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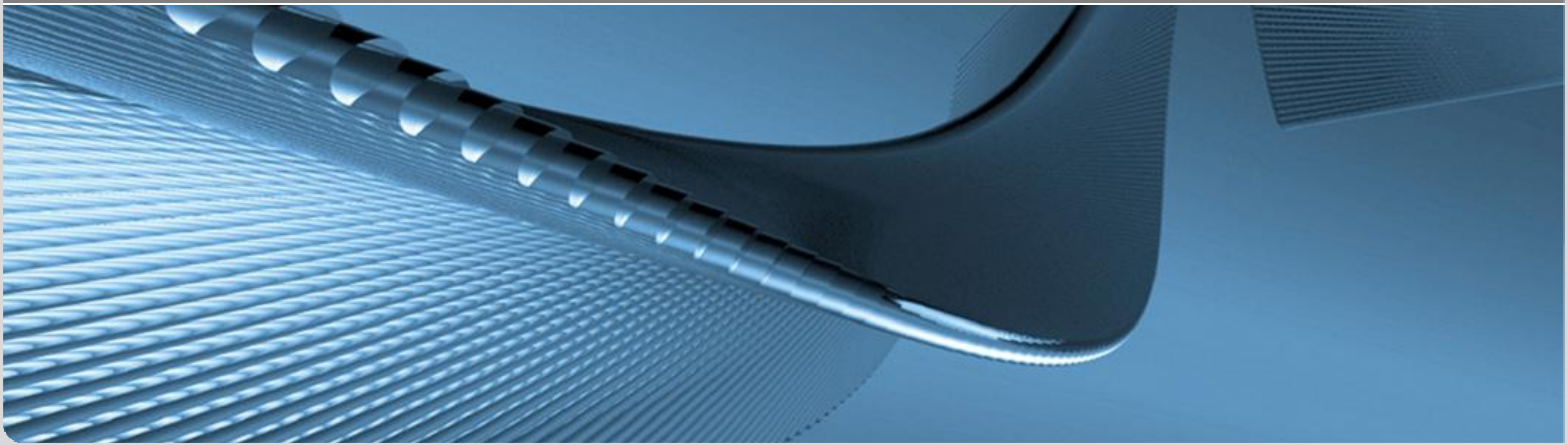
Cost effective fabrication of a fail-safe first wall

M. Rieth, B. Dafferner, S. Baumgärtner, S. Dichiser, T. Fabry, S. Fischer, W. Hildebrand, O. Palussek, H. Ritz, A. Sponda, R. Ziegler, H. Zimmermann

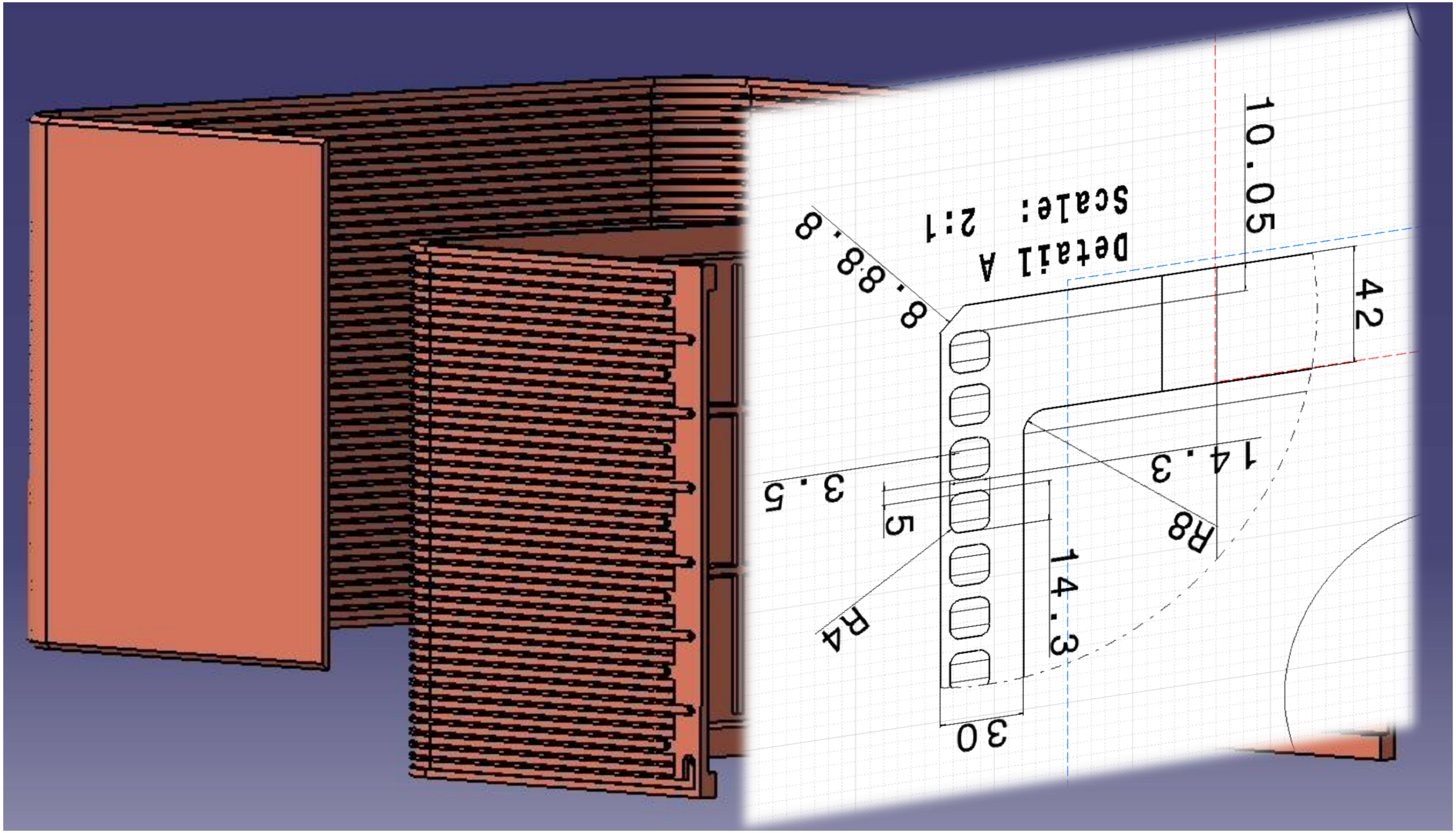
INSTITUTE FOR MATERIALS RESEARCH



Outline

- Introduction
- Basic Diffusion Weld Studies
  - Surface Processing
  - Surface Contamination
  - HT Creep under Pressure
- Problem Analysis
- Possible Solutions & Recommendations
- Conclusions

First Wall Fabrication: How …?



Fabrication/Production Criteria

- **Compatibility with industrial environment**
  - Applicability of standard fabrication processes → mass fabrication
  - Robustness against environmental influences (corrosion, rough handling, storage, …)
  - Tolerant against scattering of process parameters
- **Efficiency**
  - Costs
  - Recources
- **Safety/Reliability**
  - Dimensional Accuracy
  - Easy Quality Assurance
  - Reproducibility

General Fabrication Routes

Casting

- In principle, the complete U-bended FW could be fabricated.
- Draw-backs: The impurity levels of the Eurofer alloy would be increased (higher activation!) and voids/bubbles cannot be excluded.

Machining

- The only possible way would be ECM, EDM, or broaching. But there is a strict limitation of the channel length.
- Draw-backs: It is difficult to fabricate the required initial holes (further length restrictions!?).

Powder Metallurgy

- Route: (1) Powder compaction, (2) encapsulation, (3) HIP
- (A) embedding of U-bended tubes
- (B) embedding of straight removable rods/tubes followed by bending the FW

Solid State Welding

Assessment of Fabrication Routes

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Casting

- NOT tested yet!
- Relatively expensive due to complicated mold and filler fabrication as well as filler removal
- Material degradations are likely

Machining

- No solution available yet → Development of suitable ECM or other process necessary!
- Therefore, EXPENSIVE
- NO mass production

Powder Metallurgy

- Established in industry
- Extensive encapsulation for embedded tubes necessary
- Severe material degradation: EMBRITTLEMENT!

Solid State Welding

Diffusion Welding (1st step: low pressure with closed channels)

weld pressure by **HIP**

uniaxial pressing

WITH encapsulat

WITH pressure plates

WIT pre p

R&D since 1996

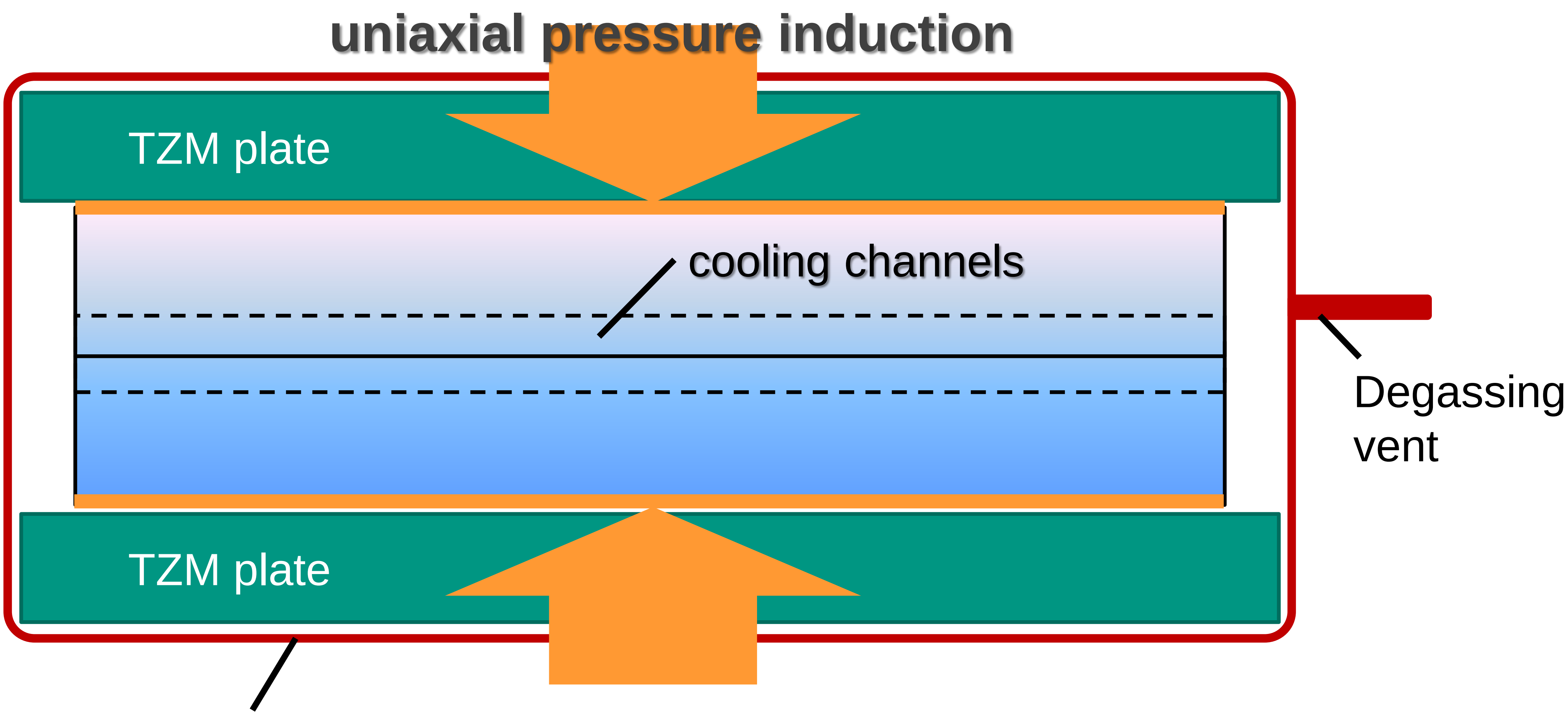
- *E. Rigal*, , DEM, CEA
- *G. Reimann*, IMF III, KIT
- *A. von der Weth, H. Kempe*, IMF II, INR, KIT
- *M. Rieth, B. Dafferner*, IMF II, KIT
- *Kawasaki Ind.*, Japan

Diffusion Welding (2st step: high pressure with open channels)

Open channels after 1st step

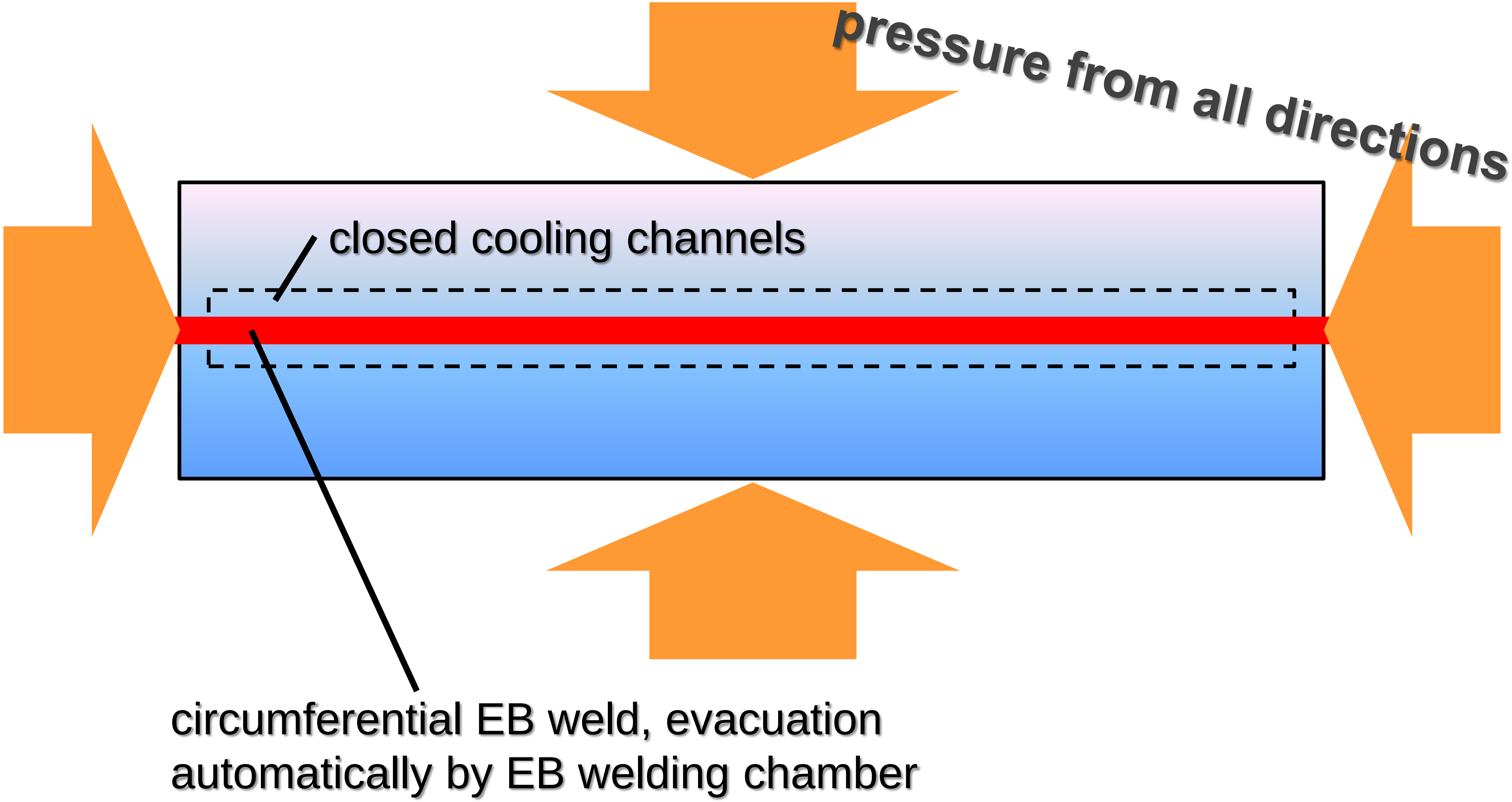
Laser welding stripes on top of channels, then DW 2nd plate

(1) Diffusion Welding: HIP & Plates

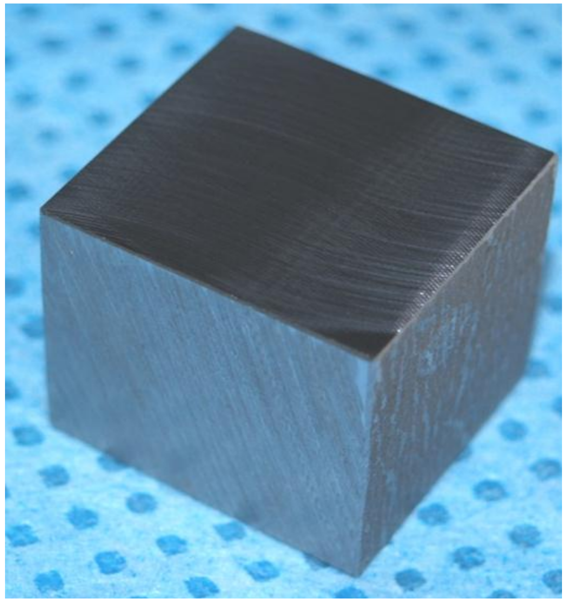


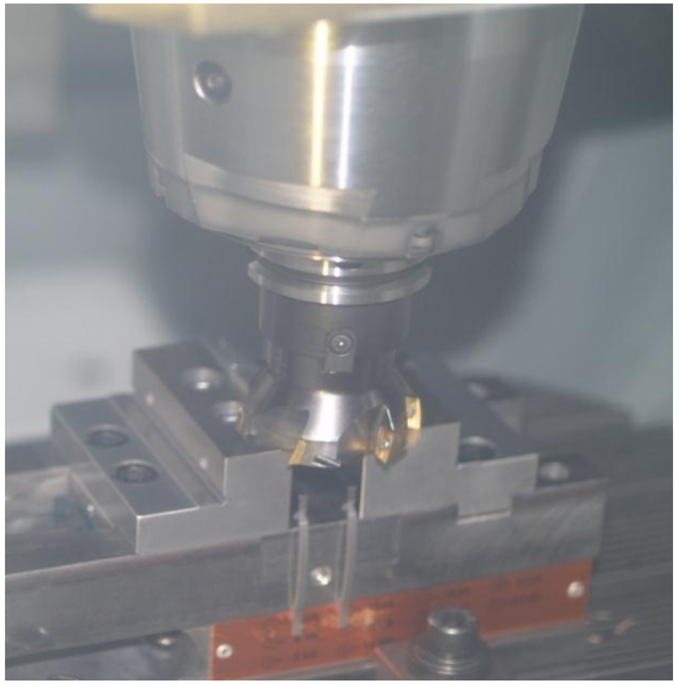
Standard casing sheet material (e.g. SS 304) with vacuum tight TIG welds and vents for evacuation

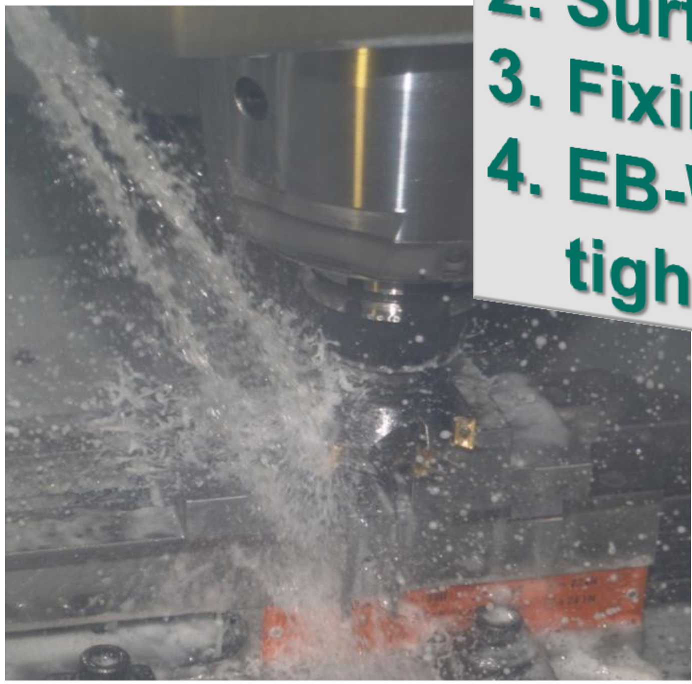
(2) Diffusion Welding: Self-Encapsulation



Basic Studies



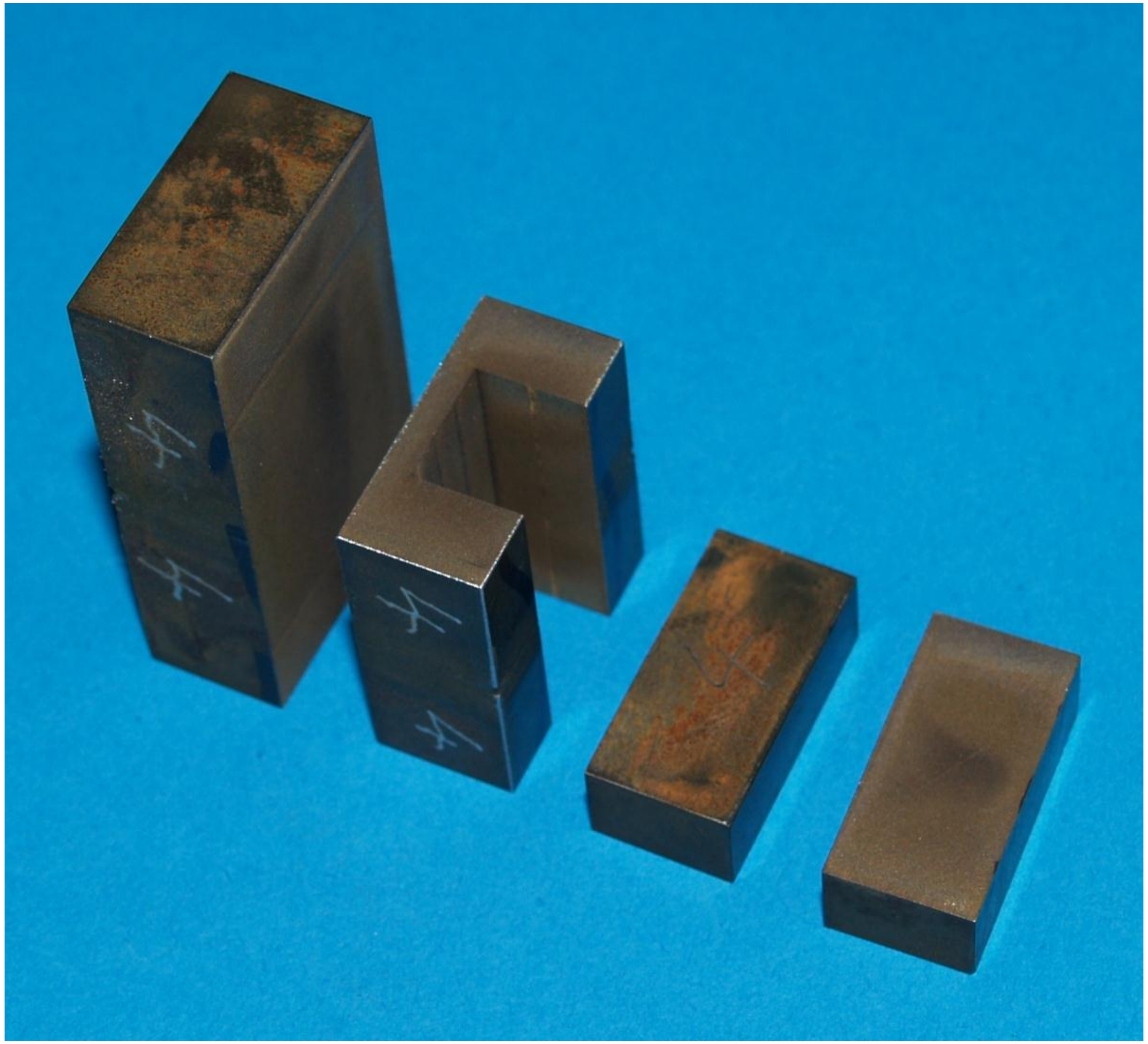


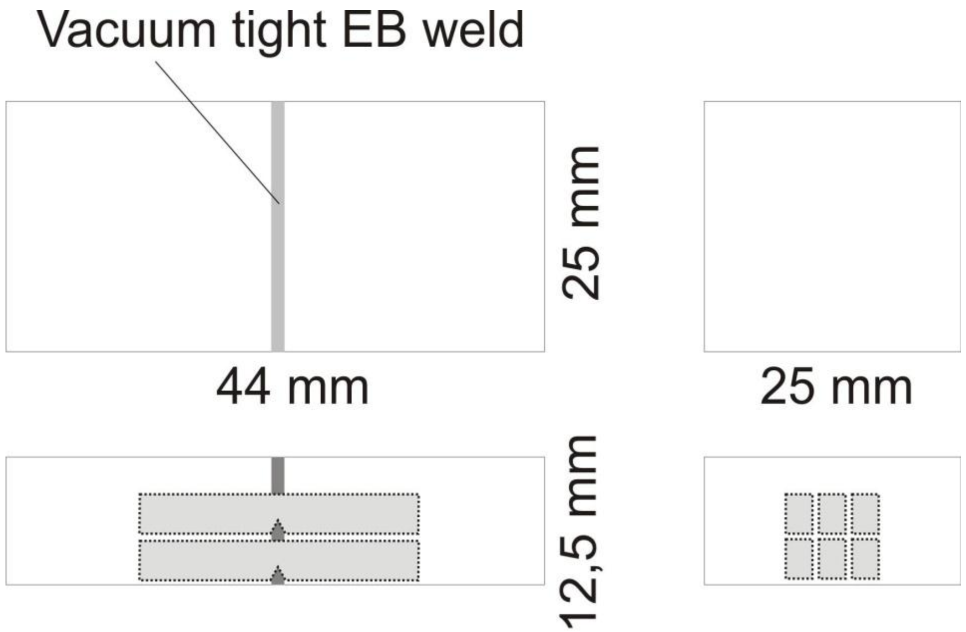


1. Standard Surfaces
2. Surface Treatment
3. Fixing
4. EB-Welding (vacuum tight)

Basic Studies: Surface Fabrication

Diffusion Weld Samples and Charpy Specimen Fabrication

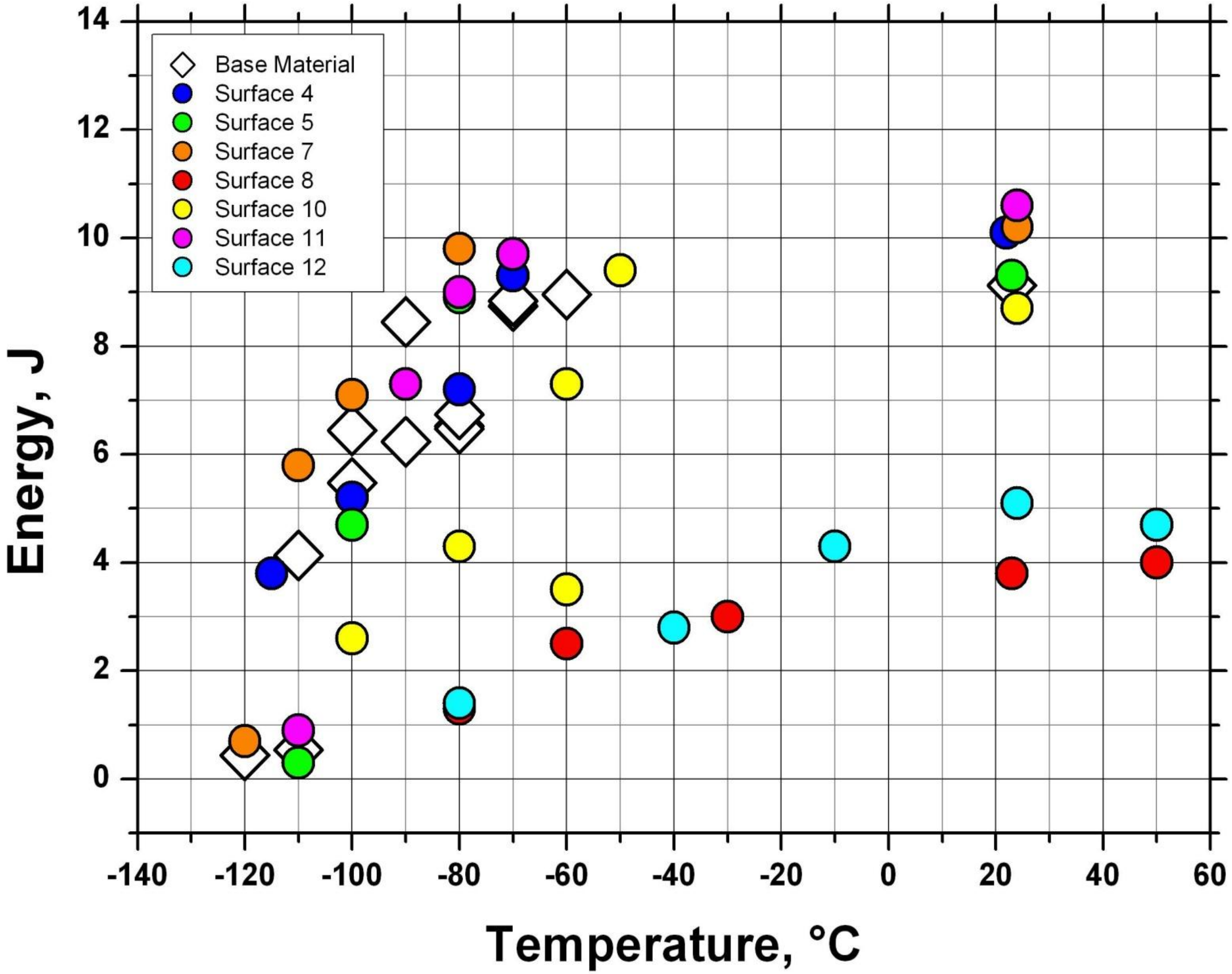




25 MPa, 1050 °C, 2 h

7 different surfaces fabricated with different tools

Surface Fabrication: Test Results

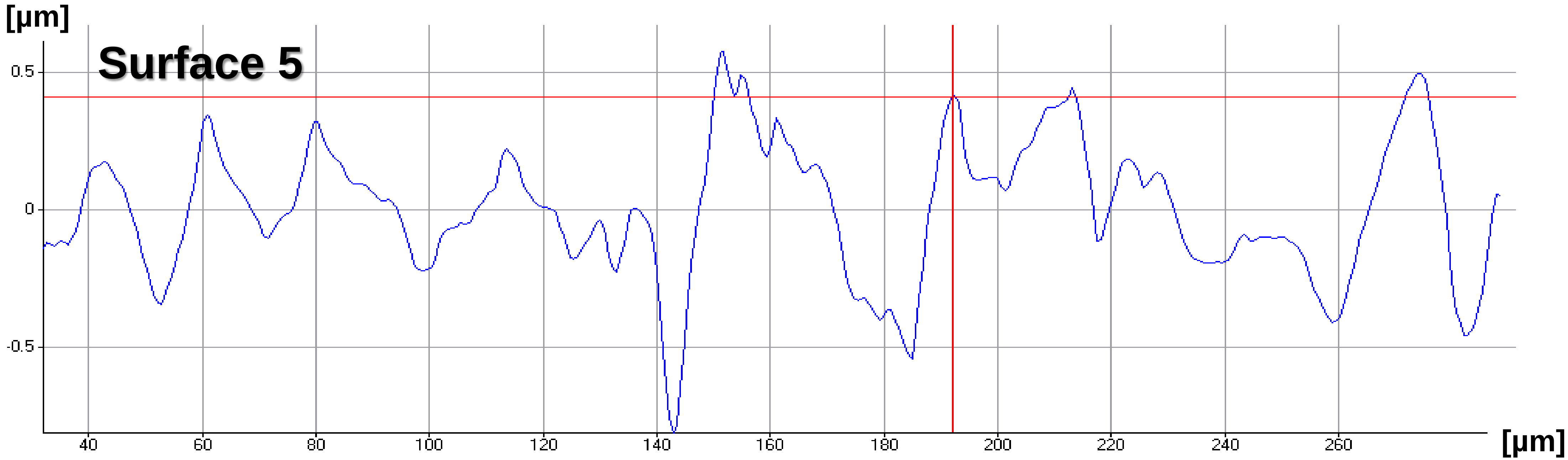


Surfaces **8**, **10**, and **12** lead to worse properties compared to the base material!

Why?

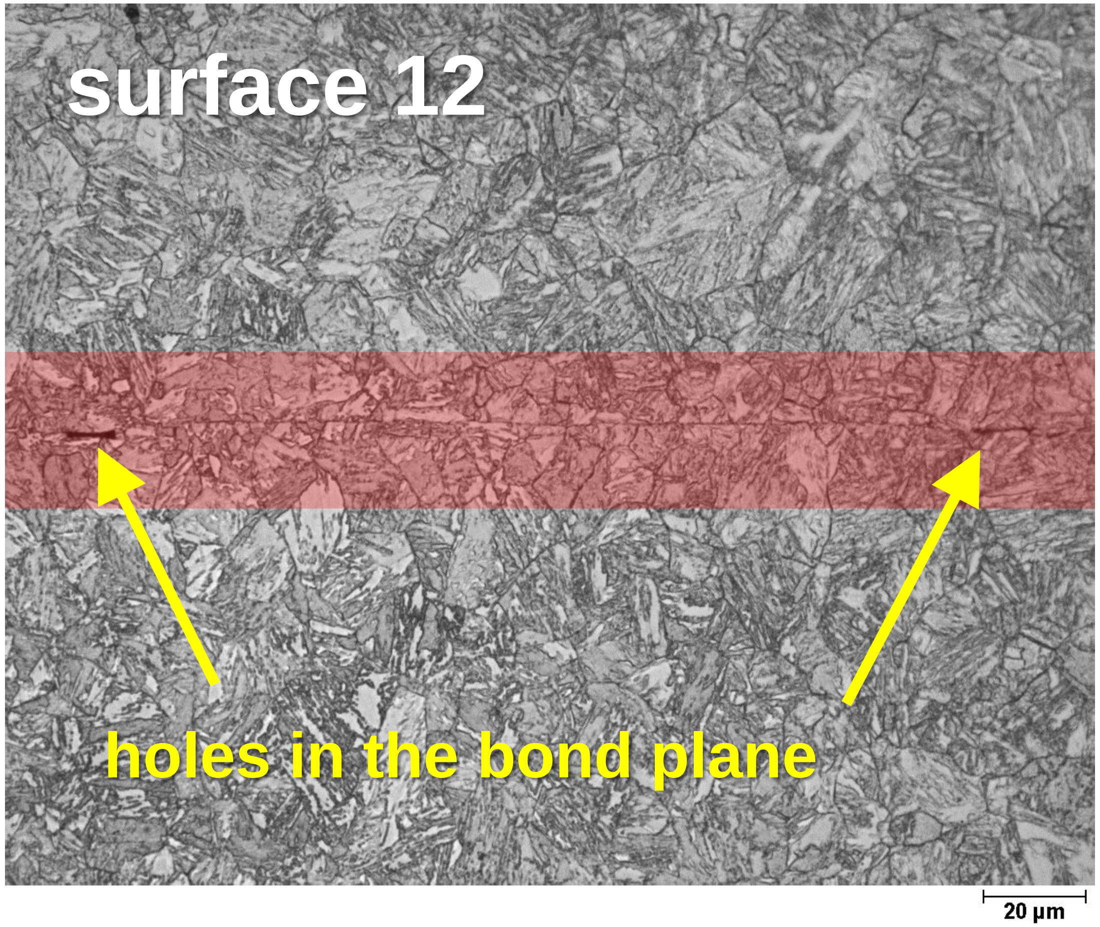
Fabrication: Surface Roughness

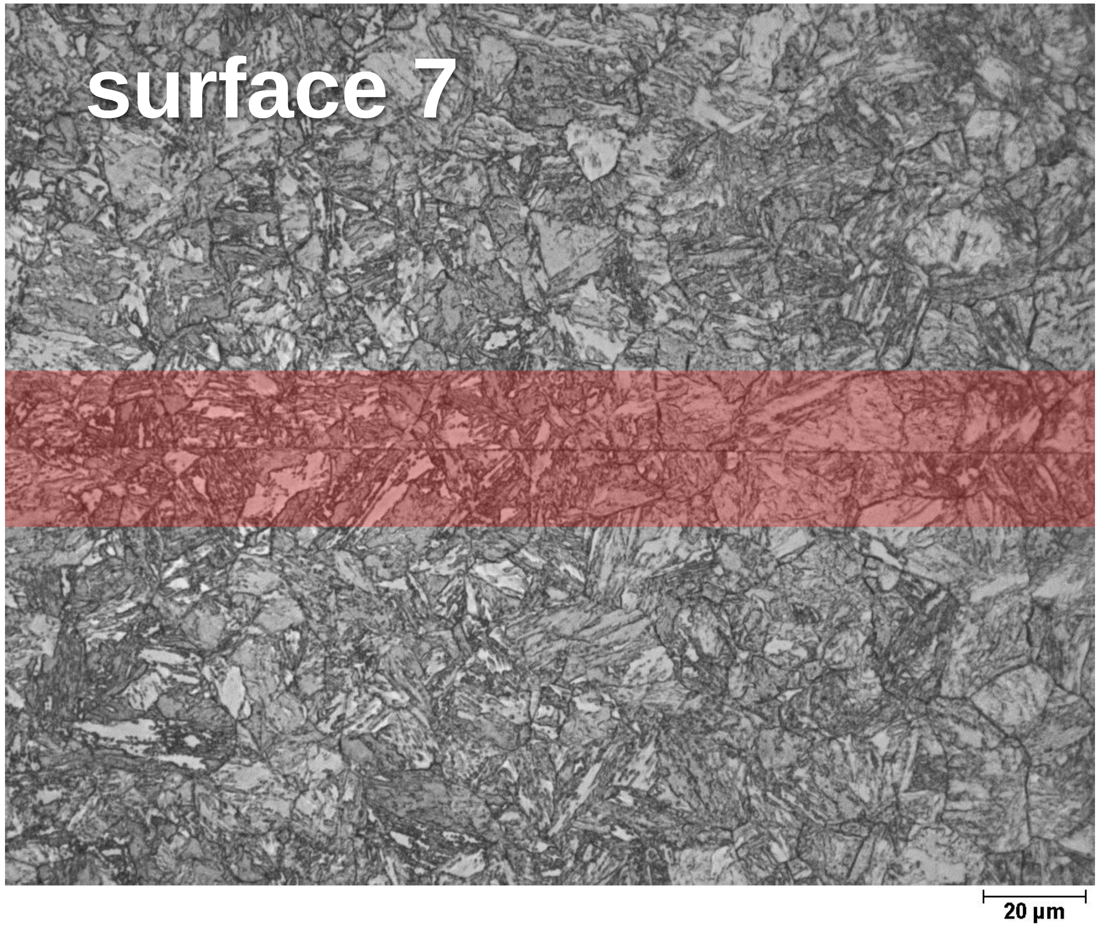
Effect of different milling parameters on surface quality



Surface Fabrication: Microstructure

Metallography of Diffusion Weld Lines

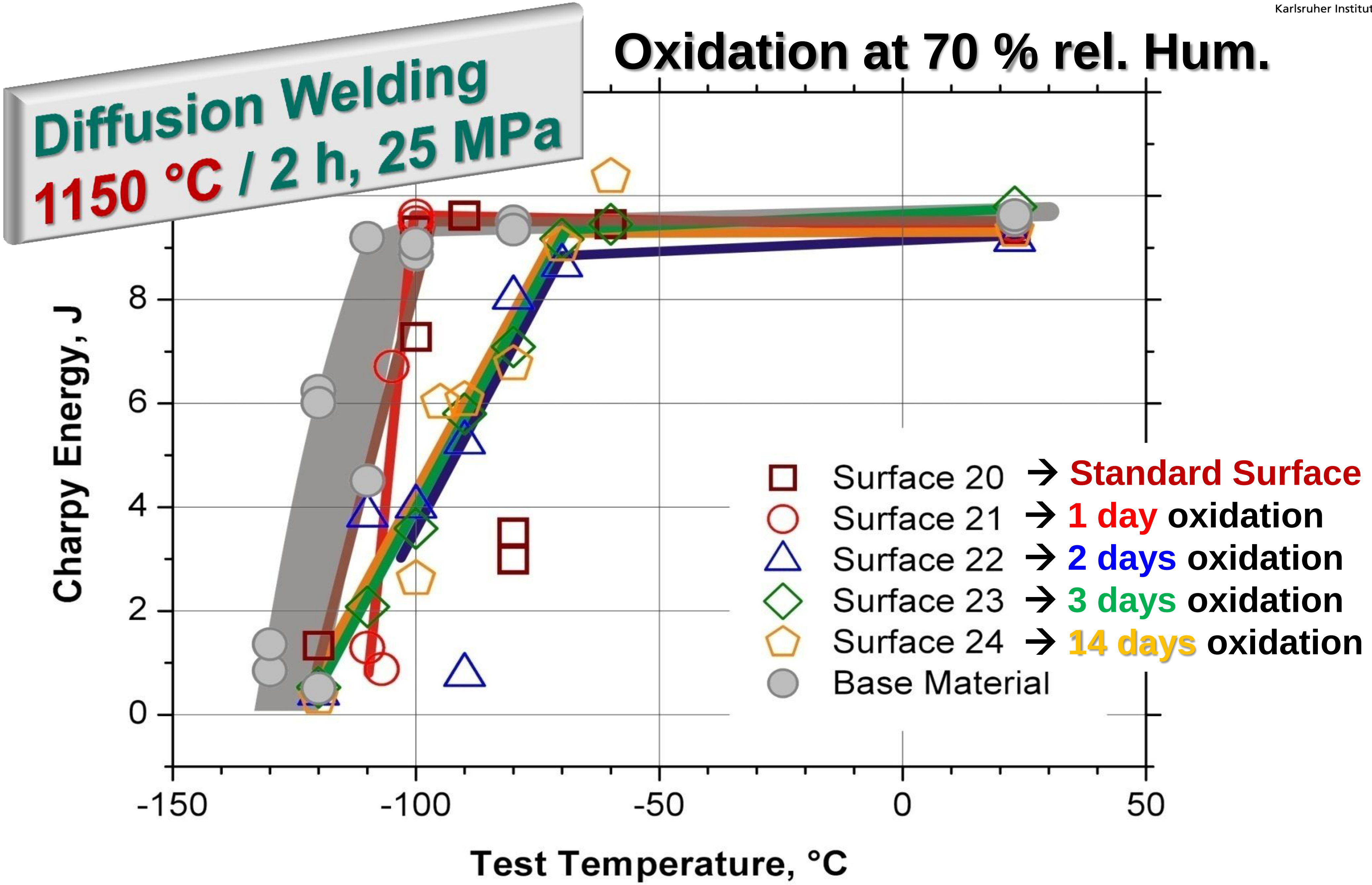




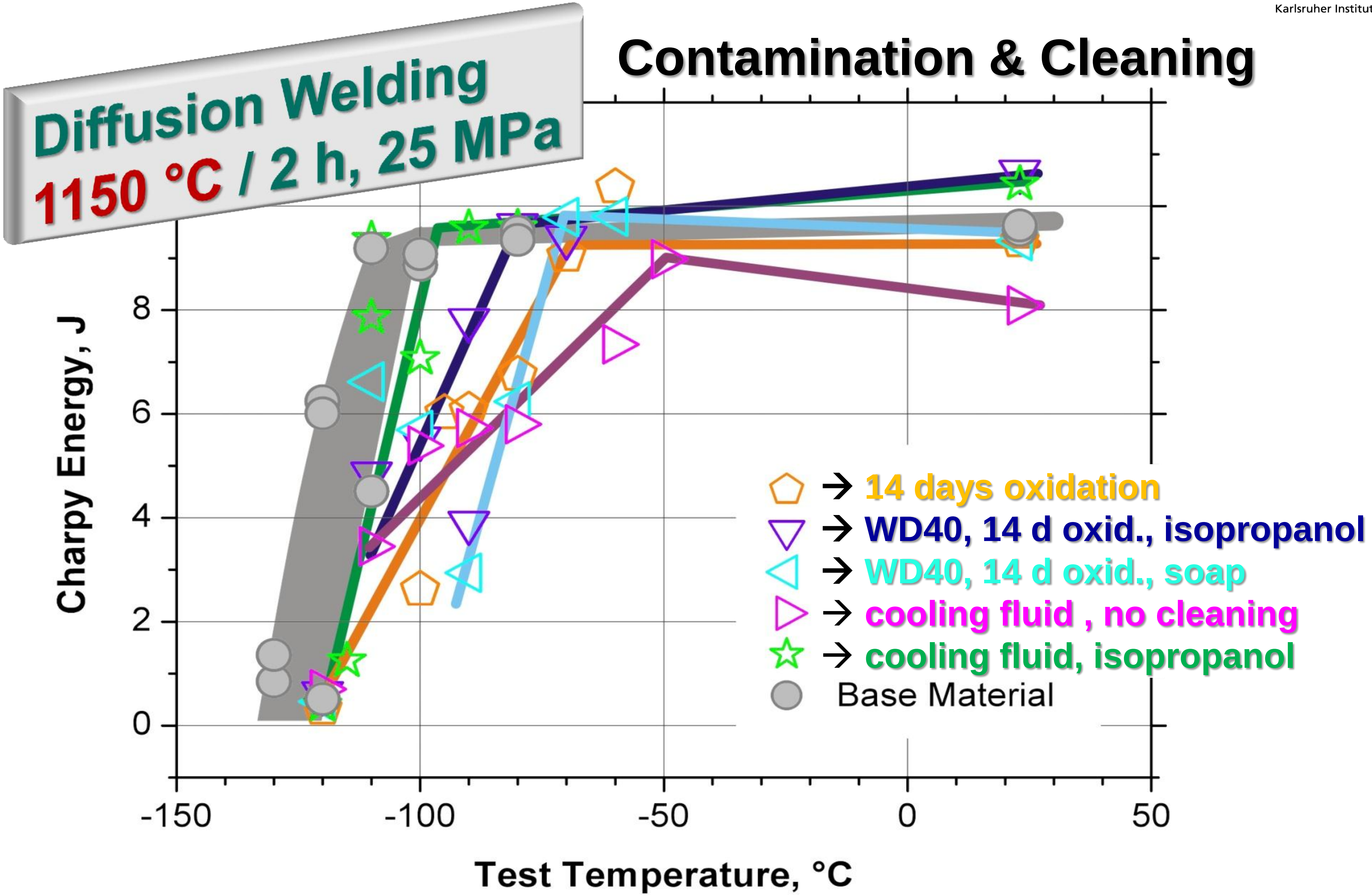
Basic Studies

Surface Contamination Study	
Surface 20:	Reference fabrication (dry milling with optimised parameters and immediate sealing by EB-welding)
Surface 21-24:	1, 2, 3, 14 days at 70% relative humidity before sealing
Surface 25:	Surface protection with oil, 14 days at 70% relative humidity, cleaning with isopropanol before sealing
Surface 26:	Surface protection with oil, 14 days at 70% relative humidity, cleaning with soap before sealing
Surface 28:	Surface fabrication with optimised parameters, but milling with industrial standard coolant, just dried before sealing
Surface 29:	Same as Surface 28, but cleaning with isopropanol before sealing

Basic Studies: Surface Contamination



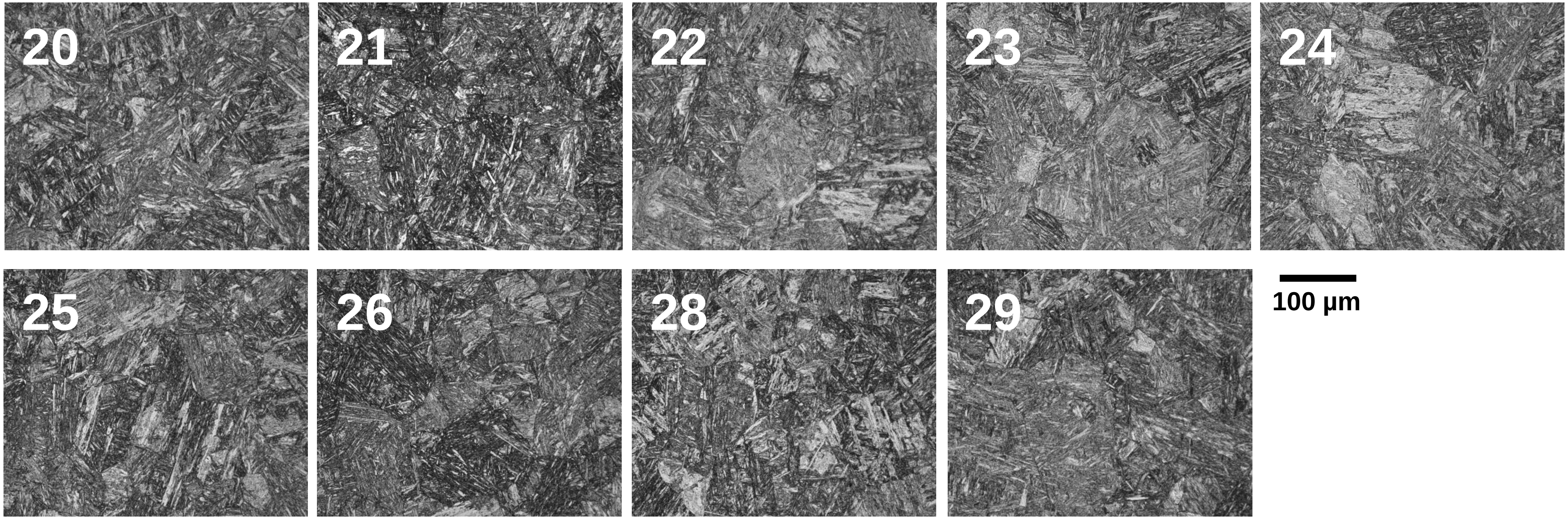
Basic Studies: Surface Contamination



 M. Rieth, B. Dafferner, *et al.* – Cost effective fabrication of a fail-safe first wall
First Joint ITER-IAEA Technical Meeting on “Analysis of ITER Materials and Technologies”, 23-25 Nov. 2010

Karlsruhe Institute of Technology (KIT), Campus Nord
Institute for Materials Research I

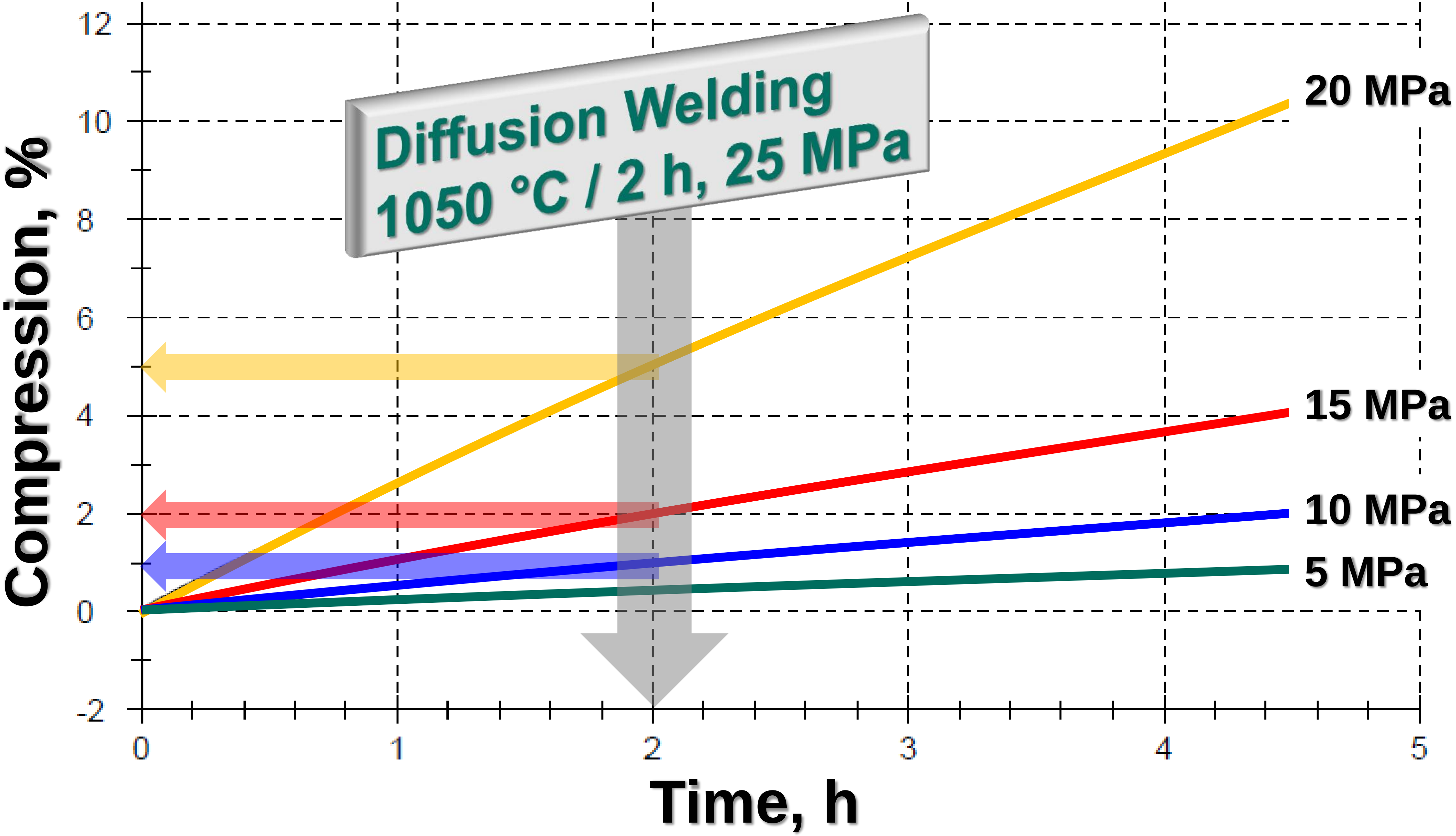
Surface Contamination: Microstructure



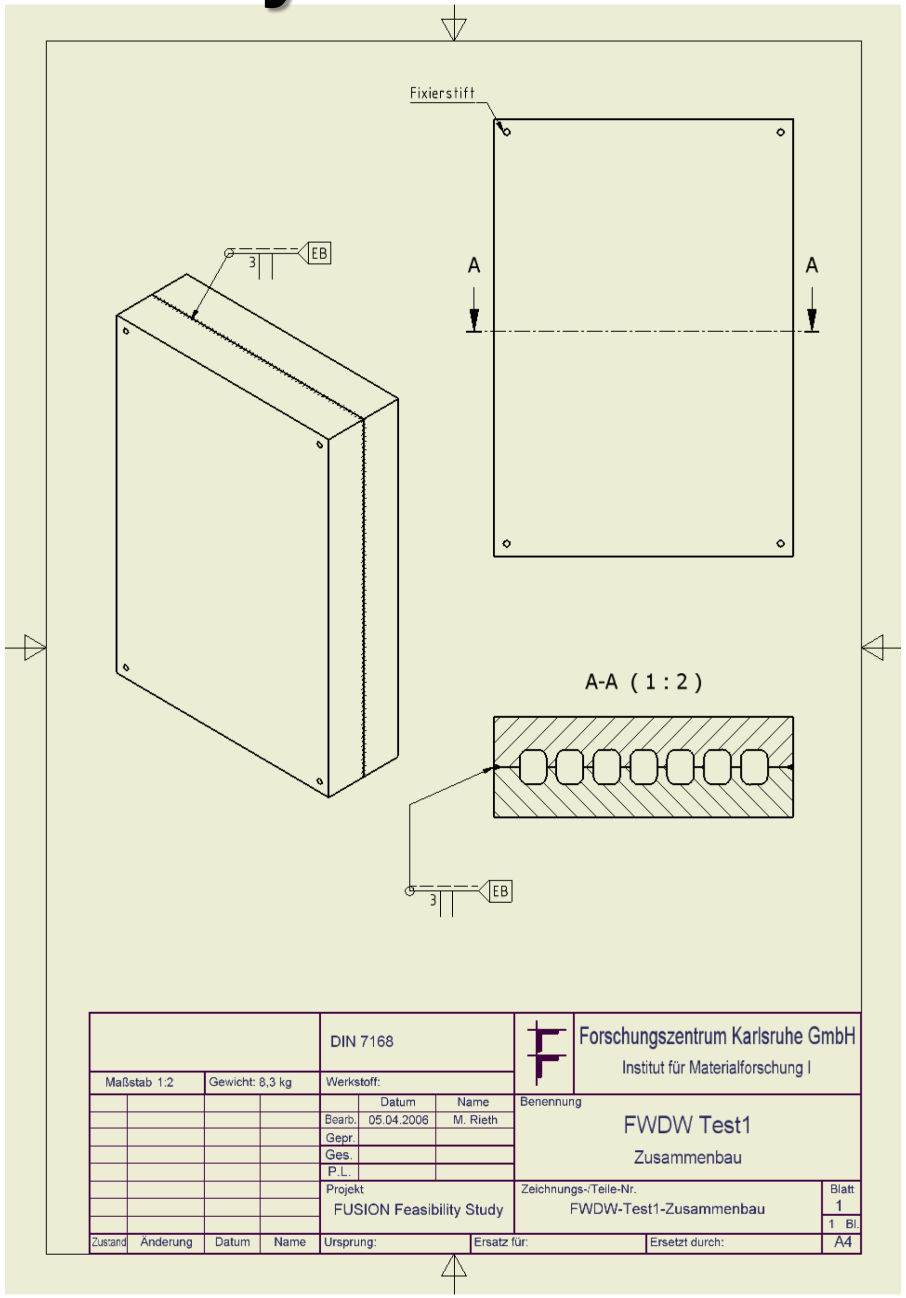
The micrographs of all weld interfaces show no weld line. That is, from a micro-structural point of view, **the diffusion welds (performed at 1150 °C, under 25 MPa, for 2 hours) are all perfect**, regardless of the fabrication history. (The Charpy test results, however, demonstrate that there are small differences, anyway.)

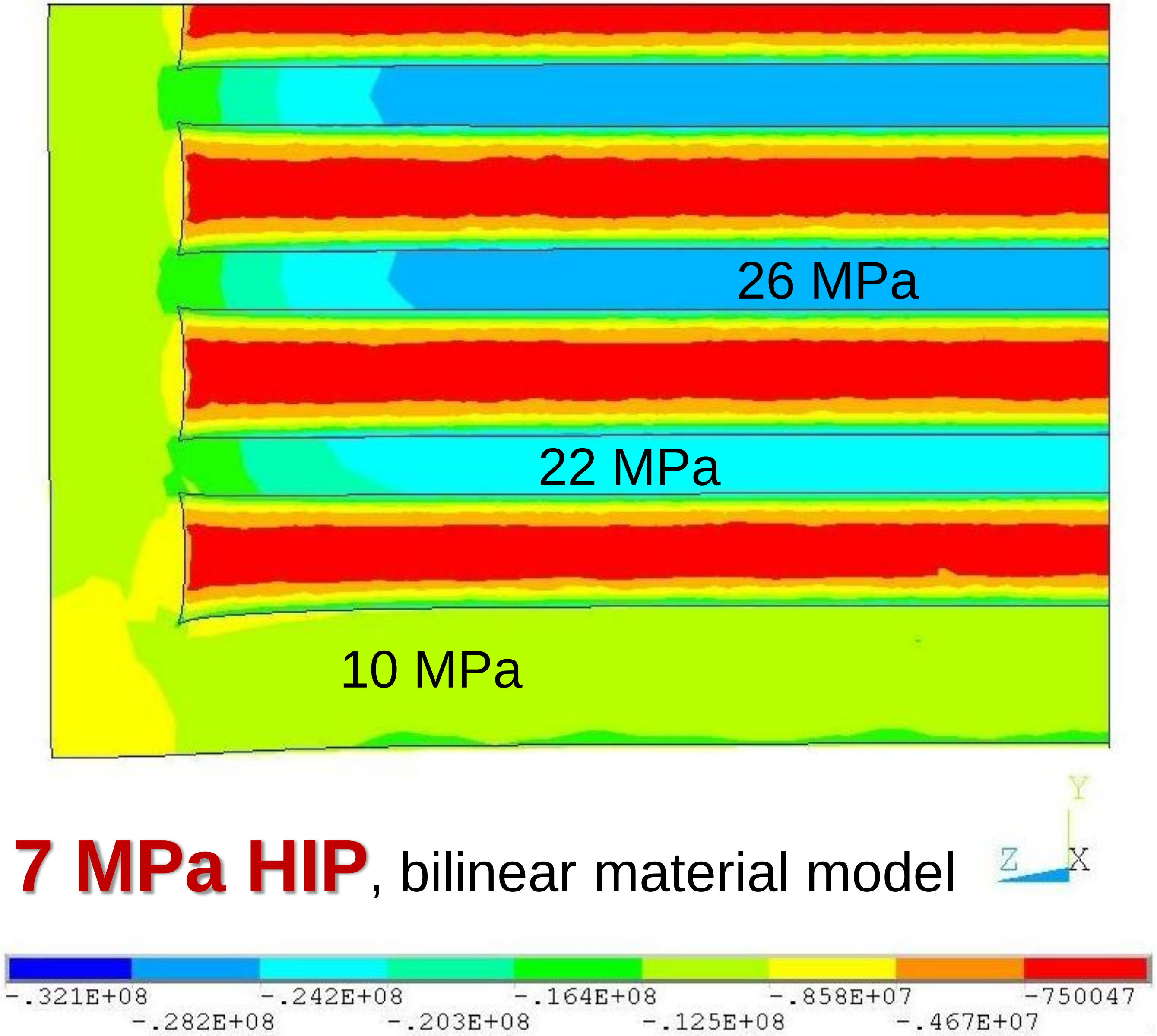
Basic Studies: High Temperature Creep

Creep tests under pressure at 1000 °C



Know-how transfer to mock-up fabrication: Theory

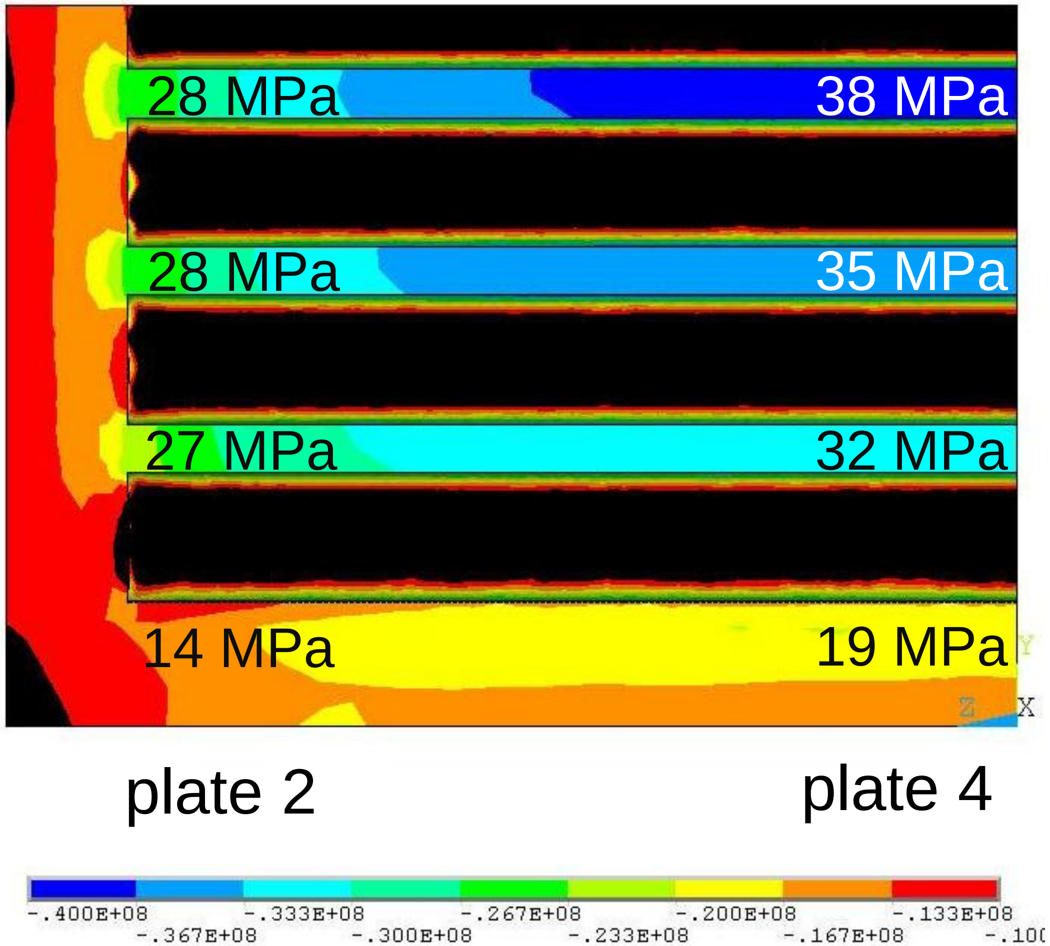


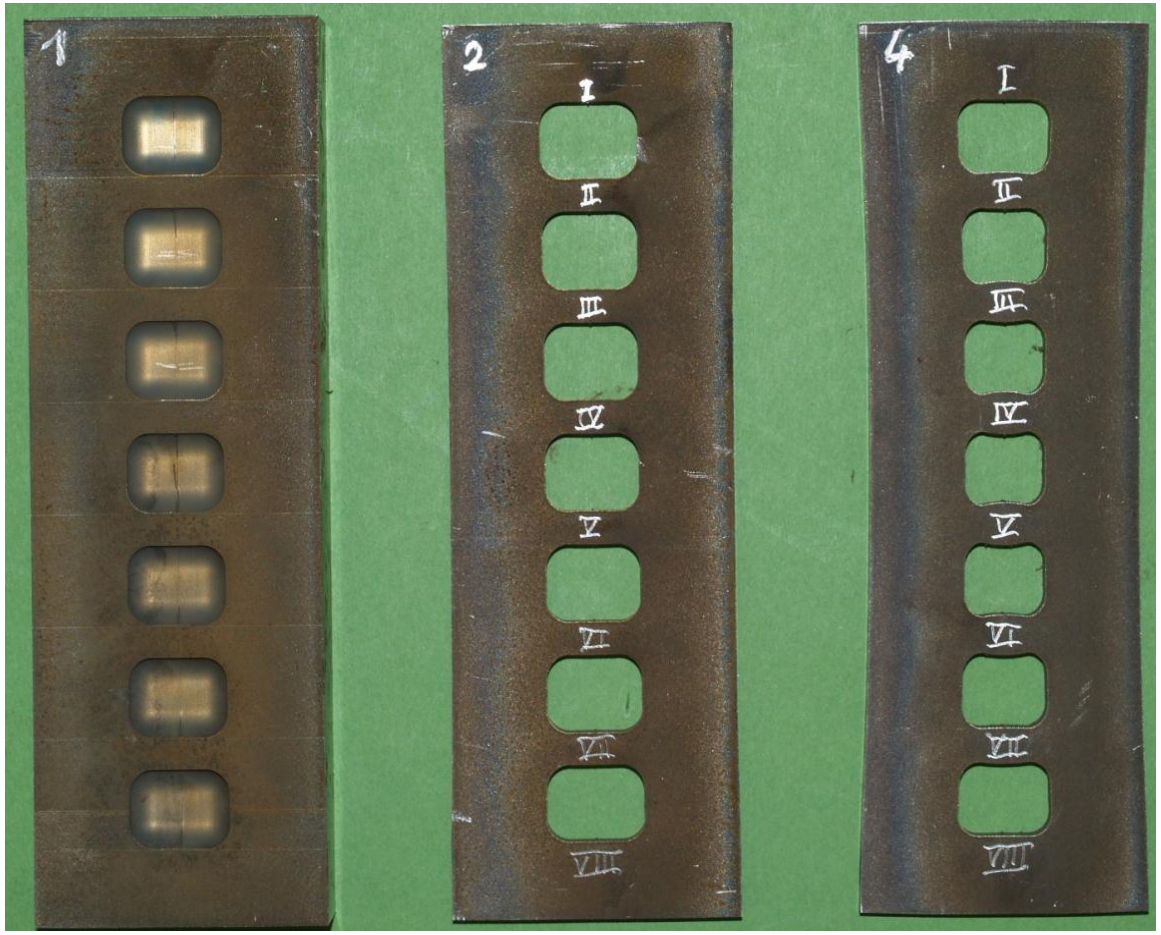


7 MPa HIP, bilinear material model

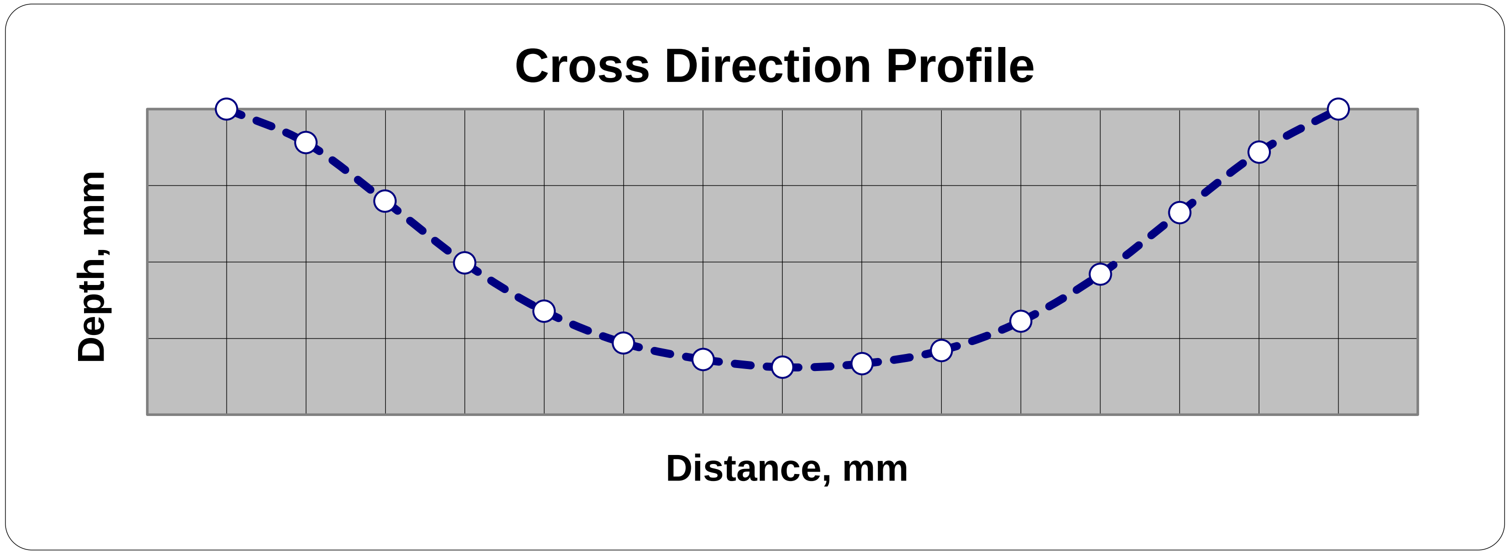
Know-how transfer to mock-up fabrication: Reality

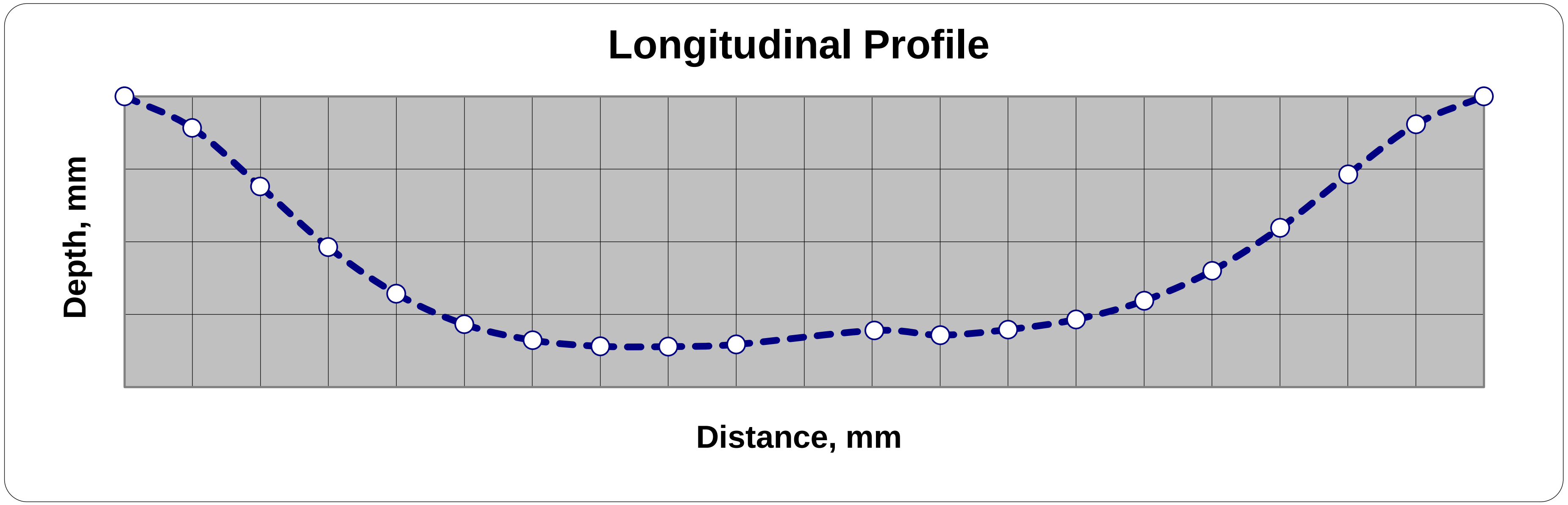
1. Long periods between surface fabrication (dry milling) and EB welding (vacuum sealing) → **7 days**
2. Minimum available HIP pressure to high → **10 MPa** instead of **7 MPa**



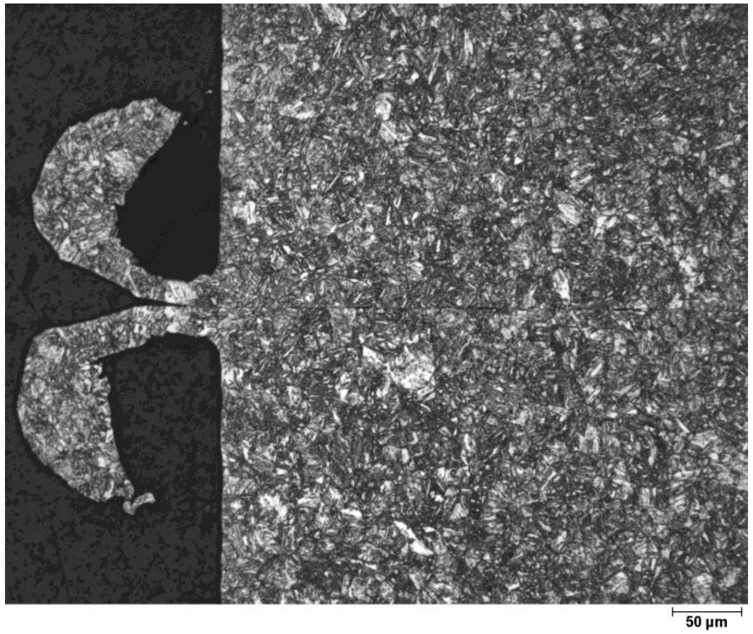


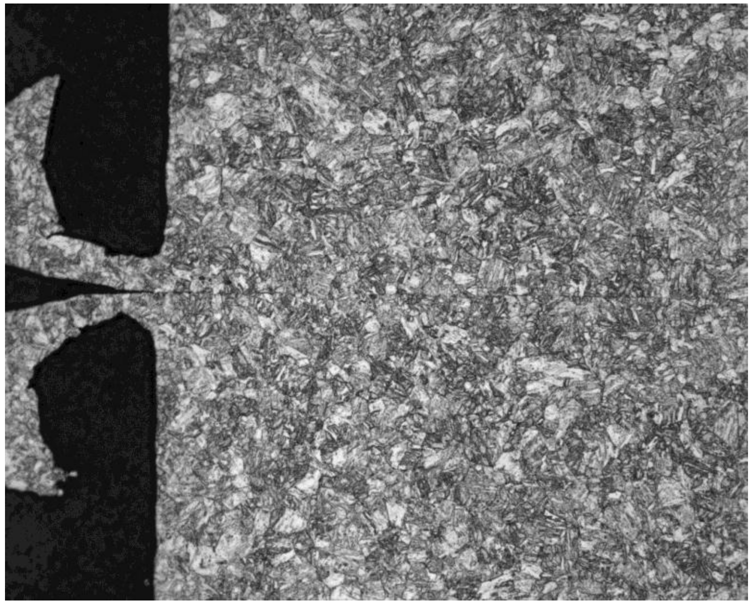
Effects of Hight Temperature Creep: Dimensional Inaccuracies

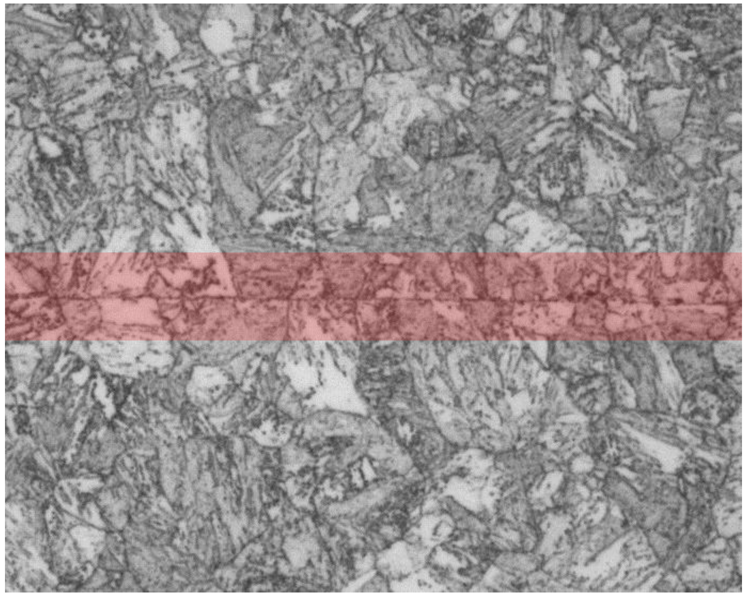




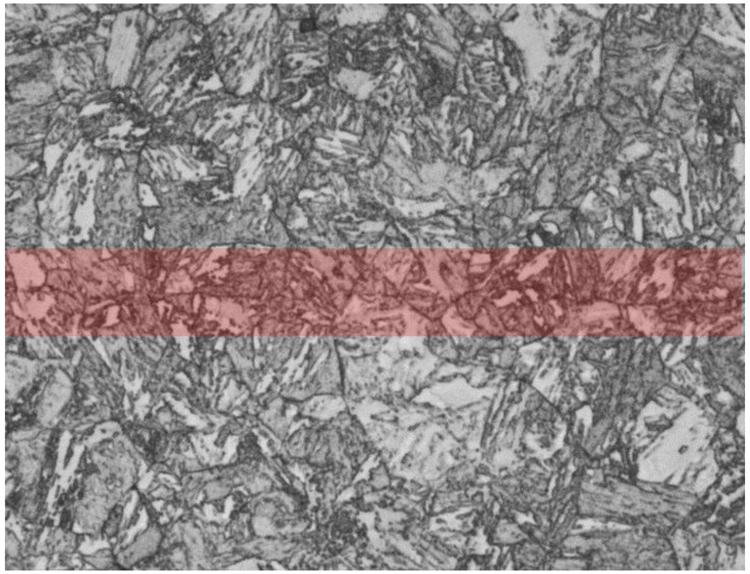
Effects of Hight Temperature Creep: Material Flow





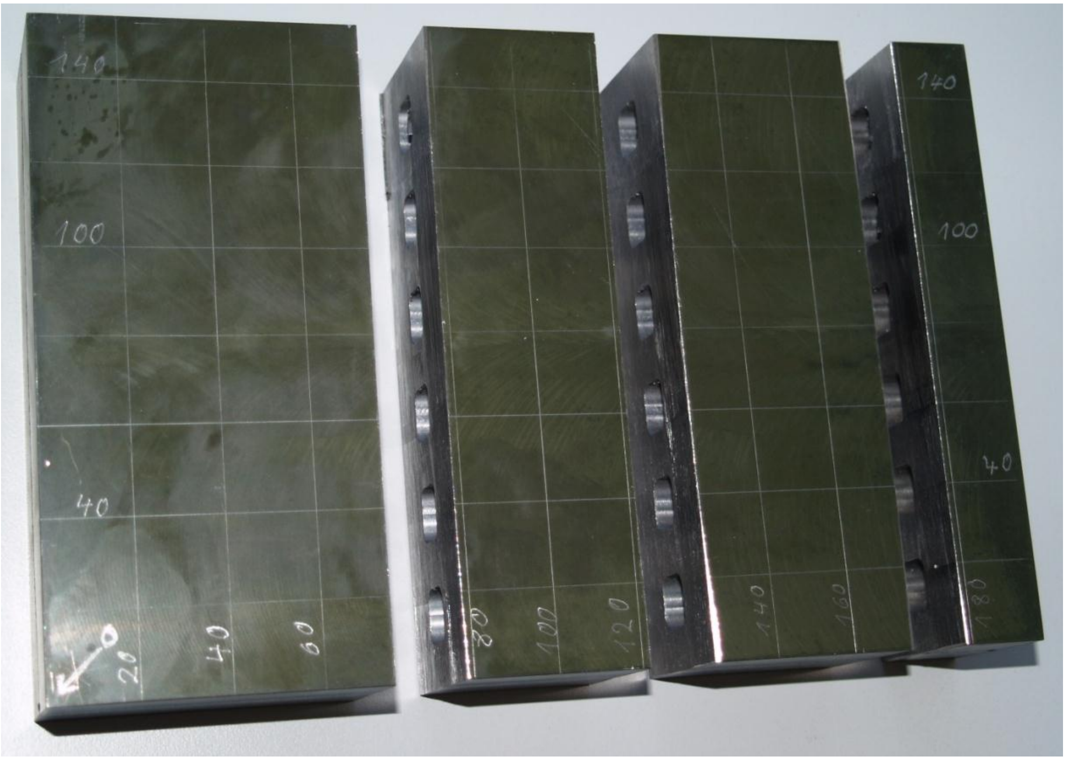


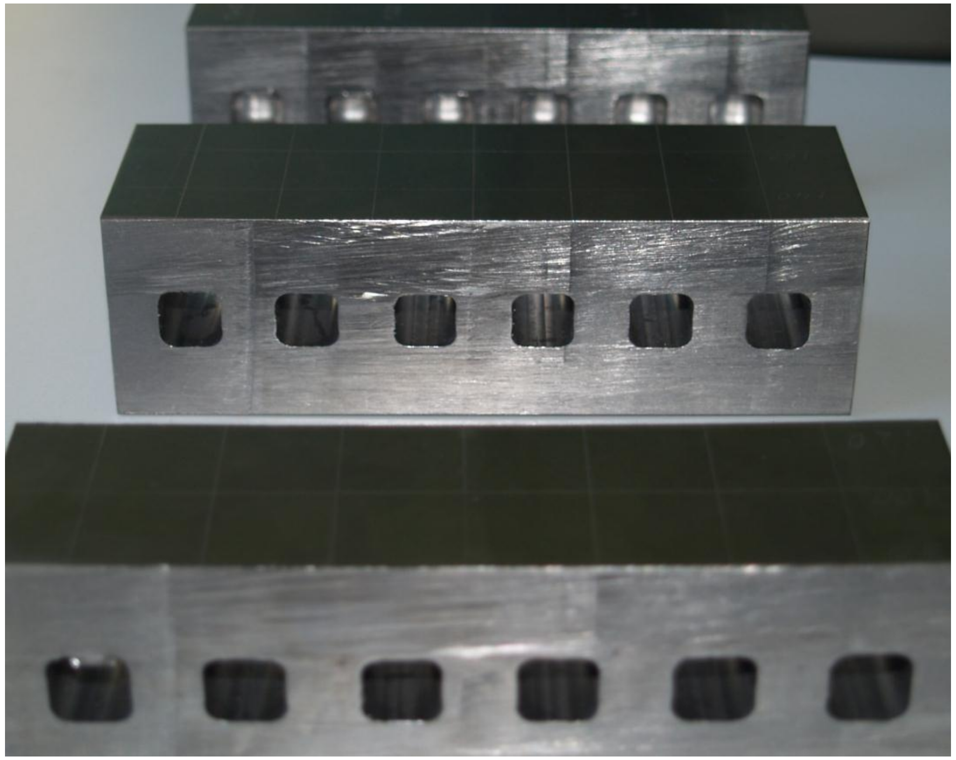
14 MPa

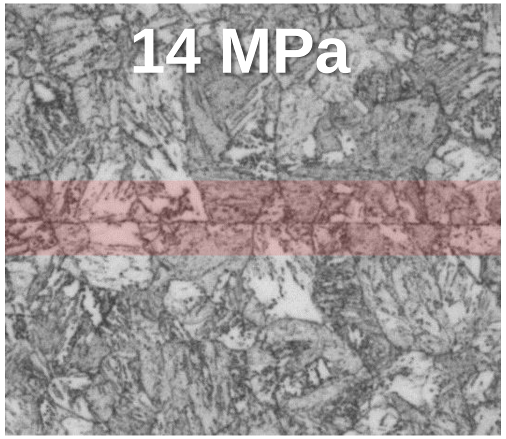


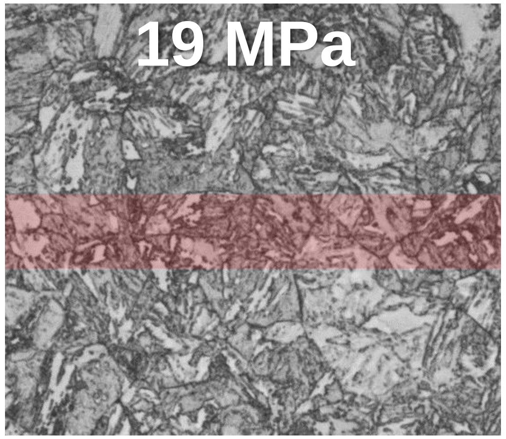
19 MPa

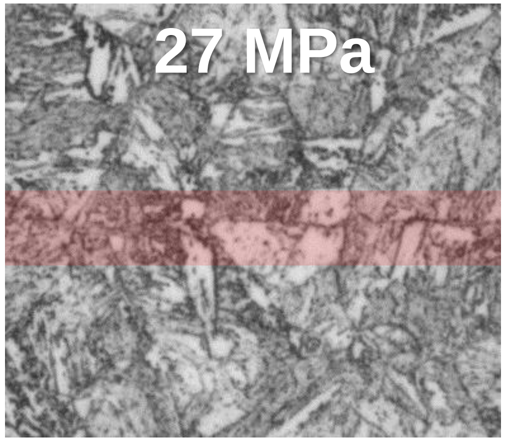
Better Results with Lower Aspect Ratio

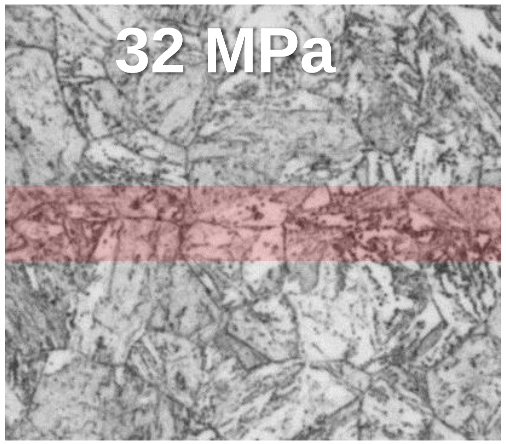












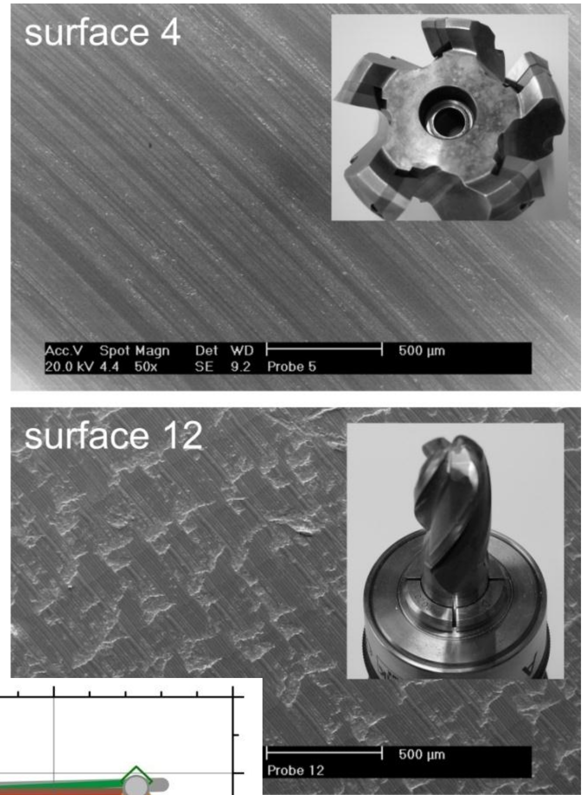
Problem Analysis

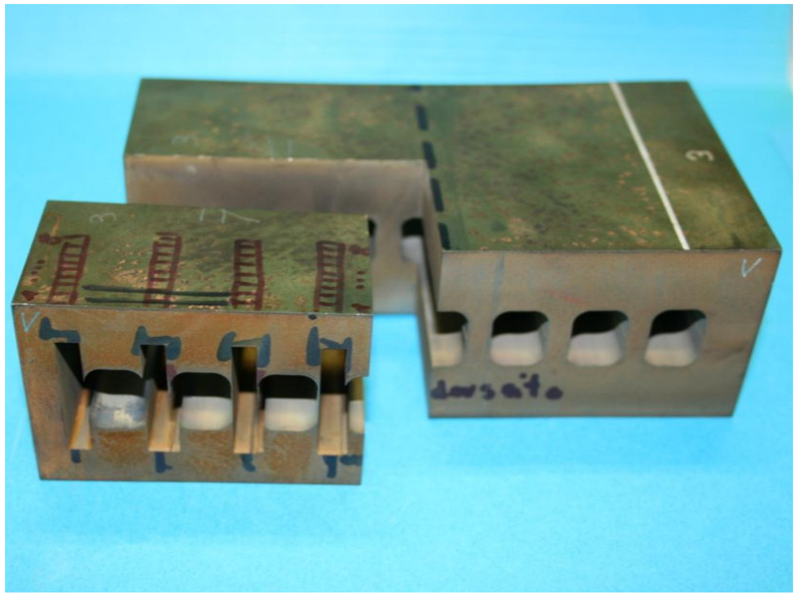
- **Increase tolerance of surface conditions**
- **Improvement of weld properties (esp.: fracture toughness)**

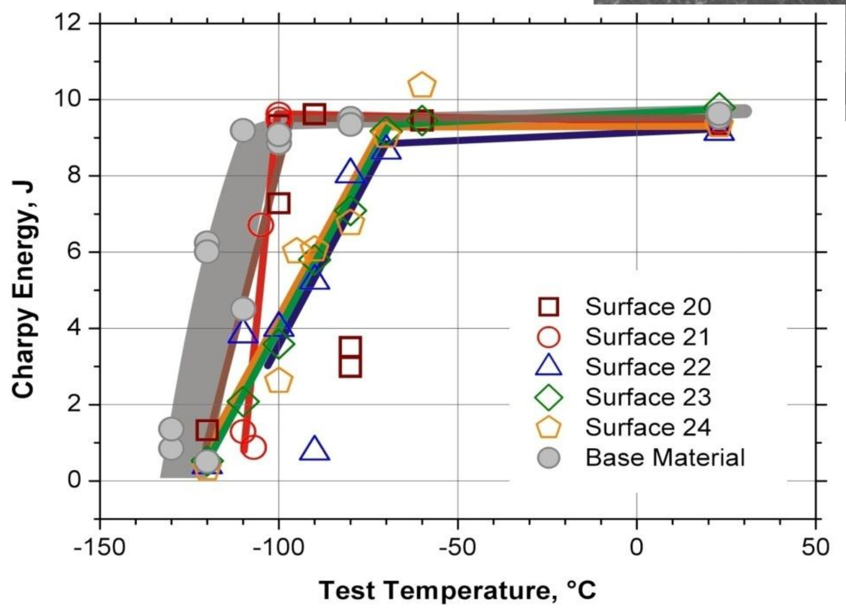
→ HIGH TEMPERATURE + HIGH PRESSURE

- **Better shape stability, dimensional accuracy**

→ LOW TEMPERATURE + LOW PRESSURE







State of the Art FW Fabrication Methods

1. Fabrication of flat FW plates with internal cooling channels by different methods:
   - CEA: closing of channels by EB, then HIP
   - CEA: rectangular tubes between two plates
   - CEA: tubes forming and HIP between two grooved plates
   - KIT: variable temperature and pressure by HIP or UP

2. Bending of the plates

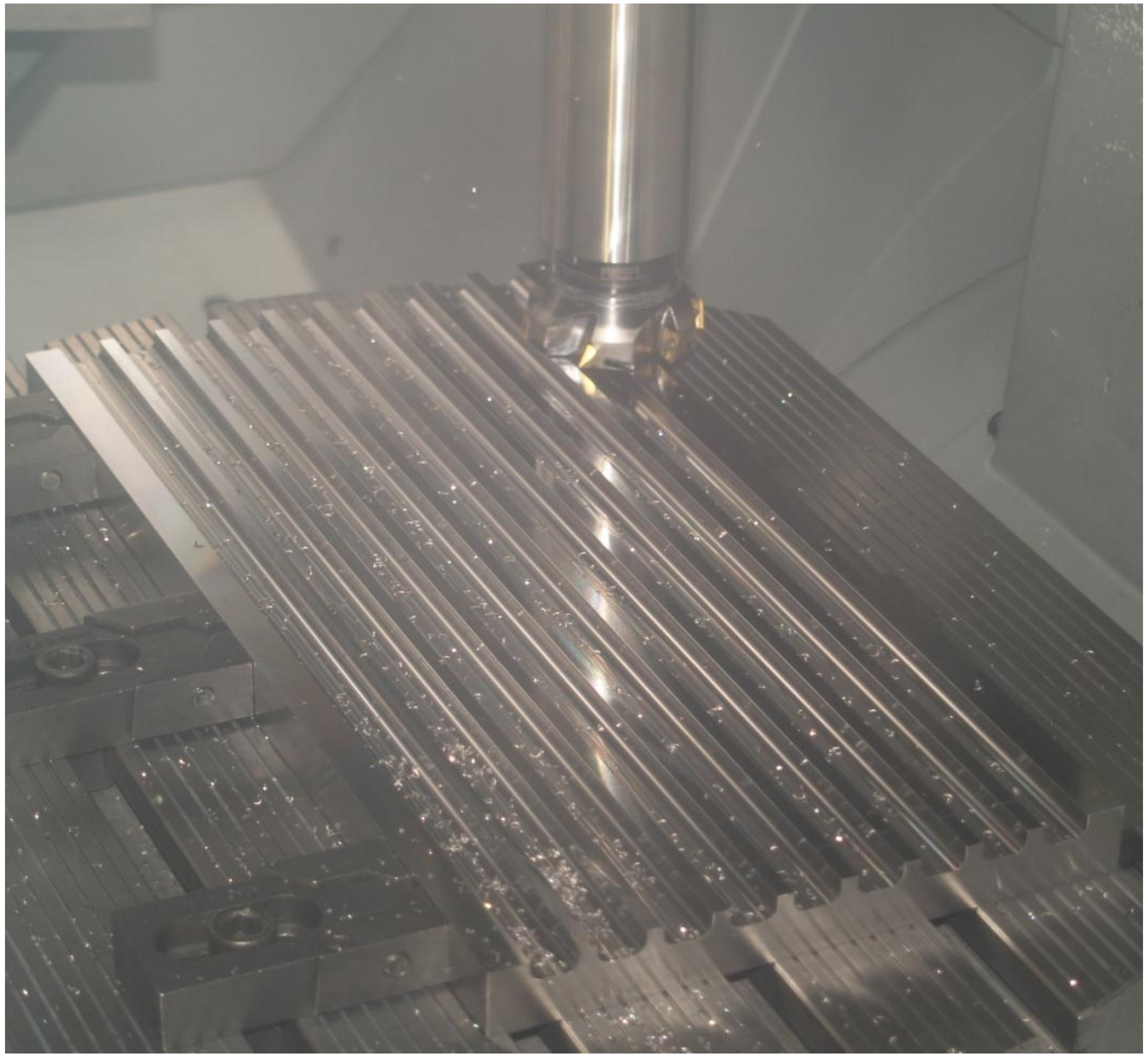
→ **Pros and cons are well known**

→ **Two additional methods with high accuracy and tolerance against process variations**

Stabilization of Cooling Channels with Inlets of Stainless Steel

Standard fabrication of the channel structure

Dry milling of the diffusion weld surfaces



Cooling Channels with Stainless Steel Inlets

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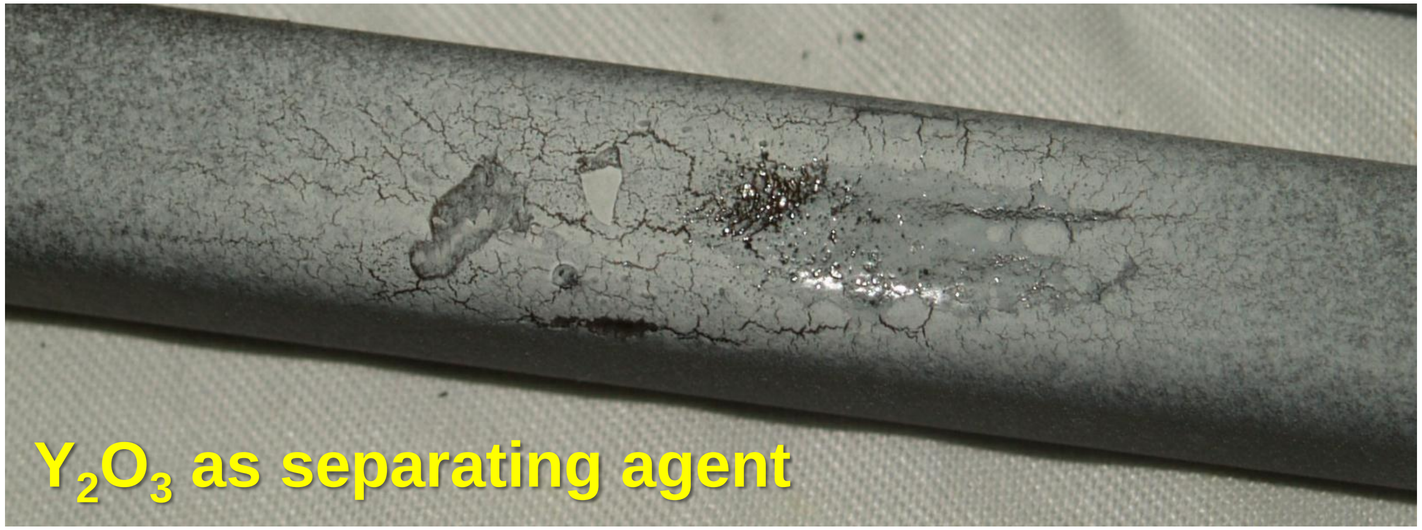
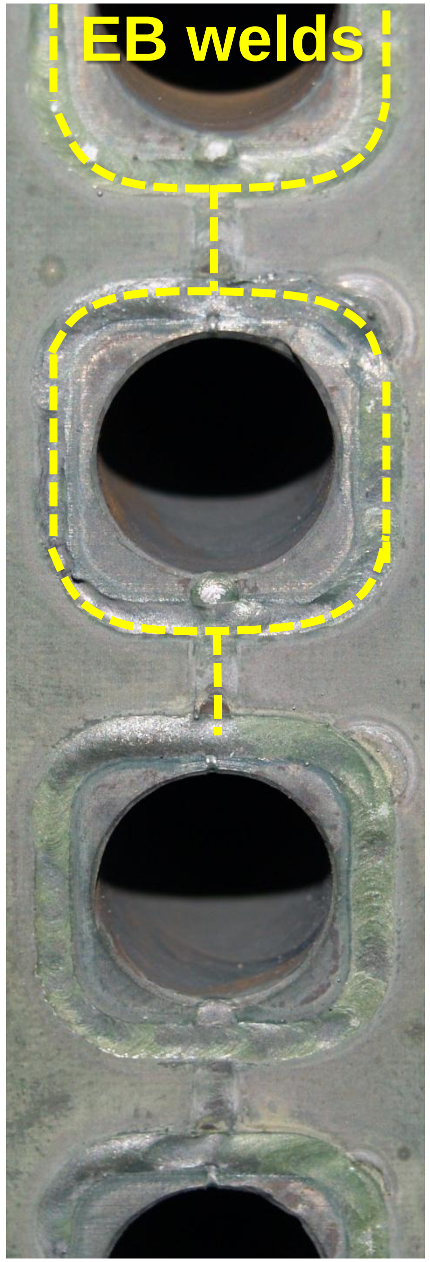
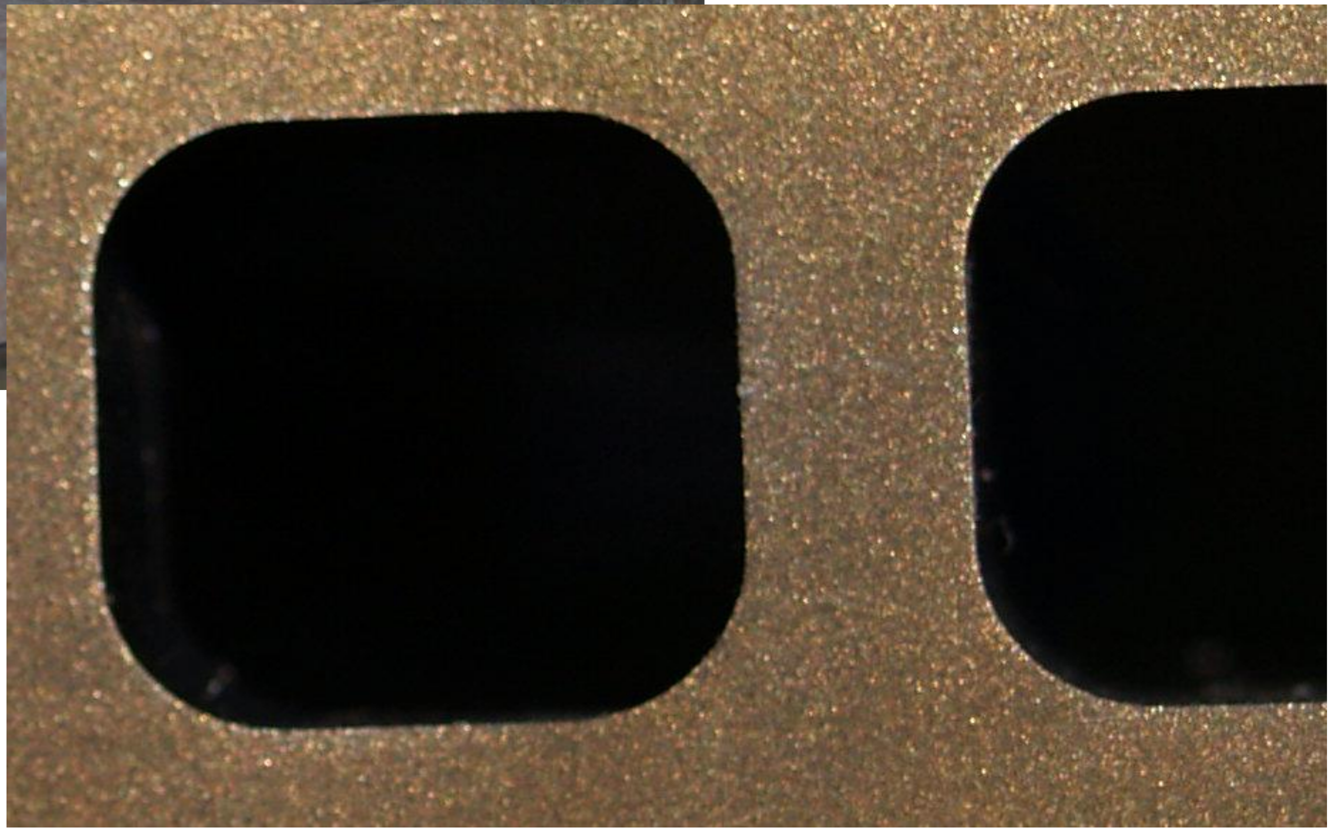




High Pressure HIP with Stabilized Channels

Before and after High Temperature – High Pressure HIP

Stabilization of Cooling Channels



No Creep Deformation

High Accuracy of the cooling channel cross-section (after removal of stabilizers)

Fail-safe First Wall Fabrication

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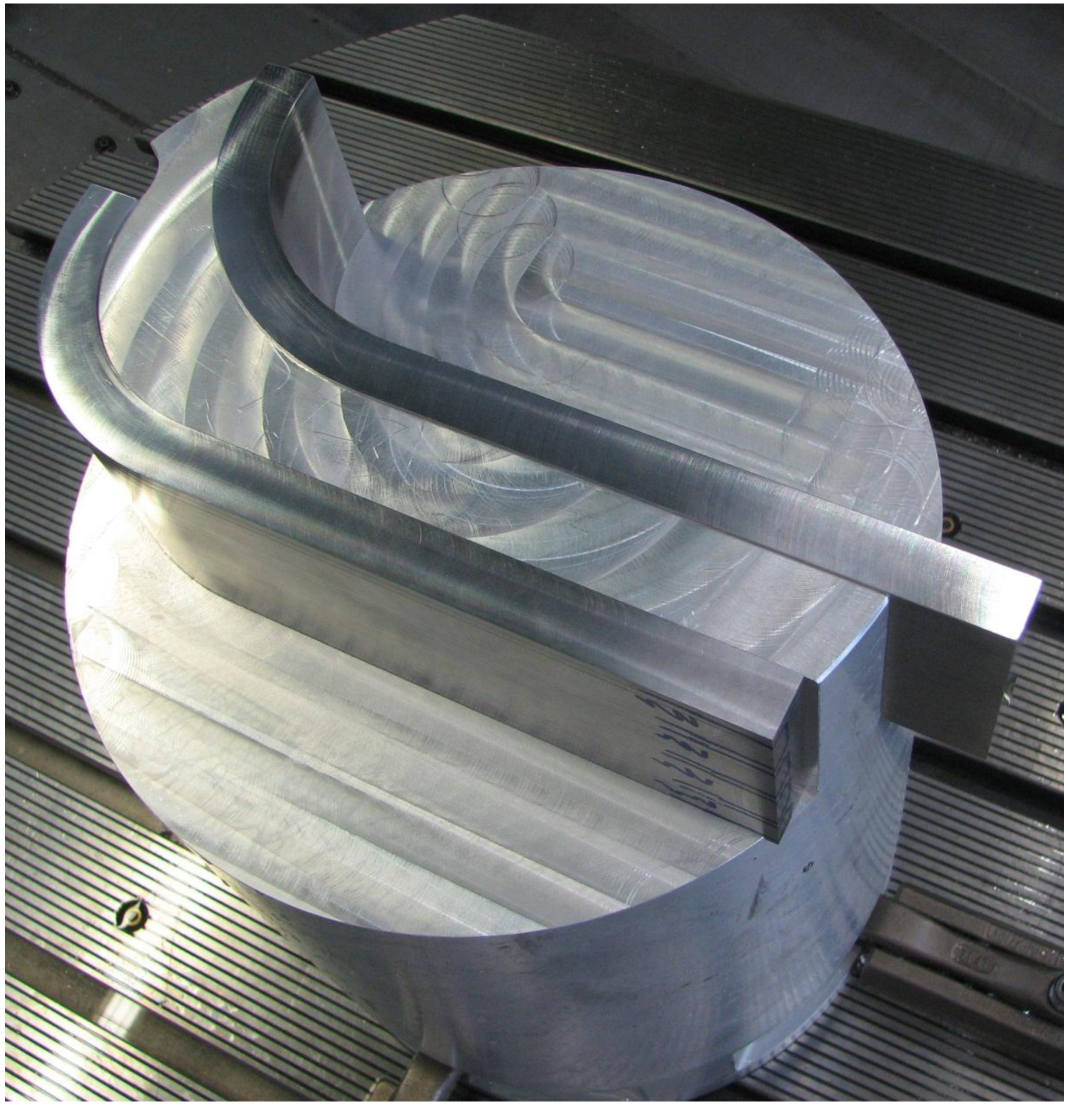
Fabrication Processes:

1. Bending of 2 plates
2. Milling of grooves into the plates
3. Fabrication and bending of pipes
4. Assembling plates and pipes
5. Sealing with EB welds
6. High temperature - high pressure HIP

Step 1: Bending of two plates

Step 2: Milling of grooves

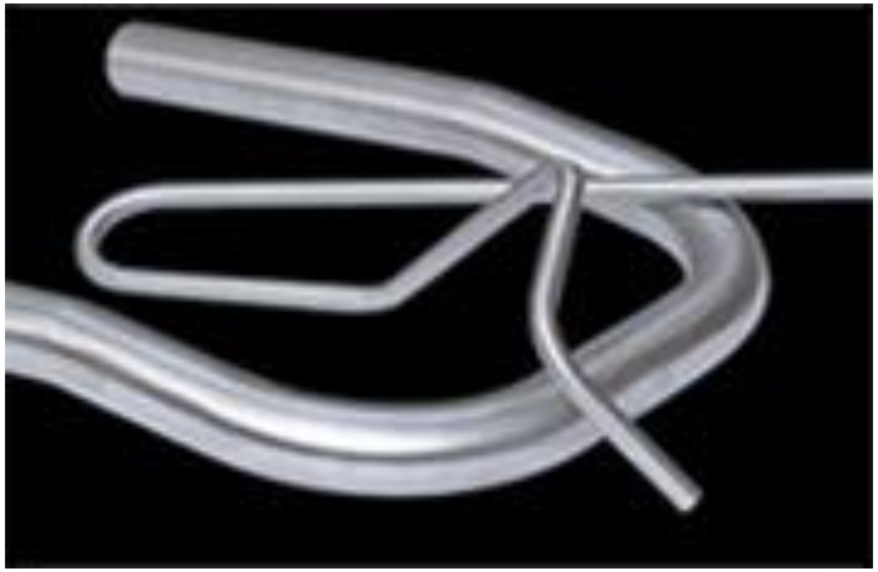


Step 3: Fabrication and bending of pipes

Commercial fabrication processes available:

- Pipe production by TIG or Laser welding.
- Bending with given dimensions
- Necessary half-finished product: steel stripes (e.g. 1mm x 40mm x 100m)

Wtube™
Wstainless™

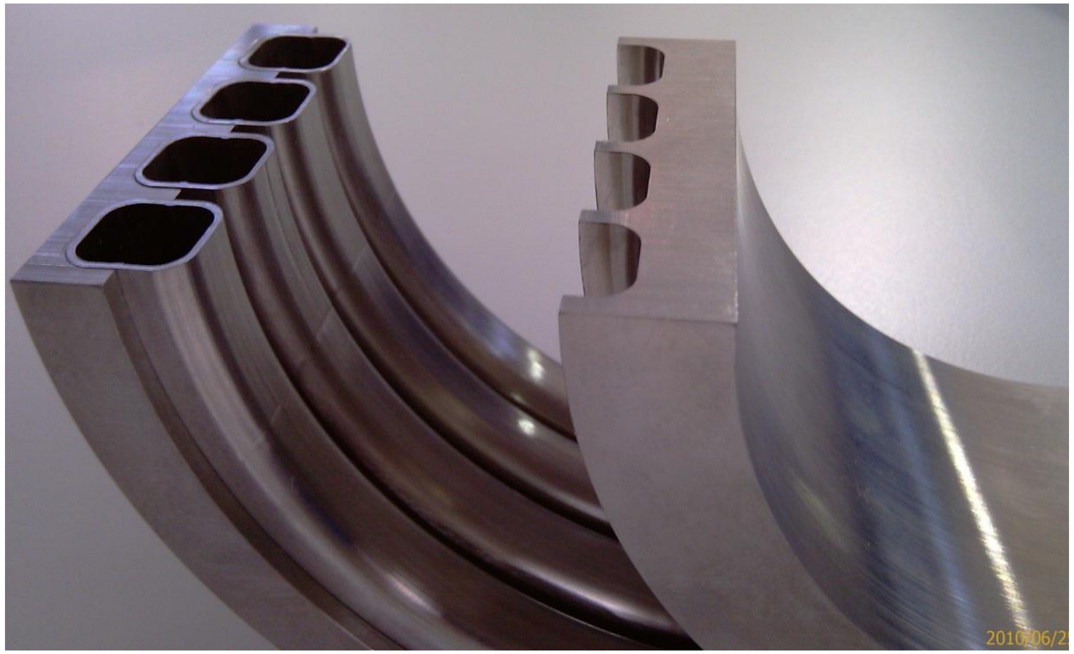


Edelstahlrohre auf höchstem Niveau

Wuppermann fertigt auf modernen, leistungsfähigen Anlagen Edelstahlrohre mit besten Oberflächen als Basis für hochwertige Komponenten.

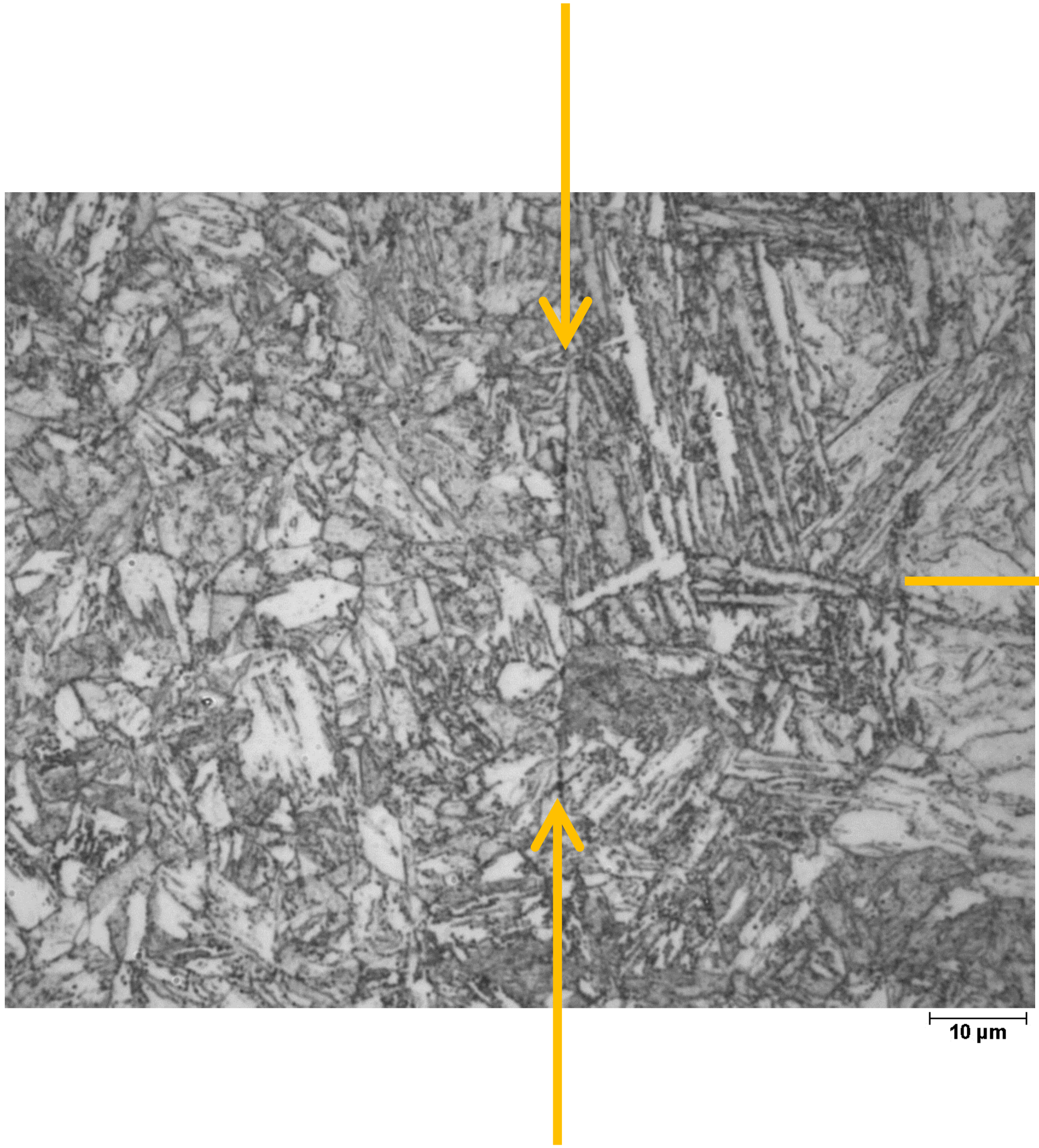
Step 4: Assembling plates and pipes

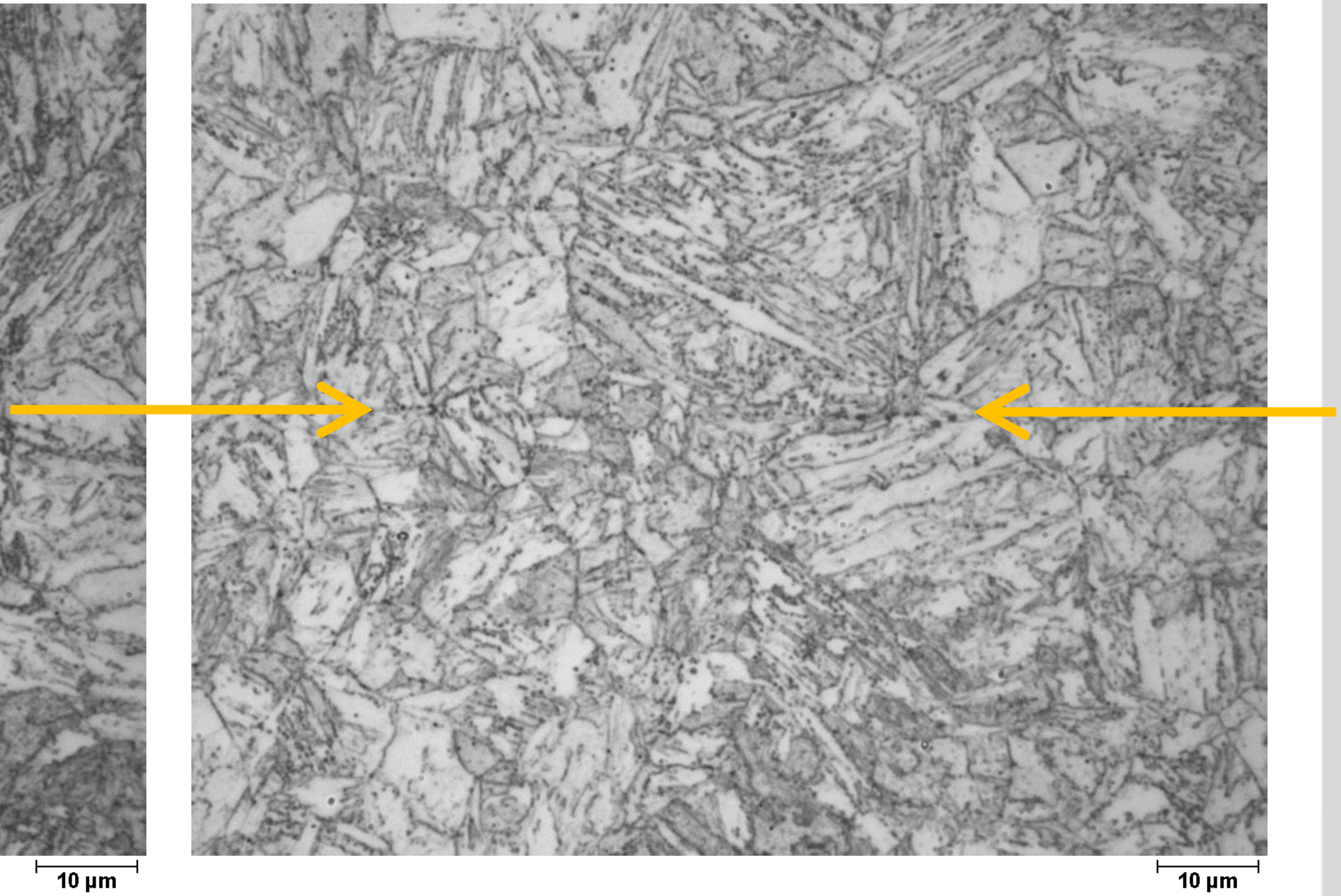
After storage of several days without special cleaning treatment



Step 5: Sealing with EB welds
Step 6: HIP (1050°C, 100MPa, 2h)

Microstructure near the weld surfaces



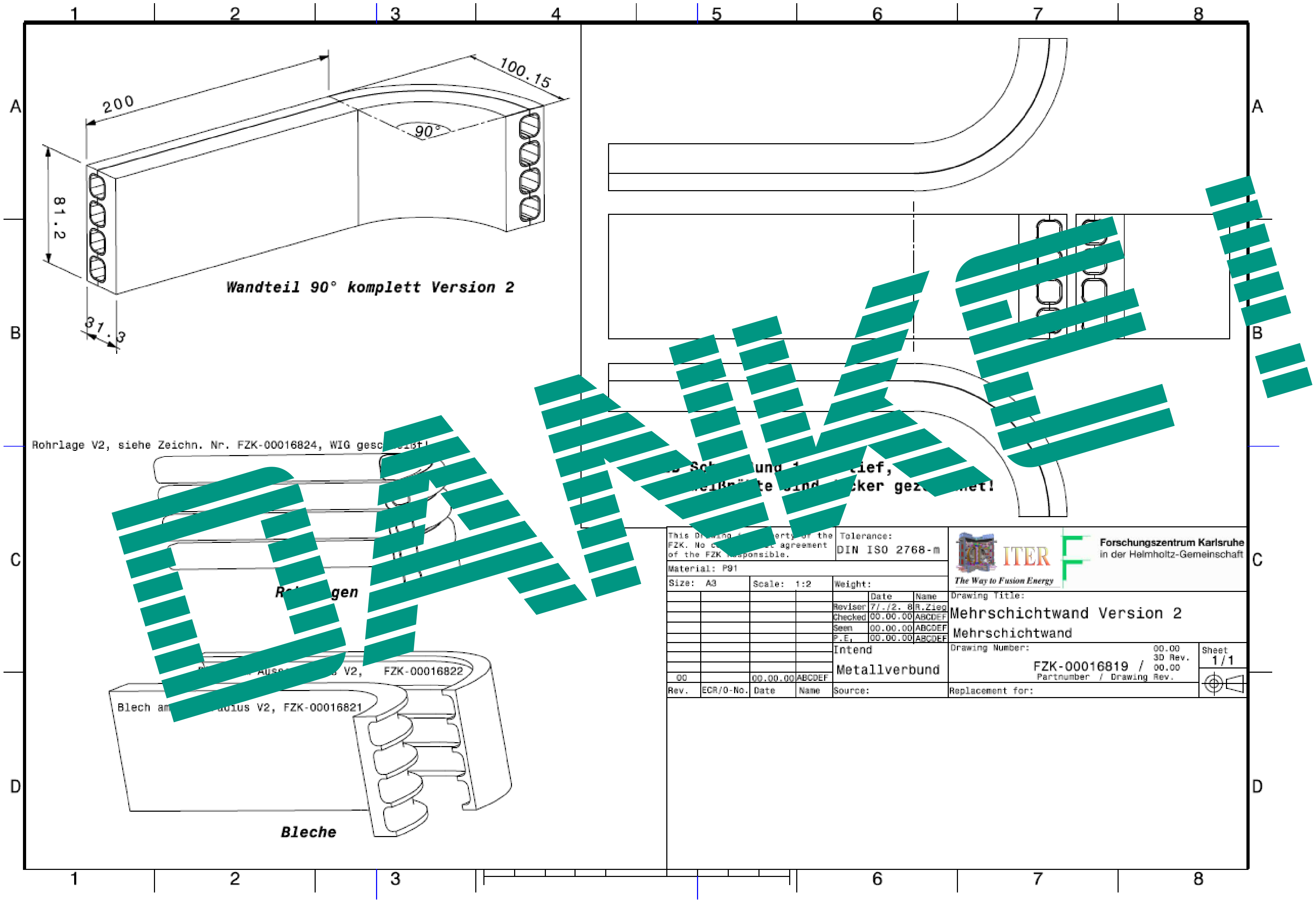


Conclusions: Which criteria are fulfilled?

- **Compatibility with industrial environment**
  - Applicability of standard fabrication processes ✓
  - Robustness against environmental influences (corrosion, rough handling, storage, ...) ✓
  - Tolerant against scattering of process parameters ✓

- **Efficiency**
  - Costs ✓
  - Recources ✓

- **Safety/Reliability**
  - Dimensional Accuracy ✓
  - Easy Quality Assurance ✓
  - Reproducibility ✓
  - Inherent Fail-safe Design ✓


DANKE!
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Tolerance:
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Material: P91
Size: A3
Scale: 1:2
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The Way to Fusion Energy
Forschungszentrum Karlsruhe
in der Helmholtz-Gemeinschaft
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