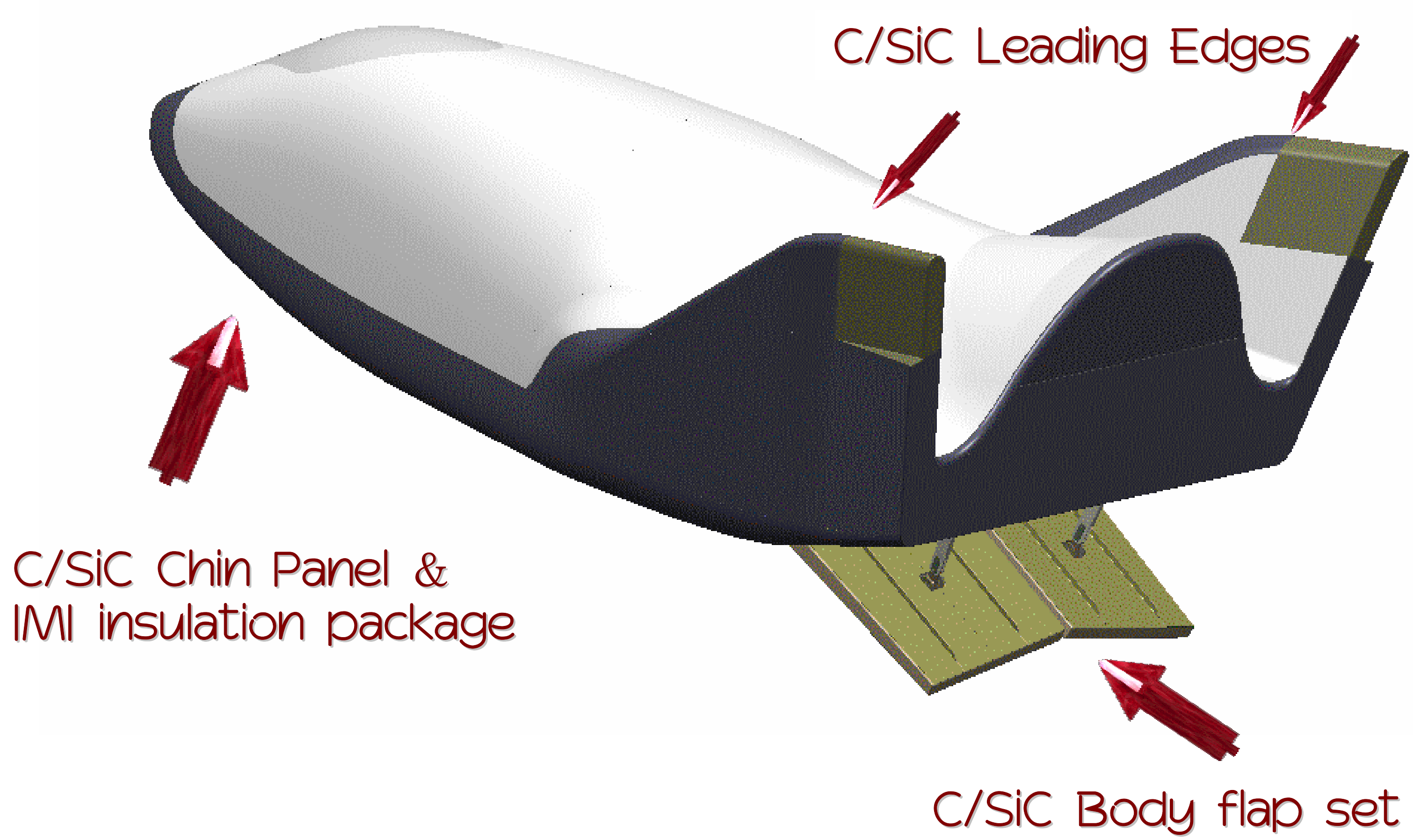
- Background and Need for Activity
- Experimental Procedure
- Test Results and Discussion
- Technology Demonstrator Sample

# BACKGROUND


C/SiC Leading Edges
C/SiC Chin Panel &
IMI insulation package
C/SiC Body flap set

# BACKGROUND

## Need for Activity

- For re-usable spacecraft, heat shields are the most critical components (1600°C)
- Currently, C/SiC based structures are favoured
- Oxidation Protection Systems are available, but
  - a true reusability has not yet been proven sufficiently
  - maintenance/refurbishment effort for multi-missions has to be assessed
  - multi-mission relevant testing has not yet been performed
- Therefore, to assess true re-usability,
  - testing under application-relevant re-entry conditions has to be performed
  - simulating a larger number of re-entry runs than currently done

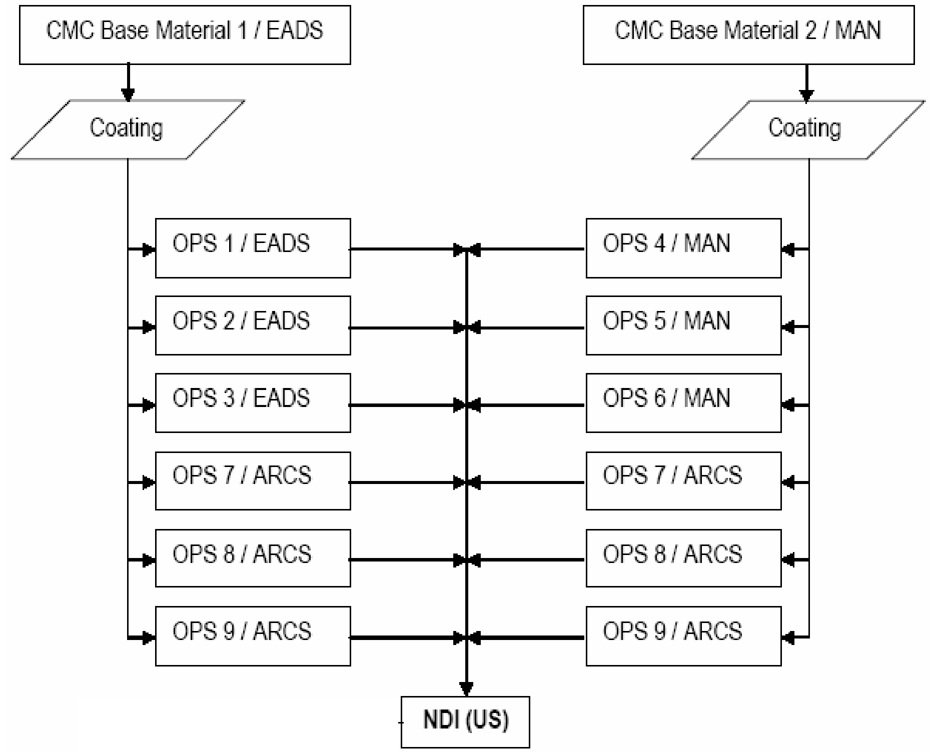
# EXPERIMENTAL

## Project Objectives

- Comparative study of various CMC/OPS combinations
  - Established systems that have already been applied for re-entry studies
  - Novel systems yet without space qualification
- Testing under re-entry relevant conditions
  - Thermo-mechanical testing in ARCS's re-entry simulation chamber
    - Temperatures of 1,450 and 1,550 °C
    - Heating/cooling rates comparable to HOPPER study
    - Severe thermal gradients within the samples
    - Constant pressure of 40 mbar
  - Plasma tests at DLR Cologne

# EXPERIMENTAL

## Base materials and OPS

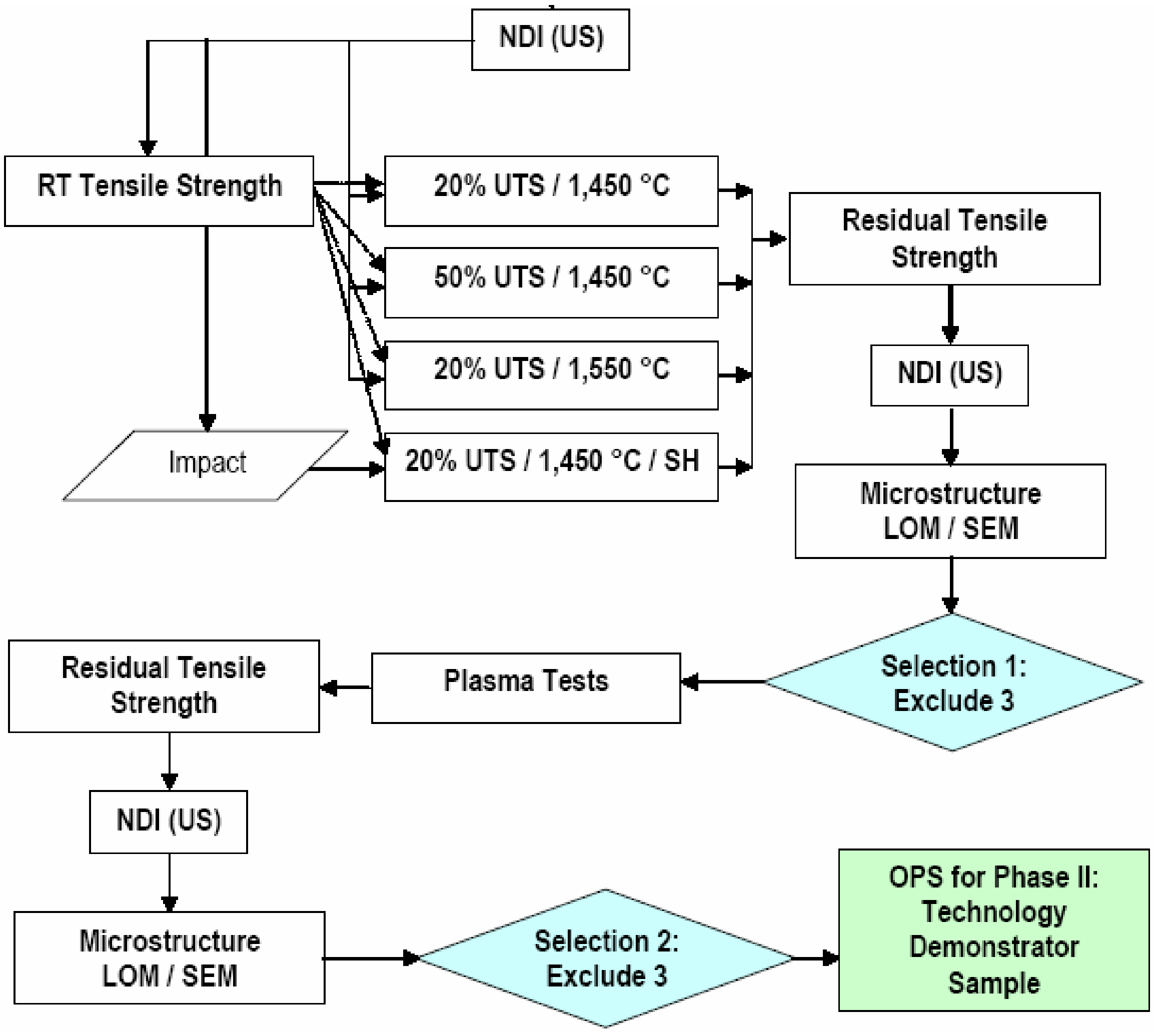



- CMC Base materials:
  - EADS base material (LPI-process)
  - MAN base material (PVI-process)
  - Samples: 230 * 10 * 3.2-3.5 mm,

  (rectangular shape)
- OPS
  - CVD-based OPS (MAN OPS 4)
  - CVD-SiC layers are typically used as a bonding layer to the substrate and often also as a top layer to provide erosion protection
  - Slurry-based OPS (EADS OPS 1, 2, 3; MAN OPS 5, 6)
  - Sol/Gel-based OPS (ARCS OPS 7, 8, 9)
  - All OPS have been applied as multi-layer systems

# EXPERIMENTAL

- **Study Logic – Phase I**
  - Series of Tests of increasing complexity
  - Selection Processes
  - Final Selection of best OPS/base material pairings



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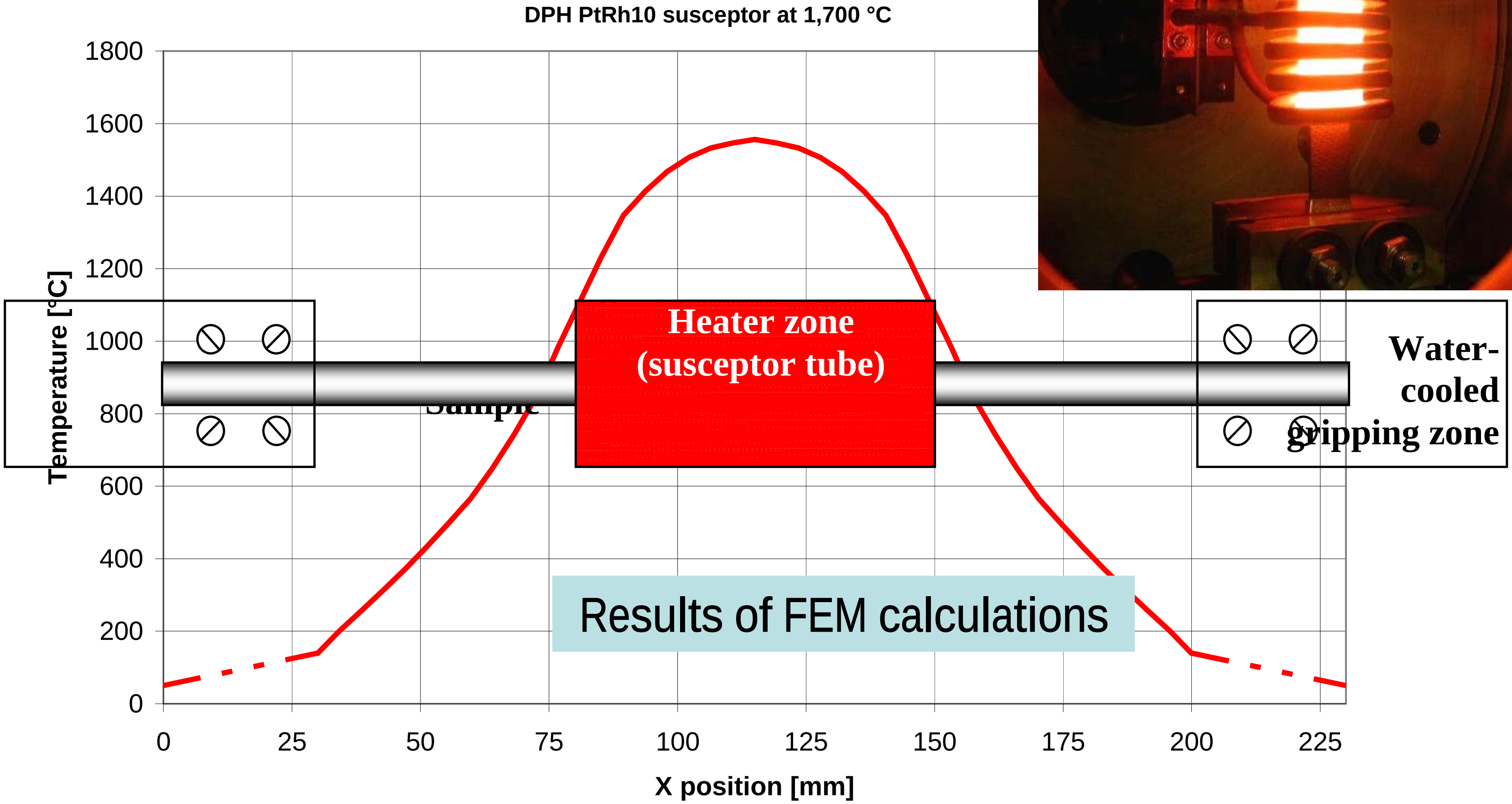
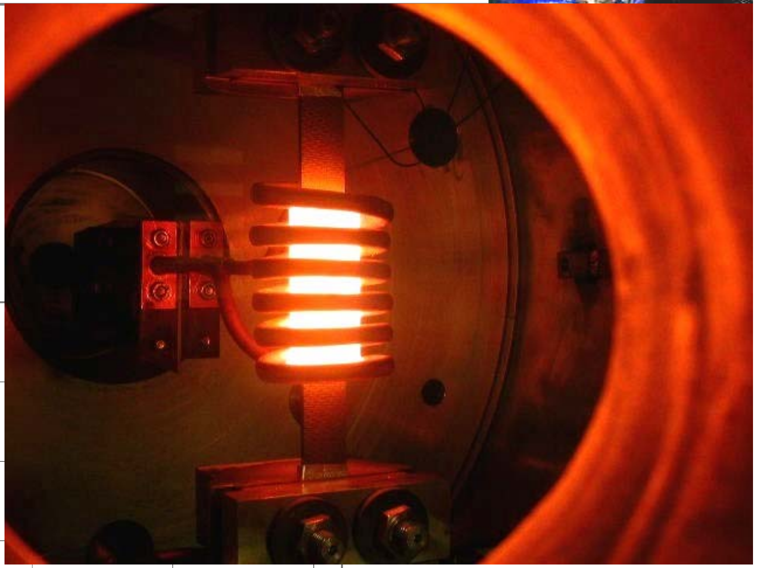
Aerospace Materials Technology

seibersdorf research
*Ein Unternehmen der Austrian Research Centers.*

# EXPERIMENTAL

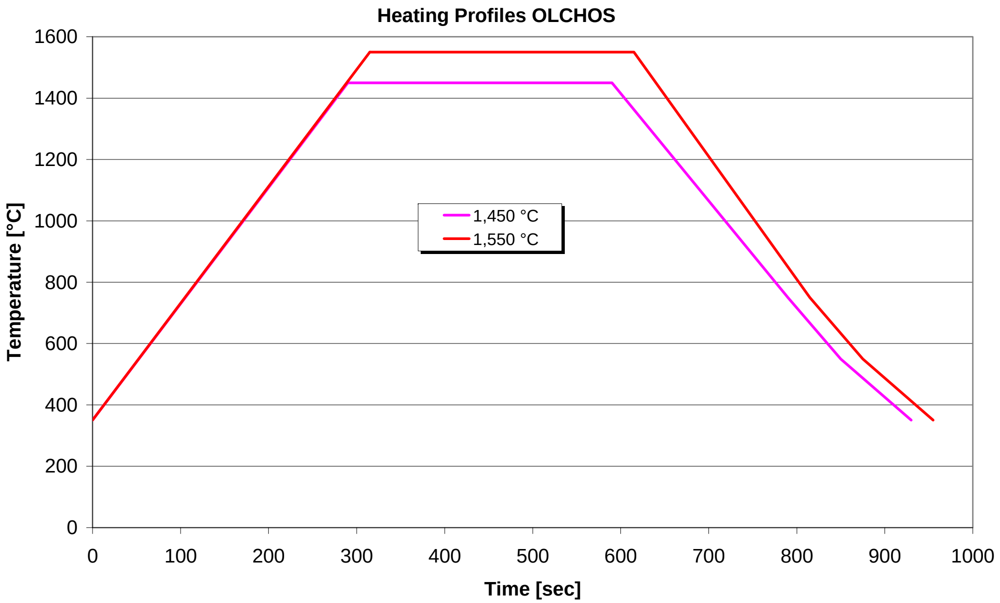
## Thermal Loads for Coupon Tests



# EXPERIMENTAL

- Thermal Loads for Coupon Tests

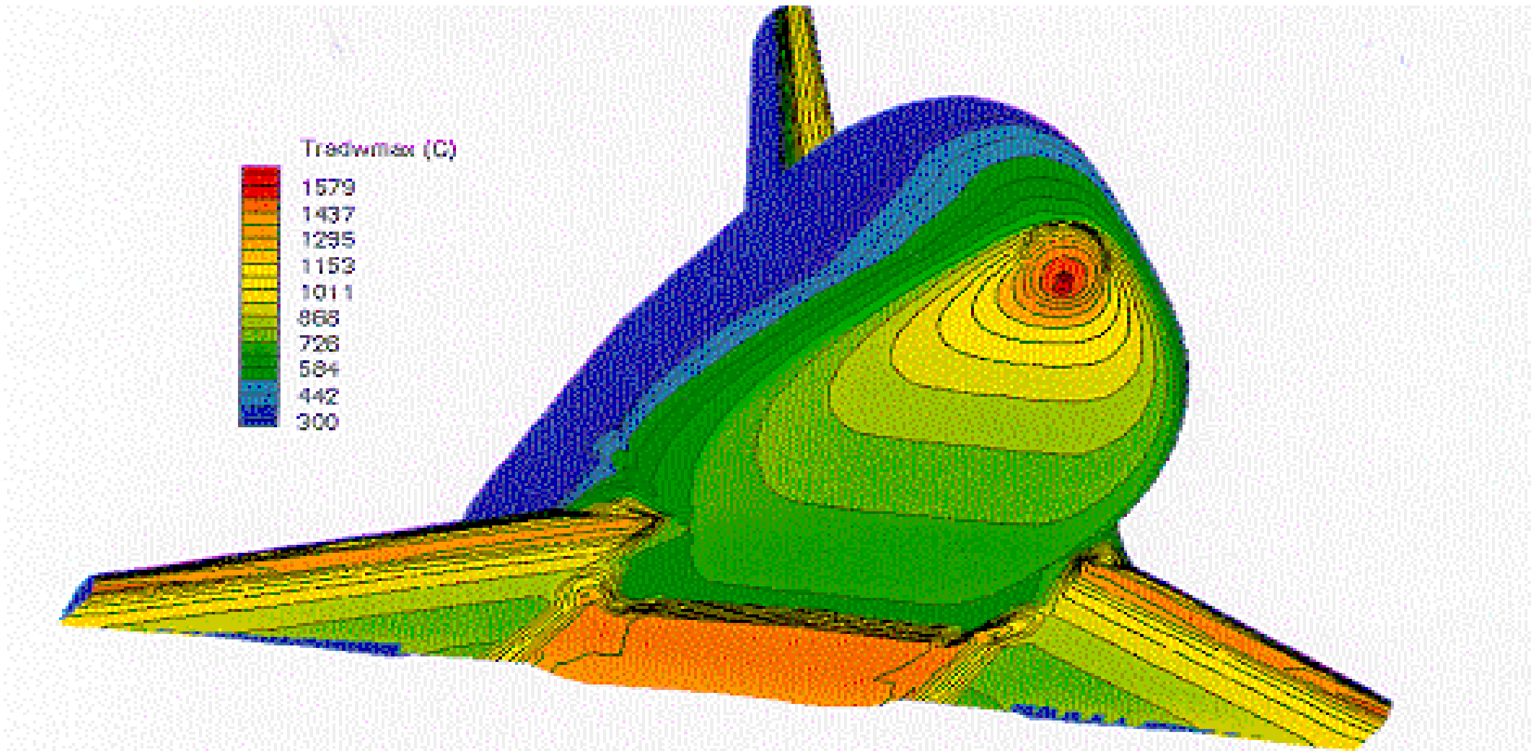



- Two temperature profiles with different maximum temperature selected

- Temperature profiles represent the expected loads of large areas of the heat shields
- Heating and cooling rates have been adopted from HOPPER study
- Additionally, severe thermal gradients within the samples applied
  - Temperatures given above are only in the centre
  - Ends of samples are held at <200 °C

# EXPERIMENTAL

## Thermal Loads for Coupon Tests




*Maximum Wall Temperature Distribution Along Trajectory Shown on "HOPPER" Concept*

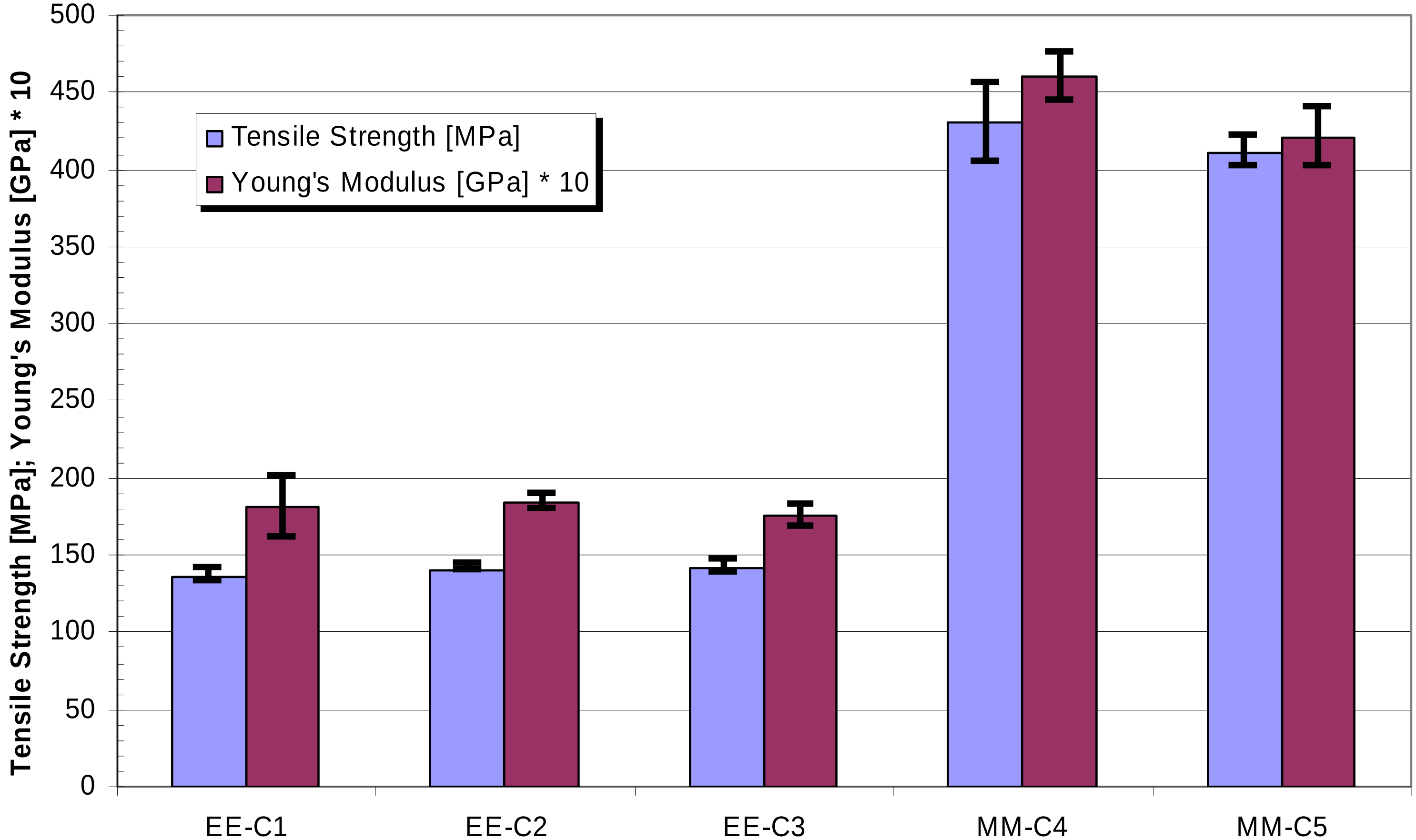
# EXPERIMENTAL

## Relevant Loads for Coupon Tests

- Mechanical loads at 20% and 50% of RT tensile strength
  - superposed a sinusoidal load of +/- 2% / +/- 5% of RT tensile strength
- Atmospheric / chemical load of 40 mbar laboratory air, 20 Nl/h gas stream
  - Constant pressure selected for simplification of tests
  - Few tests performed at 80 and 1000 mbar to assess pressure influence on specimen lifetime
- Samples will be tested for a maximum of 100 heating/cooling (i.e. re-entry) cycles

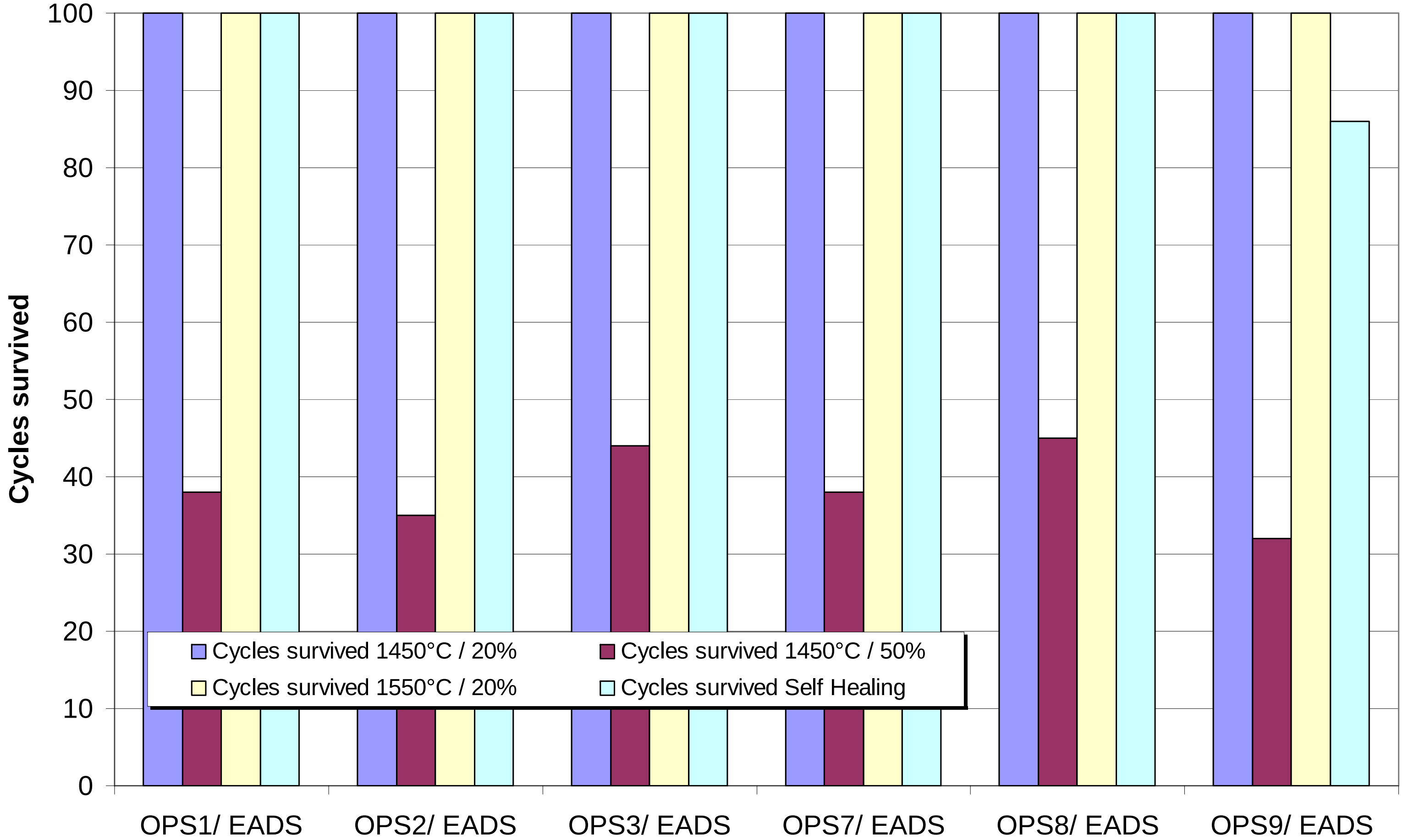
# TEST RESULTS

## Room temperature tensile tests



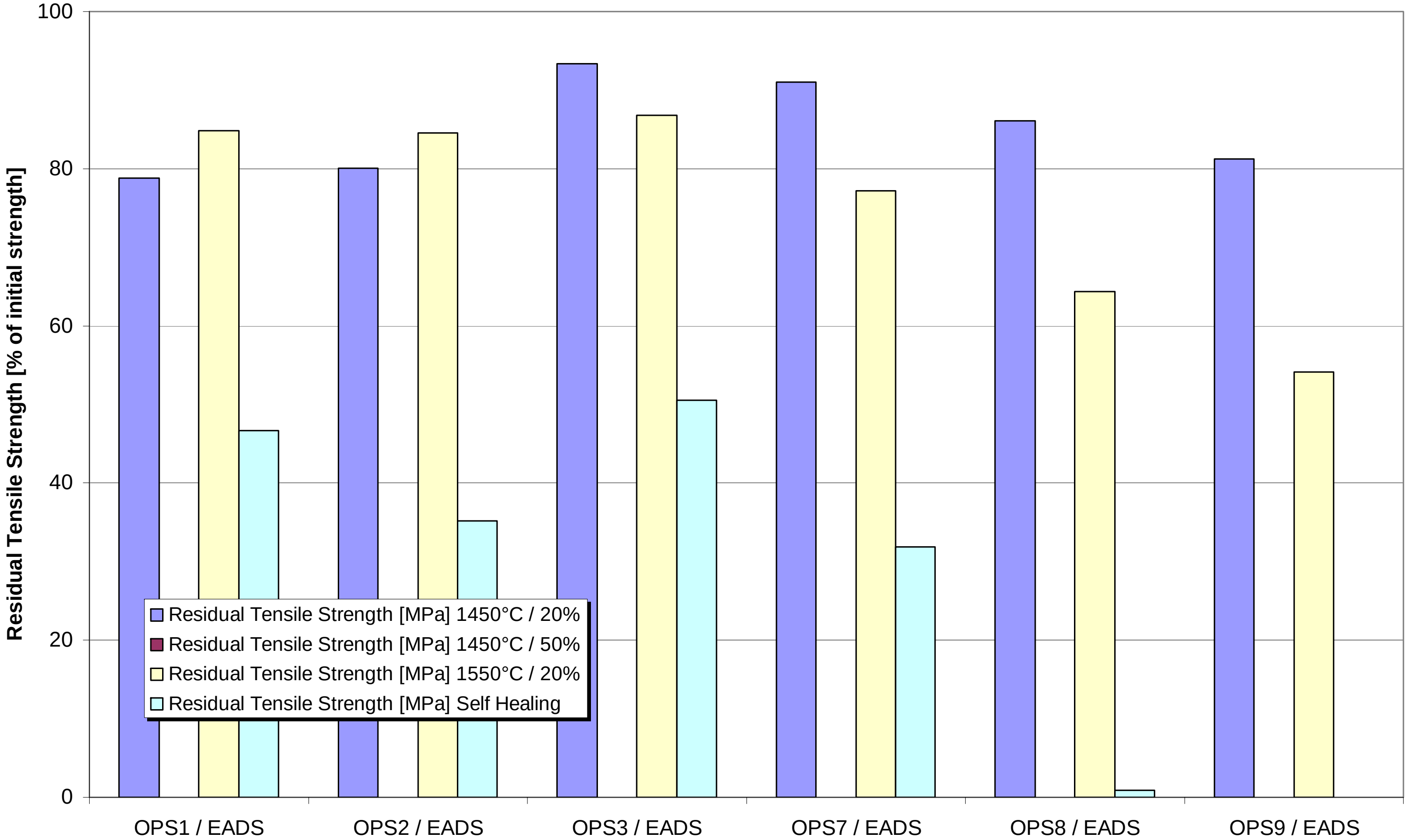
# TEST RESULTS

## All test conditions / EADS Base Material: Cycles survived

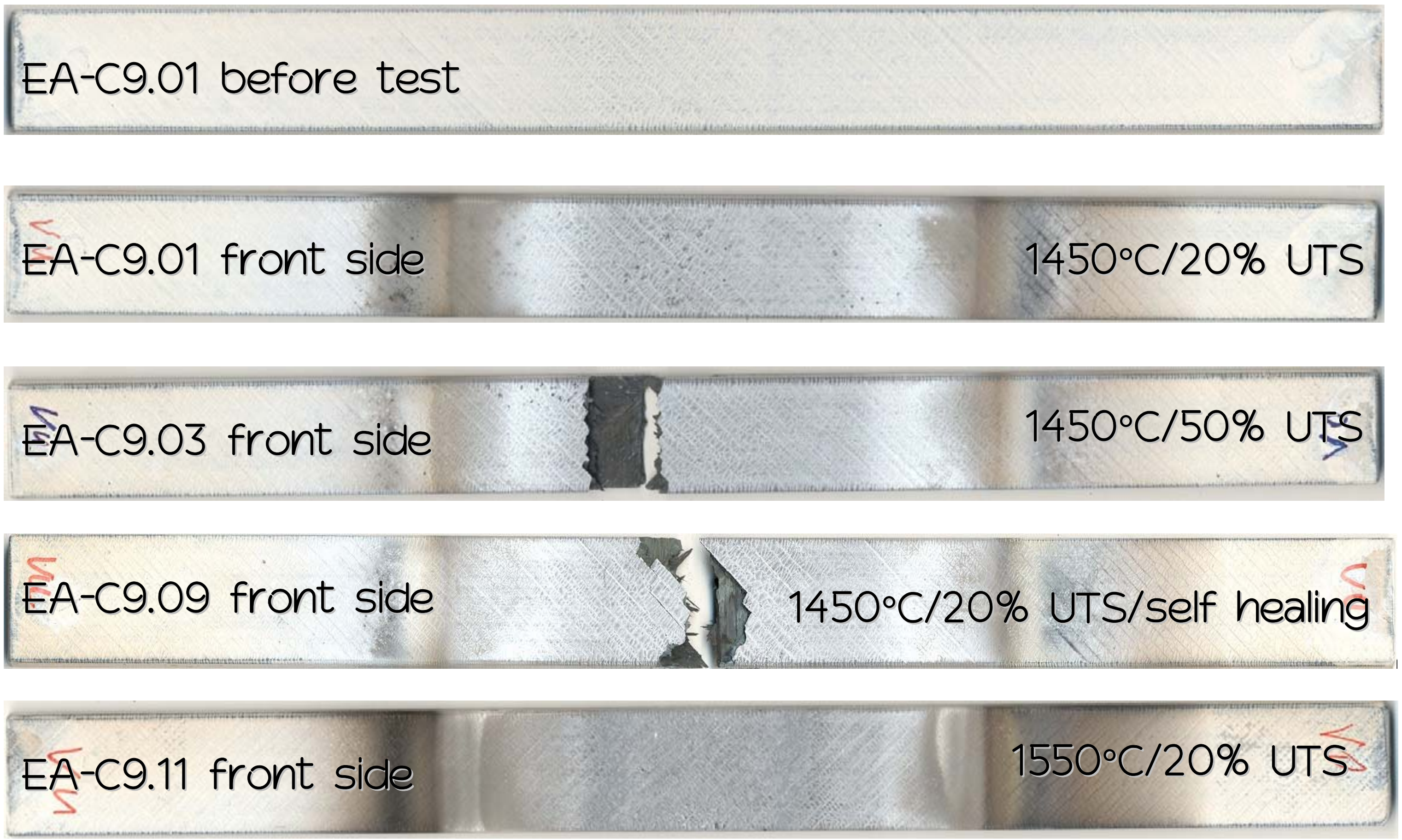


# TEST RESULTS

## All test conditions / EADS Base Material: Residual Tensile Strength

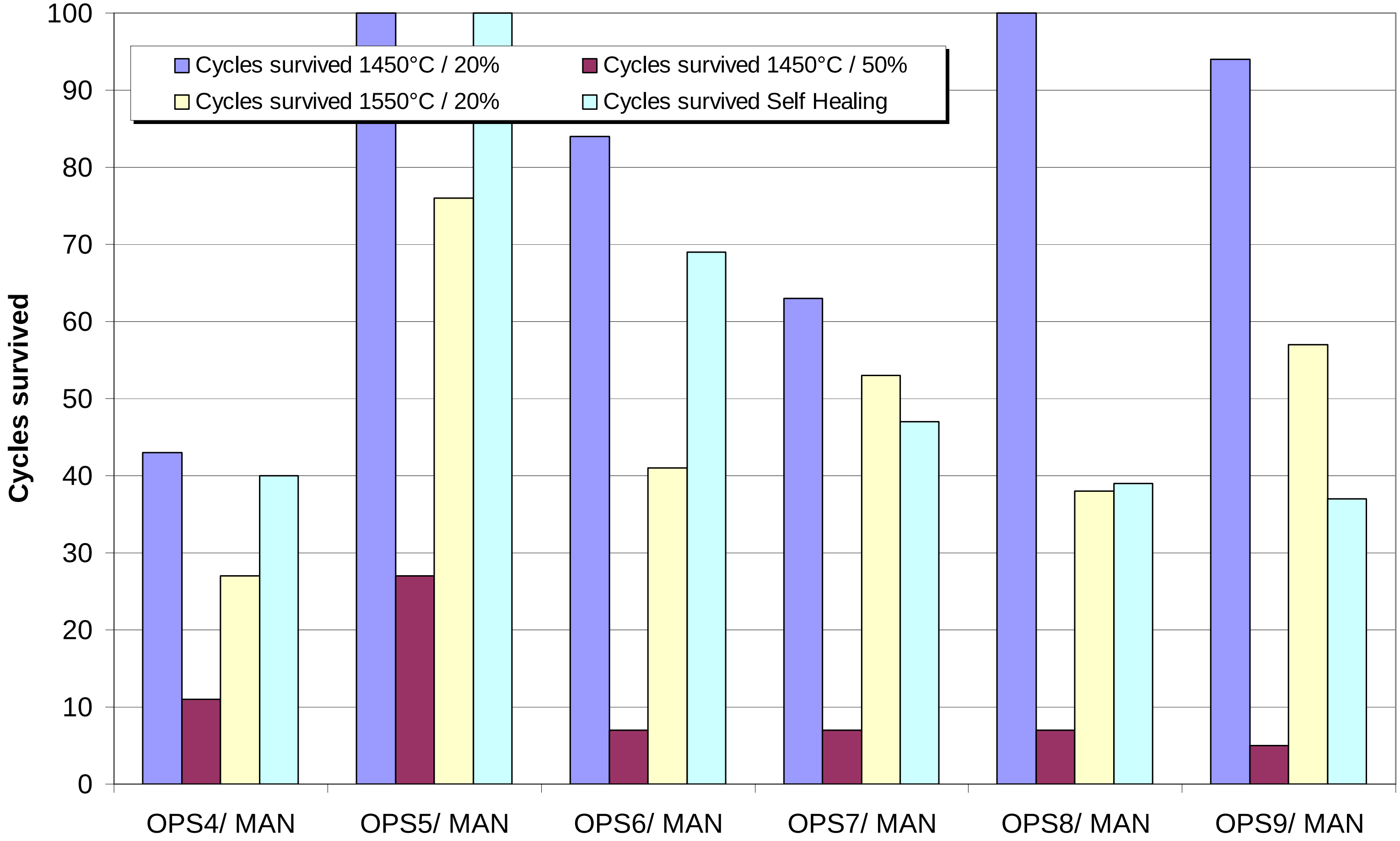


# EA Manufacturer Base Material - EADS Space Transportation
Manufacturer coating - ARC Seibersdorf



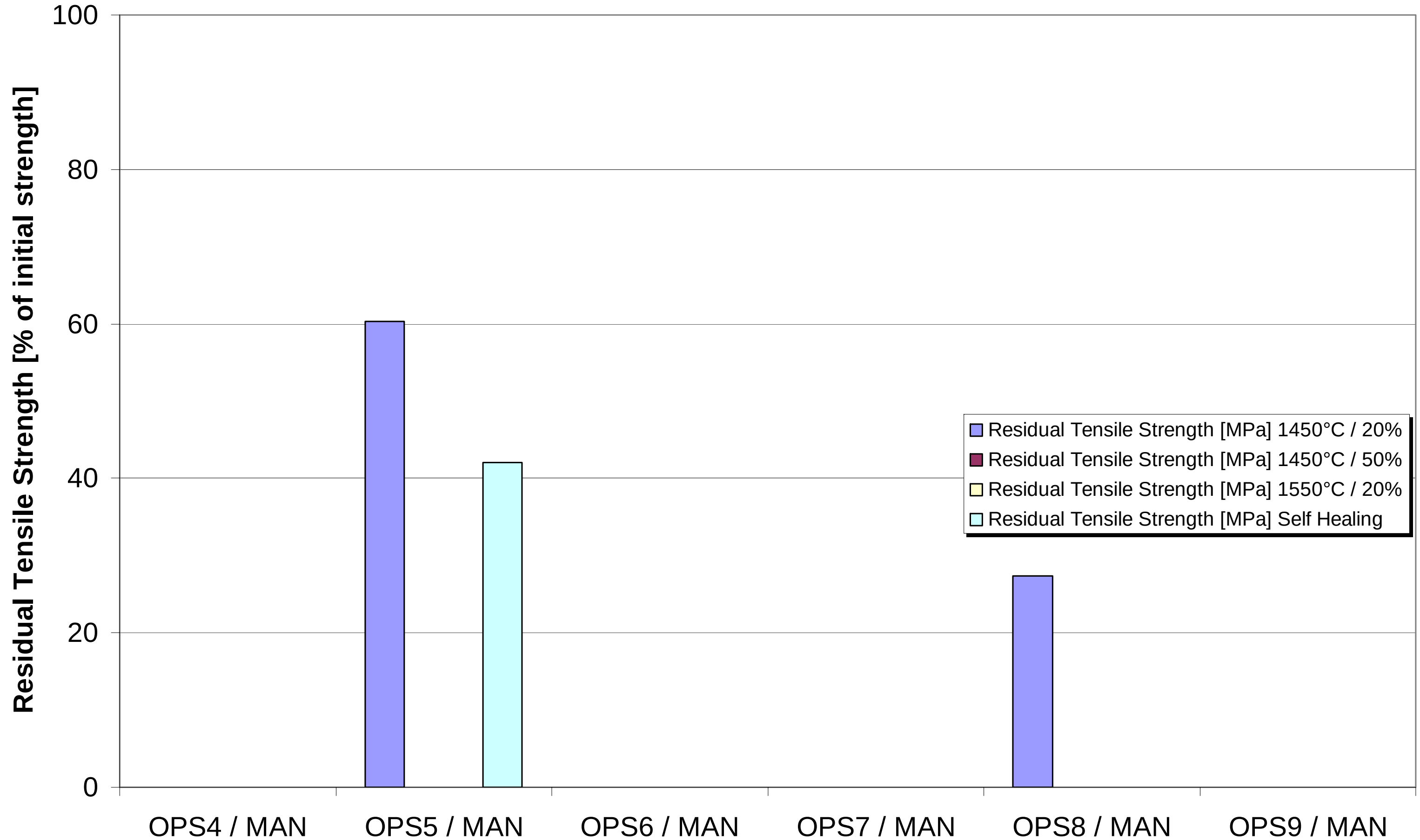
# TEST RESULTS

## All test conditions / MAN Base Material: Cycles Survived



# TEST RESULTS

## All test conditions / MAN Base Material: Residual Tensile Strength



# MA Manufacturer Base Material - MT Aerospace AG
## Manufacturer coating - ARC Seibersdorf


94 cycles

5 cycles

37 cycles

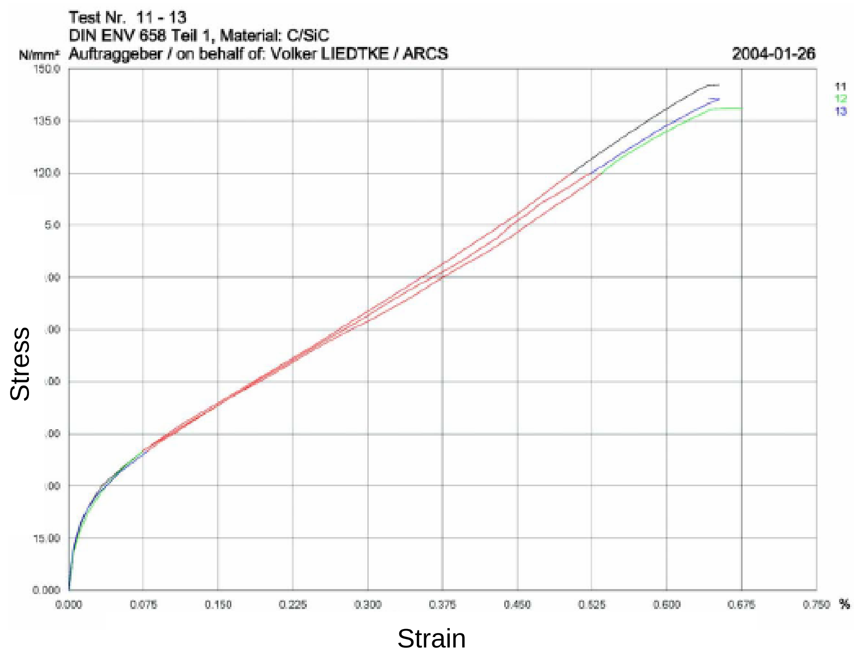
57 cycles

# TEST RESULTS

## Thermo-mechanical tests – Influence of test conditions: Load level

Stress-strain curve for EADS base material shows two regions

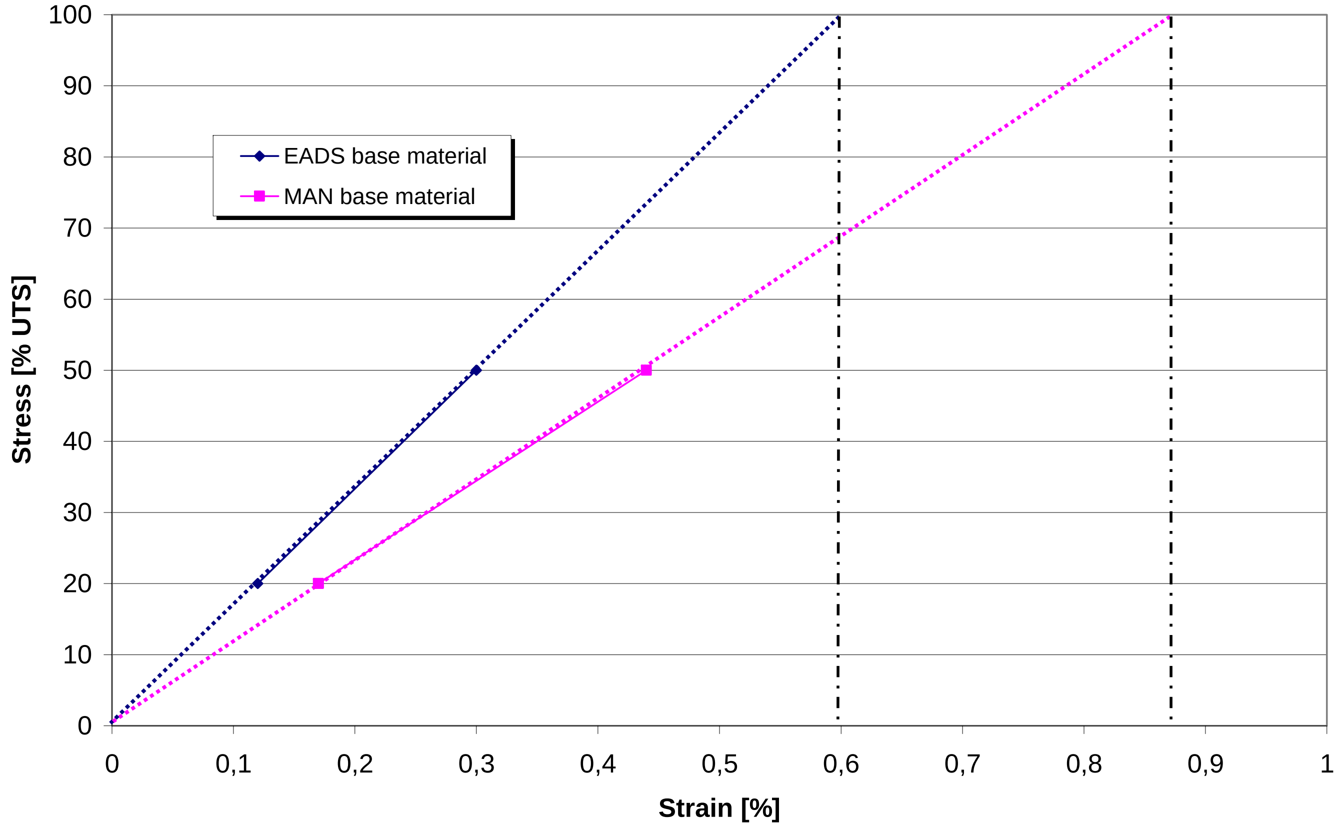
- <u>up to 0.14 % elongation</u>:
  the composite deforms showing a high E modulus (approx. 40 GPa) attributed to the CVD-SiC Coating.
- <u>from 0.14 % elongation:</u>
  the coating is broken and the composite follows an elastic deformation behaviour like the base material, which has a lower Young’s modulus (approx. 14 GPa).




*From literature, the maximum strain of CVD-SiC layers can be found to be 0.1 to 0.15 %*
*Young’s modulus of 30-60 GPa also in line with experimental findings as shown above*

# TEST RESULTS

## Thermo-mechanical tests – Influence of test conditions: Load level




Stress-strain correlation for EADS and MAN base materials at RT (average of several tests)

# TEST RESULTS

## Thermo-mechanical tests – Influence of test conditions: Load level

- Significant difference between testing at 20 % UTS and 50 % UTS
- The higher load level reduces specimen lifetime significantly
- Not a single specimen did survive the full 100 cycles at this load! Cracks in the OPS give way to oxygen
- Rapid destruction of underlying carbon fibres
- Fatigue damage can be excluded
- Samples were subject to the same number of mechanical load cycles at RT
- No clear indication that there is any damage
- Residual tensile strength almost preserved
- A closer look onto the RT tensile tests for EADS base material gives some indication on the suggested damaging mechanism!

# TEST RESULTS

## Tests at various pressures

- Besides the standard pressure of 40 mbar, specimens have been tested at 80 mbar and at atmospheric pressure (1000 mbar).
- Streaming conditions for all pressures were held constant.

| Sample Designation | Tensile strength at RT [kN] | Pressure [mbar] | Internal number | **Cycles survived** | **$\Delta m/m_0$ %** | **Residual Strength [kN]** | **[% RT]** |
|---|---|---|---|---|---|---|---|
| EE-C2.04 | 10,38 | 40 | 84 | **100** | **0,04** | **8,31** | **80,1%** |
| EE-C2.10 | 10,38 | 80 | 103 | **100** | **0,06** | **7,05** | **68,0%** |
| EE-C2.11 | 10,38 | 1000 | 104 | **45** | **-2,93** | **n/a** | **n/a** |
| EE-C3.04 | 10,65 | 40 | 85 | **100** | **0,09** | **9,94** | **93,4%** |
| EE-C3.12 | 10,65 | 80 | 109 | **100** | **0,13** | **8,81** | **82,7%** |
| MM-C4.04 | 30,51 | 40 | 29 | **43** | **-2,13** | **n/a** | **n/a** |
| MM-C4.10 | 30,51 | 80 | 35 | **46** | **-1,65** | **n/a** | **n/a** |
| MM-C4.11 | 30,51 | 1000 | 36 | **18** | **-2,36** | **n/a** | **n/a** |

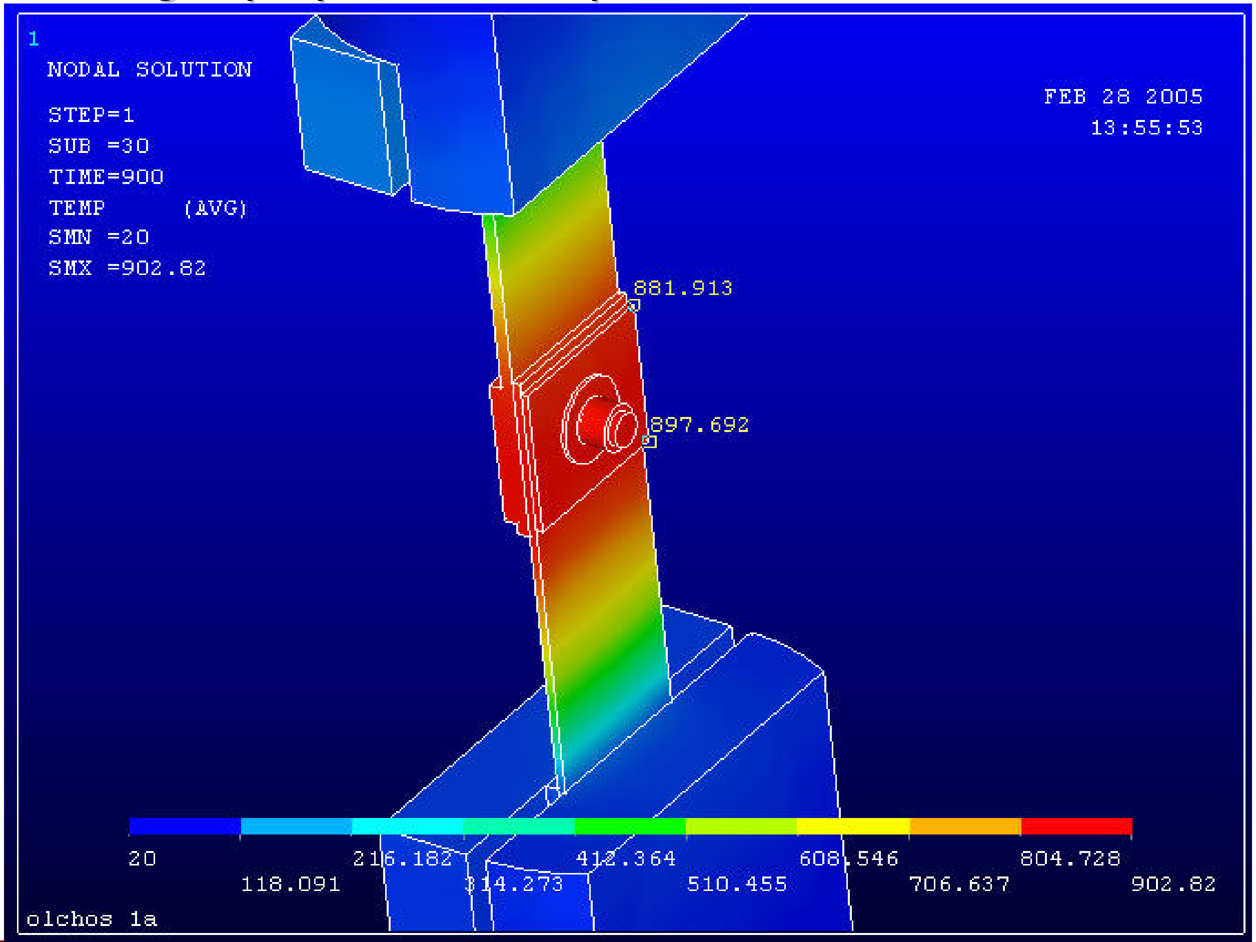
# PHASE II – TECHNOLOGY DEMONSTRATOR SAMPLE

## FEM calculations – Thermal Modelling of proposed Concepts

### EADS TDS

- Attachment point of the C/SiC trailing edge on the metallic elevon box
- Metal-to-Ceramic joints
- Stress-free fasteners

Stationary conditions; gradient in the sample



# PHASE II – TECHNOLOGY DEMONSTRATOR SAMPLE

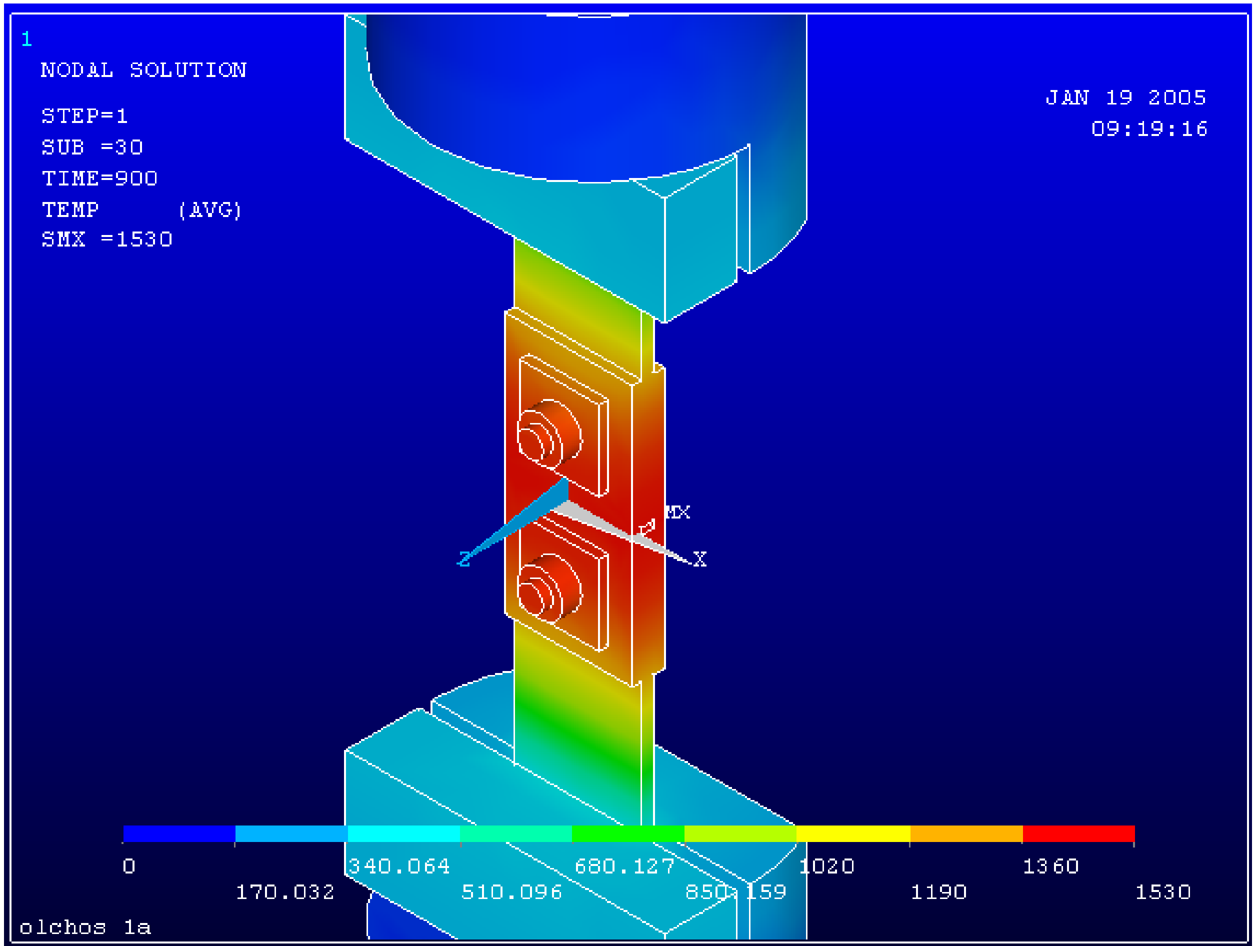
## FEM calculations – Thermal Modelling of proposed Concepts

### MAN TDS

- Fixation of body flap
- Ceramic-to-Ceramic joints

  2 different types

Stationary conditions; gradient in the sample



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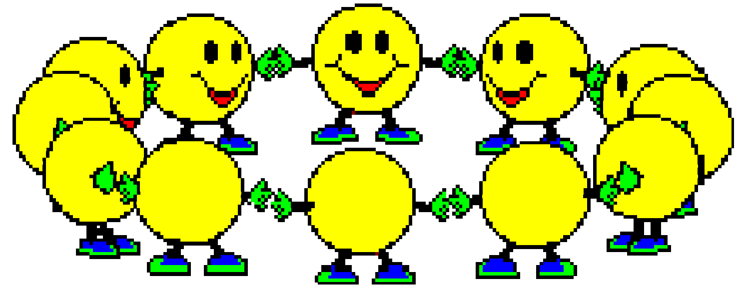
- Roland and Mario Holzbauer – Software Technicians
- Inmaculada Huertas Olivares – Project Coordination
- Alfred Karlovsky – Technician RT Tensile Tests and Servo-Hydraulic test machine
- Dietrich Klausinger – Mechanical Workshop
- Markus Langer – Technician Thermo-Mechanical Testing and Sol-Gel OPS Application
- Volker Liedtke – Project Manager
- Hans Lichtl – Metallography and Technical Support
- Grazyna Mozdzen – Light Optical Microscopy
- Michael Scheerer – FEM Calculations and Thermal Modelling



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