BAM

Bundesanstalt für Materialforschung und -prüfung

Sicherheit in Technik und Chemie

SPP 2006 Meeting , 8th October 2021

PRESENTATION OF INTERDISCPLINARY PROCECT ON HEA PROCESSING

SURDIA (SURFACE DEGRADATION PHENOMENA AND UTILIZATION OF INNOVATIVE ALLOYS) - CURRENT R&D AT BAM -

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HEAs on the way for application in components

HEA concepts

- First studies in 2004
- Ongoing development of further concepts
- Use of precipitation hardening
- TWIP, TRIP
- Multi-Phase CCAs

Manu-facturing of HEAs

Early-stage

- Small-scale buttons for basic metall. investigation

Meanwhile

- Casting of ingots
- Cold-rolled sheet metal
- **Reasonable quantities**

Processing of HEAs

Machining

- **Milling**
- Grinding
- …

Joining

- Welding
- Brazing
- AM

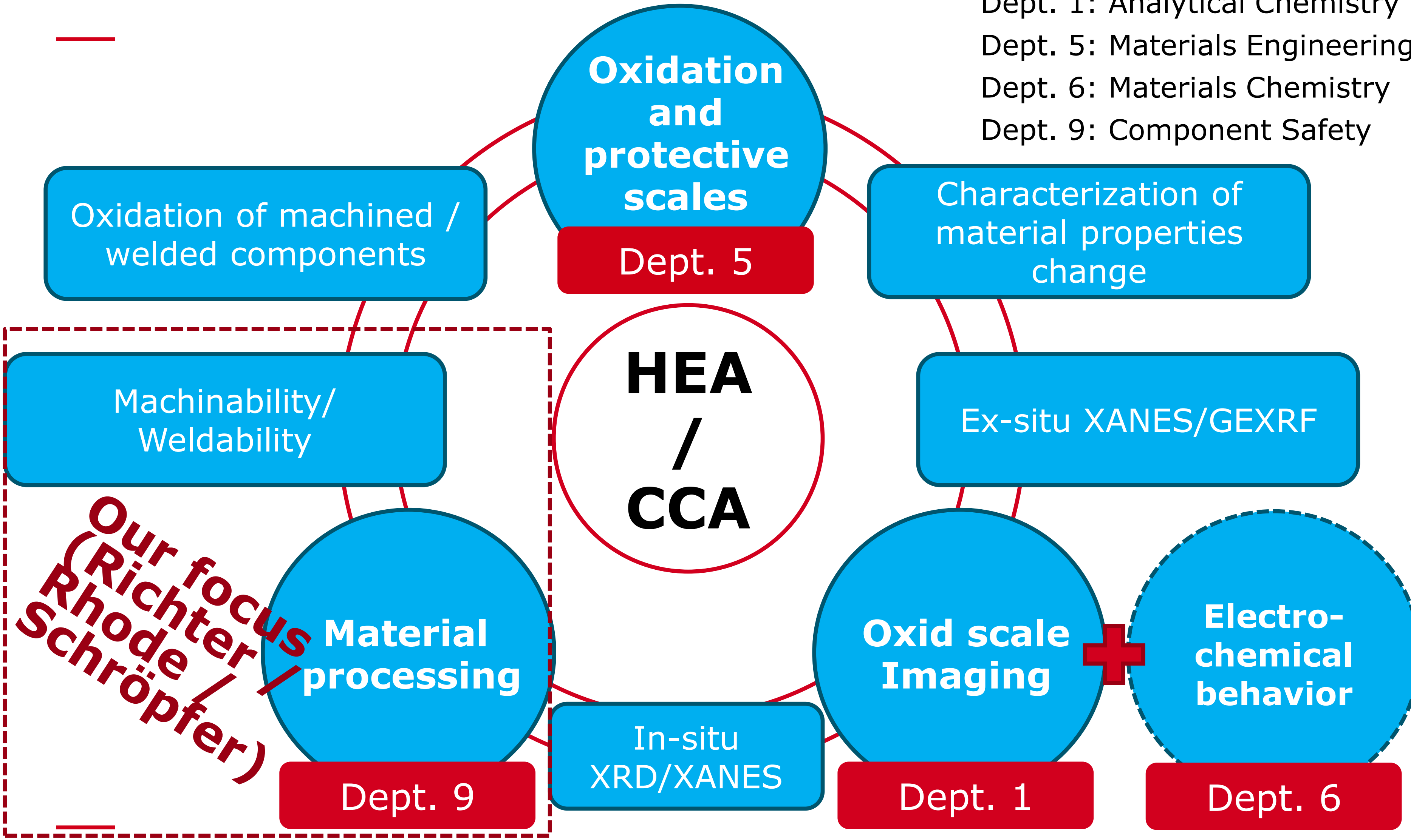
Influence on application properties?

- **Surface integrity**
- **Machinability**
- Weldability

- Component performance/ safety
- Corrosion?
- …

Interdisciplinary collaboration to investigate degradation by processing

Dept. 1: Analytical Chemistry
Dept. 5: Materials Engineering
Dept. 6: Materials Chemistry
Dept. 9: Component Safety



Current research at BAM Berlin

BAM

Basic research on HEAs/MEAs:

– Weldability by
  - Tungsten Inert Gas (TIG) Welding and
  - Friction Stir Welding (FSW)

– Machinability by
  - Conventional milling and
  - Ultrasonic assisted milling

Synthesis laboratory is in progress!
- Arc melter
- Rolling facility
- Furnaces
- Etc…

Processing influence on application properties

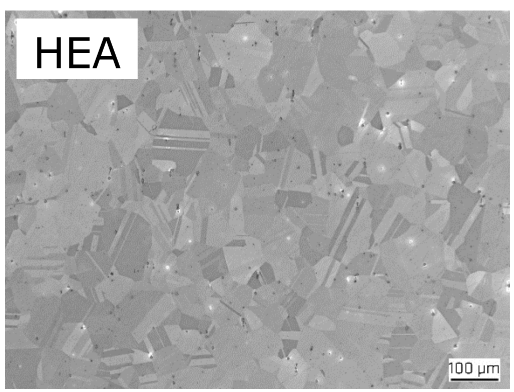
– *Mechanical performance of welded joints*
– *Surface integrity → electrochem. and high-temperature corrosion*
– *Hydrogen diffusion and adsorption*

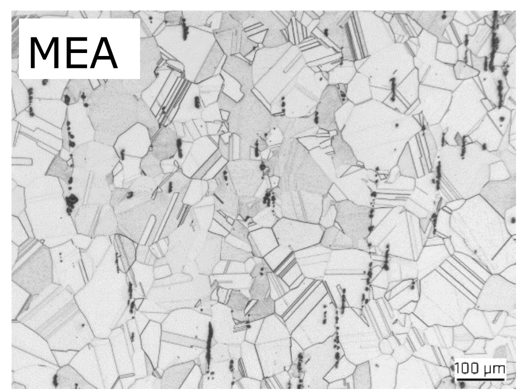
Experimental - Materials

At. -%	Co	Cr	Fe	Mn	Ni	HV 0.5
HEA	19.7	20.7	19.6	20.1	19.9	172
MEA	33.0	34.3	-	-	32.7	251

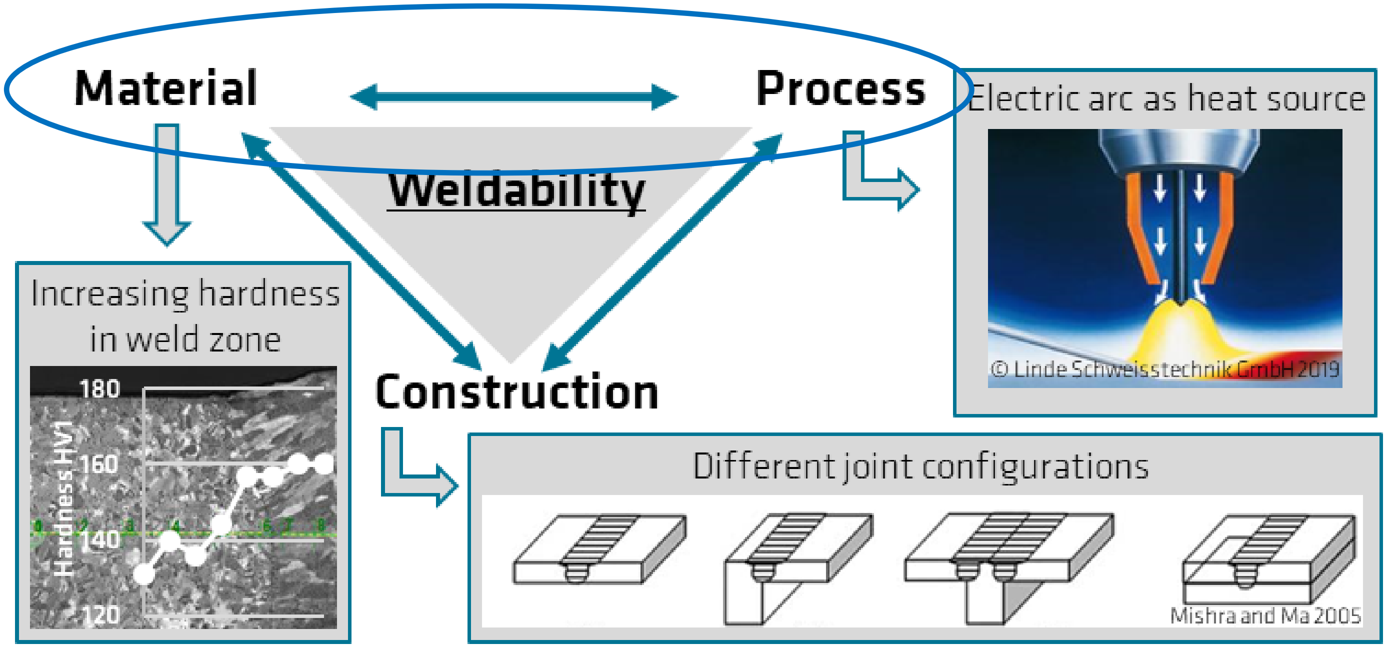
Preparation of two alloys (provided by group of Jun.–Prof. G. Laplanche, RUB):

1. Vacuum induction melting of elements (99.9 wt.-% purity)
2. Homogenizing (1200 °C for 48 h)
3. Rotary swaging (from diameter 40 mm to 16 mm)
4. Recrystallization (HEA: 1020 °C, MEA: 1060 °C, for 1 h)





Welding of HEAs
Challenges for welding of HEAs weldability



- Weldability is a subject to a complex interaction of material, welding process conditions and construction/component design

→ Current research regarding HEAs focusses on material and welding process interactions

Welding of HEAs
Typical welding defects

Welding process related defects

- Pores
- Tunnel defects
- Slag inclusions…

→ Process parameter adaption

Material related welding defects

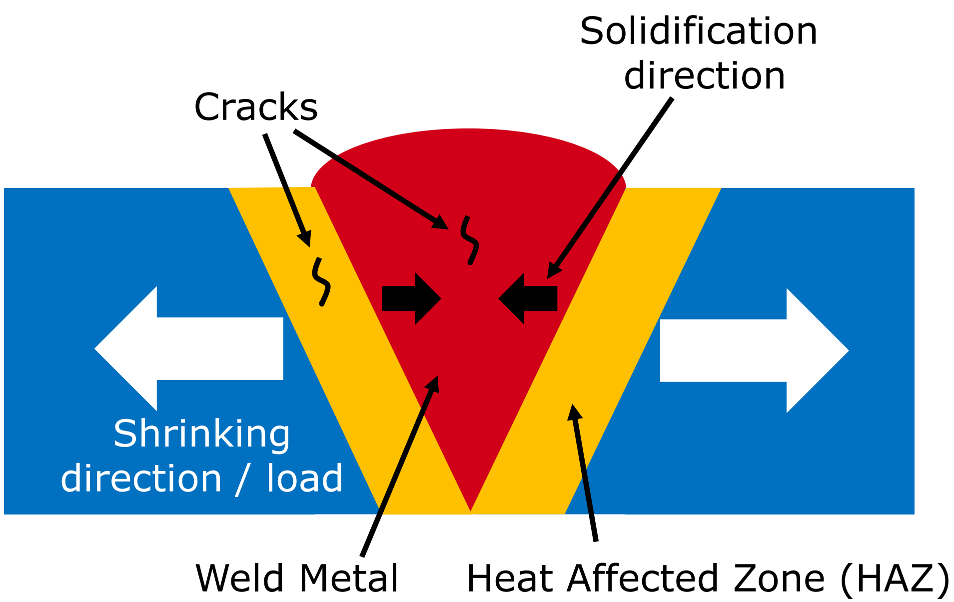
Hot cracking (T > 200°C)

- Solidification cracks, liquation cracks

Cold cracking (T < 200°C)

- Hydrogen assisted cracking, Hardening cracks (phase transformation)

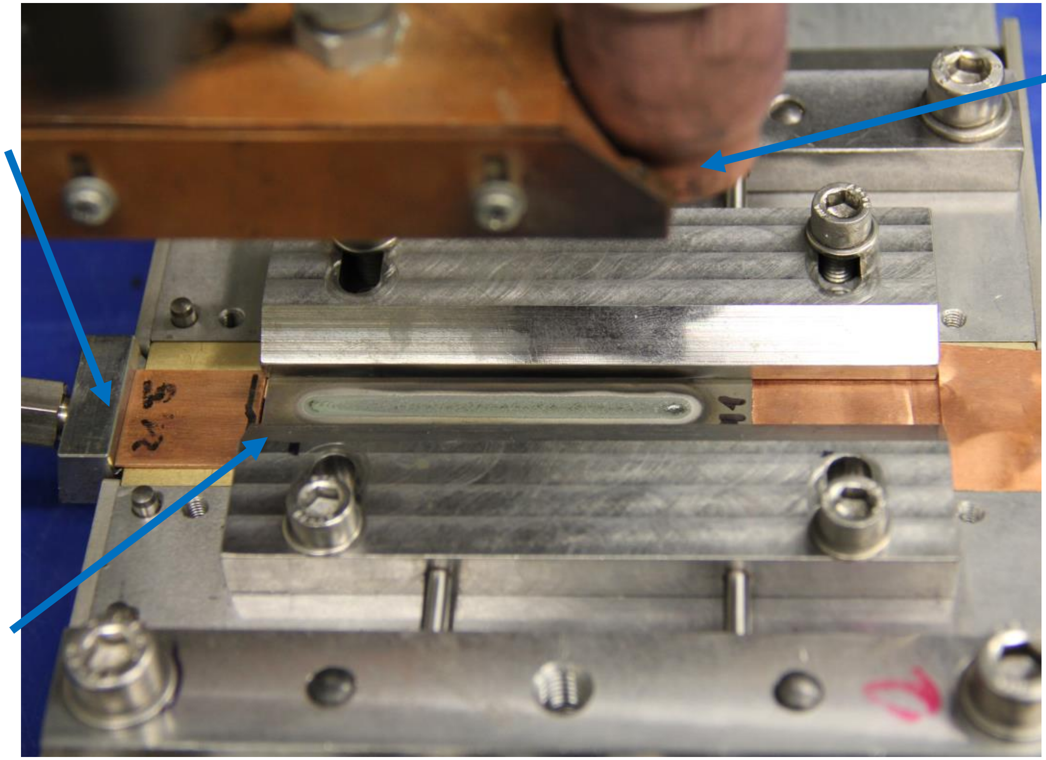
→ Temperature control (e.g. preheating, post weld heat treatment-PWHT)



Welding of HEAs
First time bead-on-plate TIG welding

Shielding gas

Sample (14x80 mm)

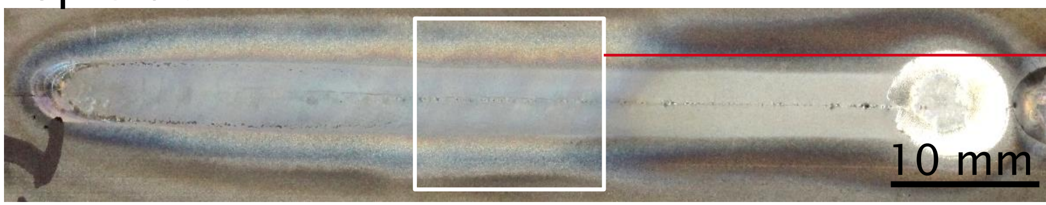


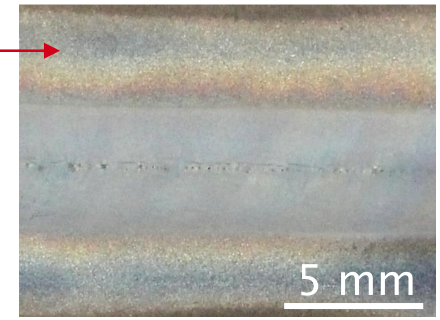
TIG torch

- Shielding gas : Argon
- Root shielding gas: Argon + 7,5 % H_2

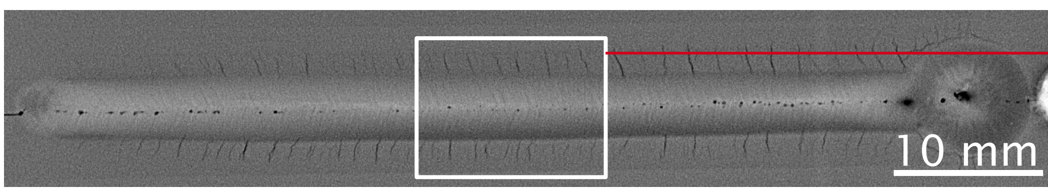
Welding of HEAs
Bead-on-plate TIG welding of CoCrFeMnNi-HEA

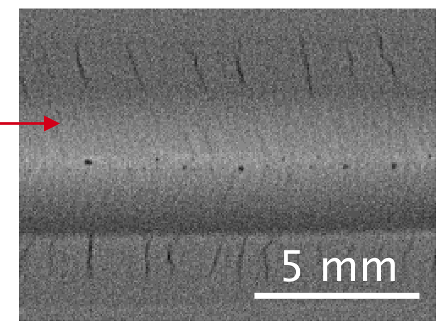
Top side





Root side

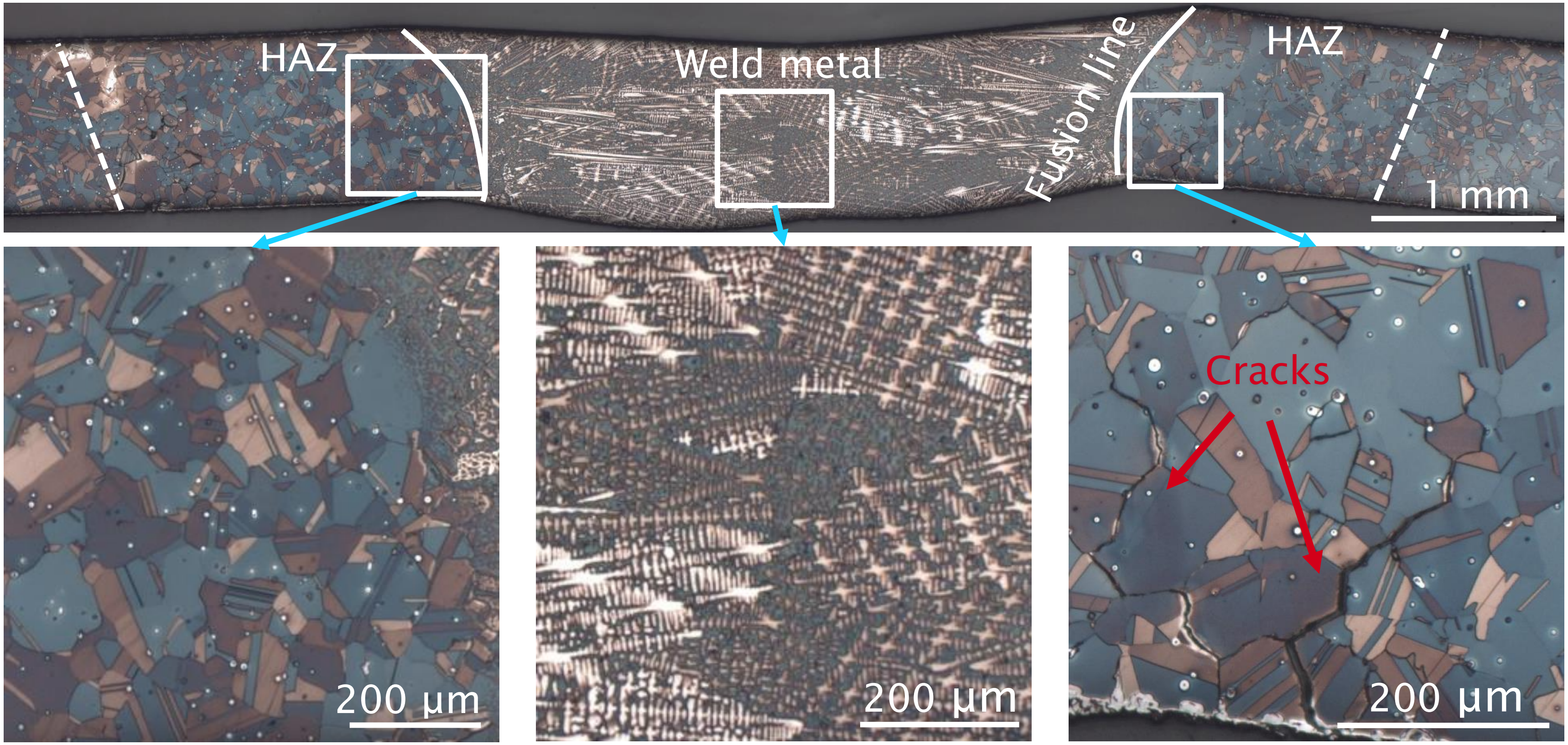




- Full penetration
- Heat tint colors in weld seam vicinity (→ corrosion resistance!)
- Pores in weld metal (→ fatigue behavior?)
- Risse in der WEZ (→ general defect-free welding possible?)

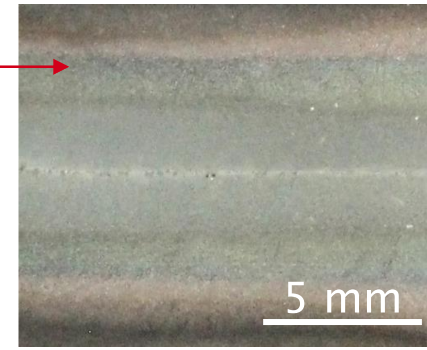
Welding of HEAs
Bead-on-plate TIG welding of CoCrFeMnNi-HEA - Microstructure

- Dendritic microstructure of weld metal → micro-segregations
- Intergranular cracks in heat-affected zone (HAZ) of base material

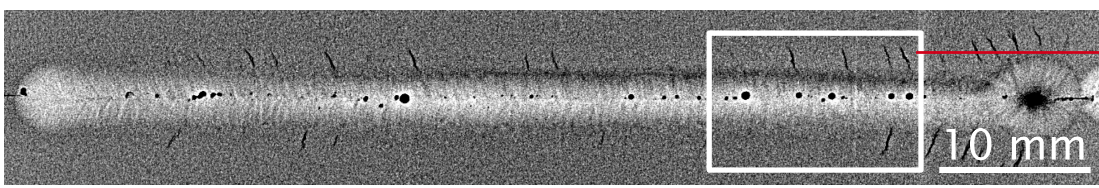


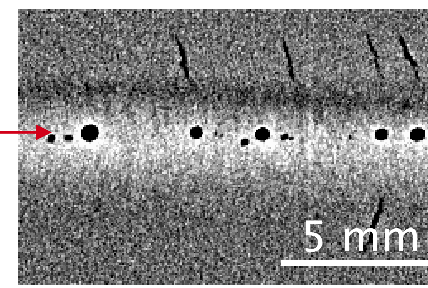
Welding of HEAs
Bead-on-plate TIG welding of CoCrNi-MEA

Top side



Root side





- Full penetration
- Heat tint colors in weld seam vicinity (→ corrosion resistance!)
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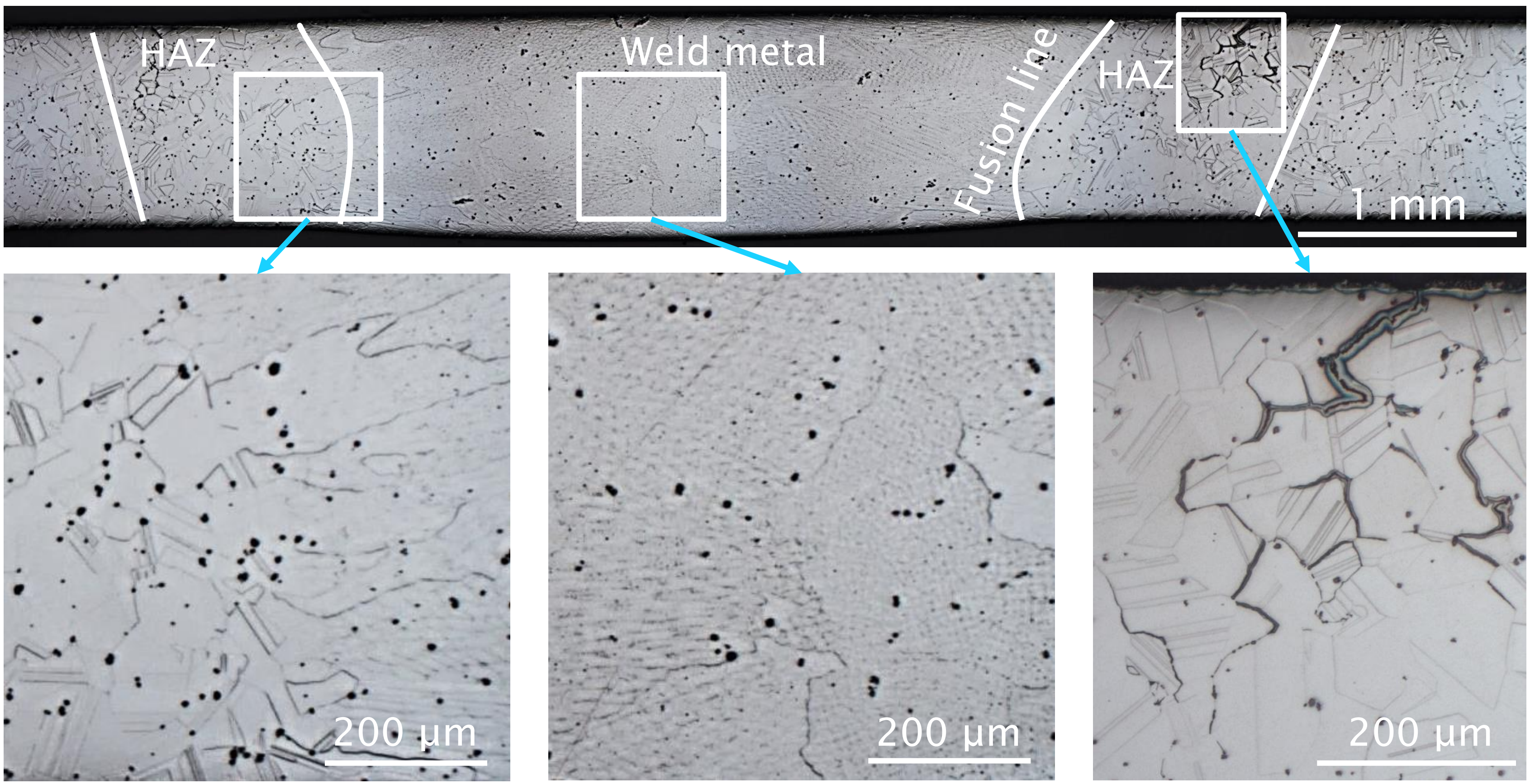
- Risse in der WEZ (→ general defect-free welding possible?)

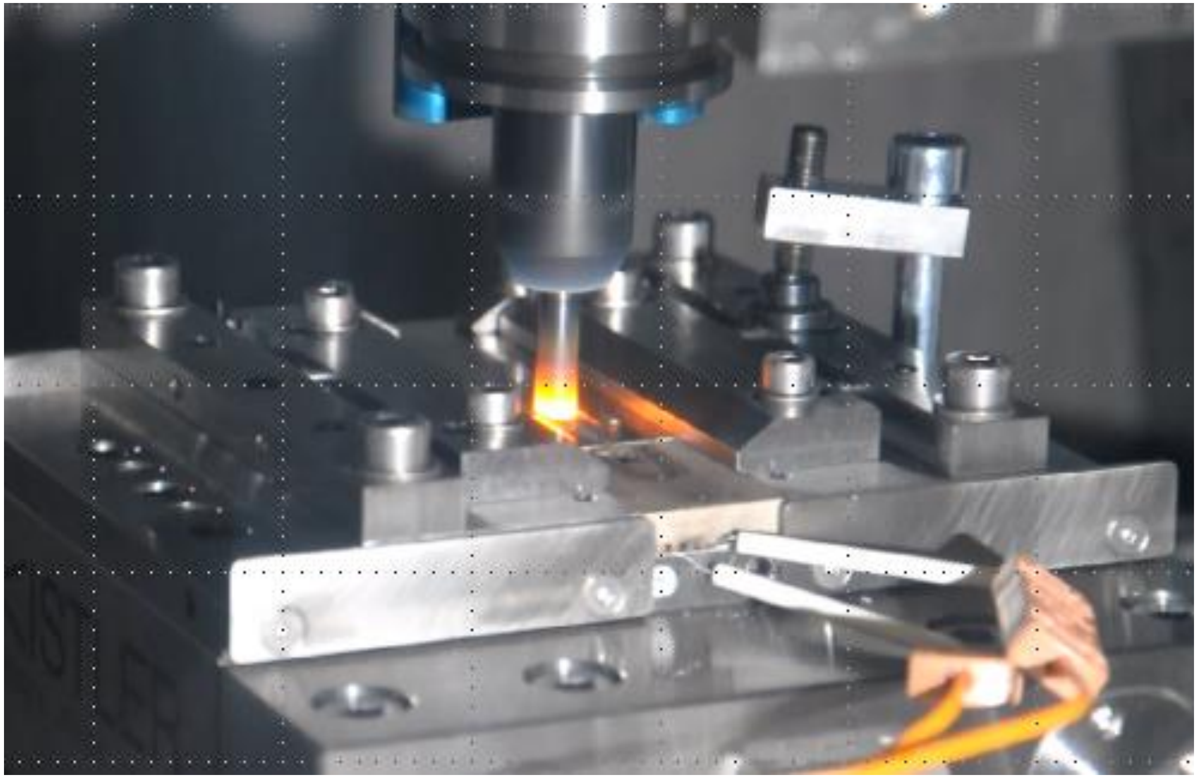
Welding of HEAs
Bead-on-plate TIG welding of CoCrNi-MEA - Microstructure

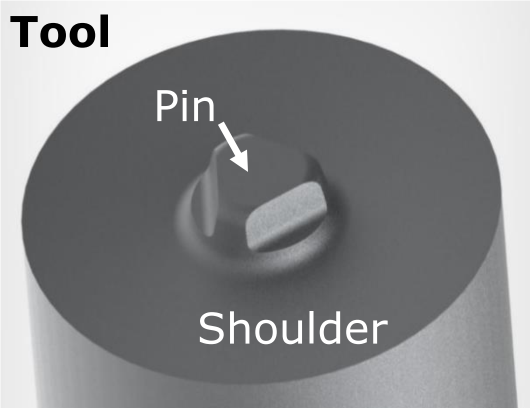
- Dendritic microstructure in weld metal
- Also intergranular cracking in HAZ

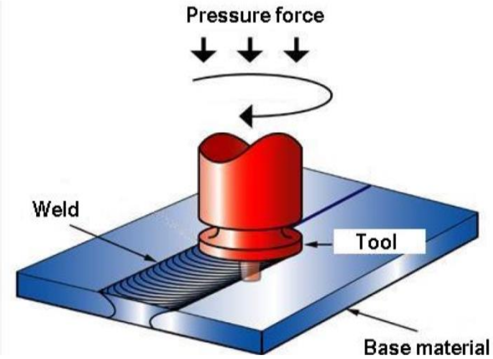


Welding of HEAs
Could solid state welding be the answer instead of fusion welding?

- **Friction stir welding (FSW)** of HEAs is becoming focus of interest
- Recently, pre-studies at BAM for process development:



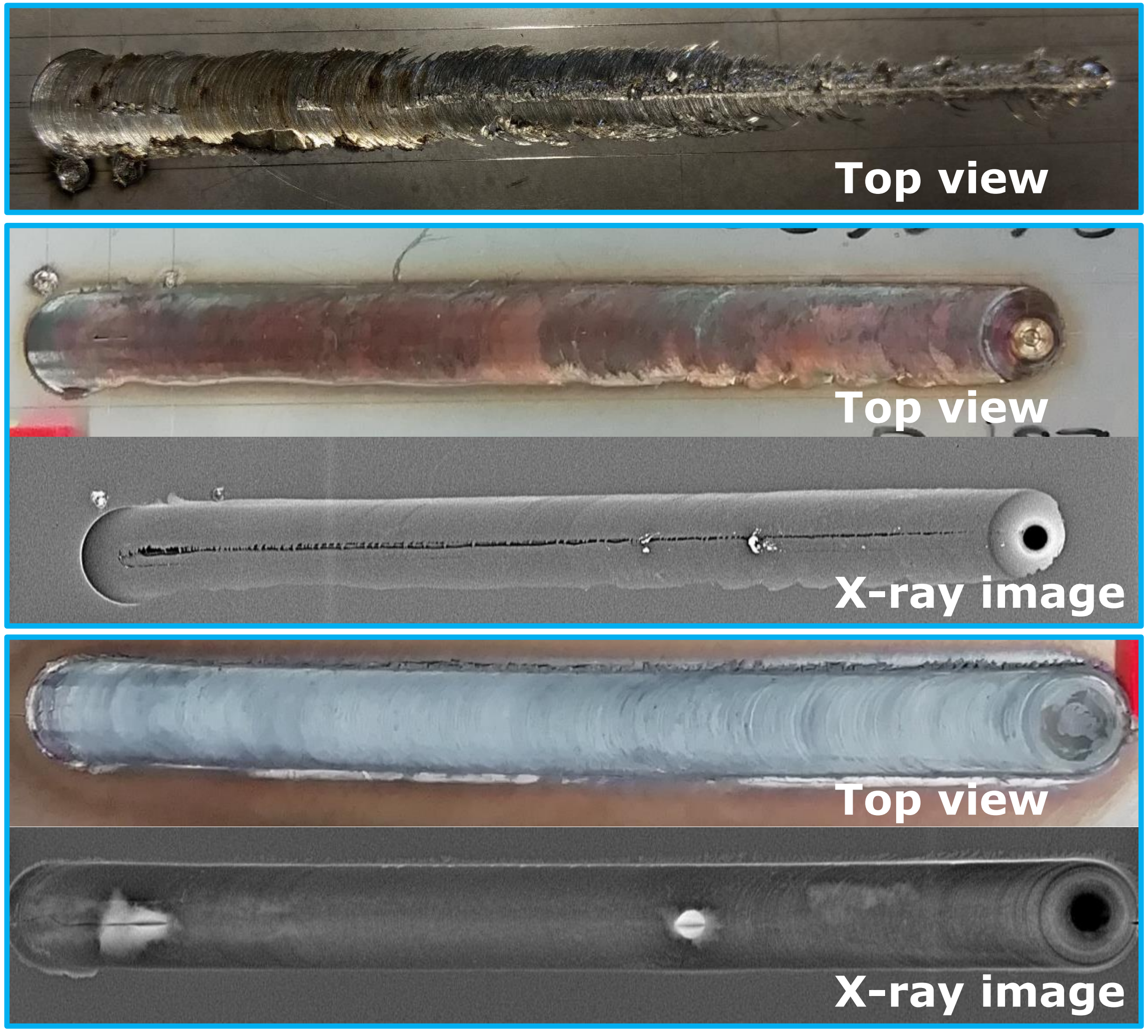




Meilinger, 2013

Welding of HEAs

Friction stir welding – challening parameter adaption (ongoing work)



First „try"

Heat dissipation Improved → top view looks good, but.

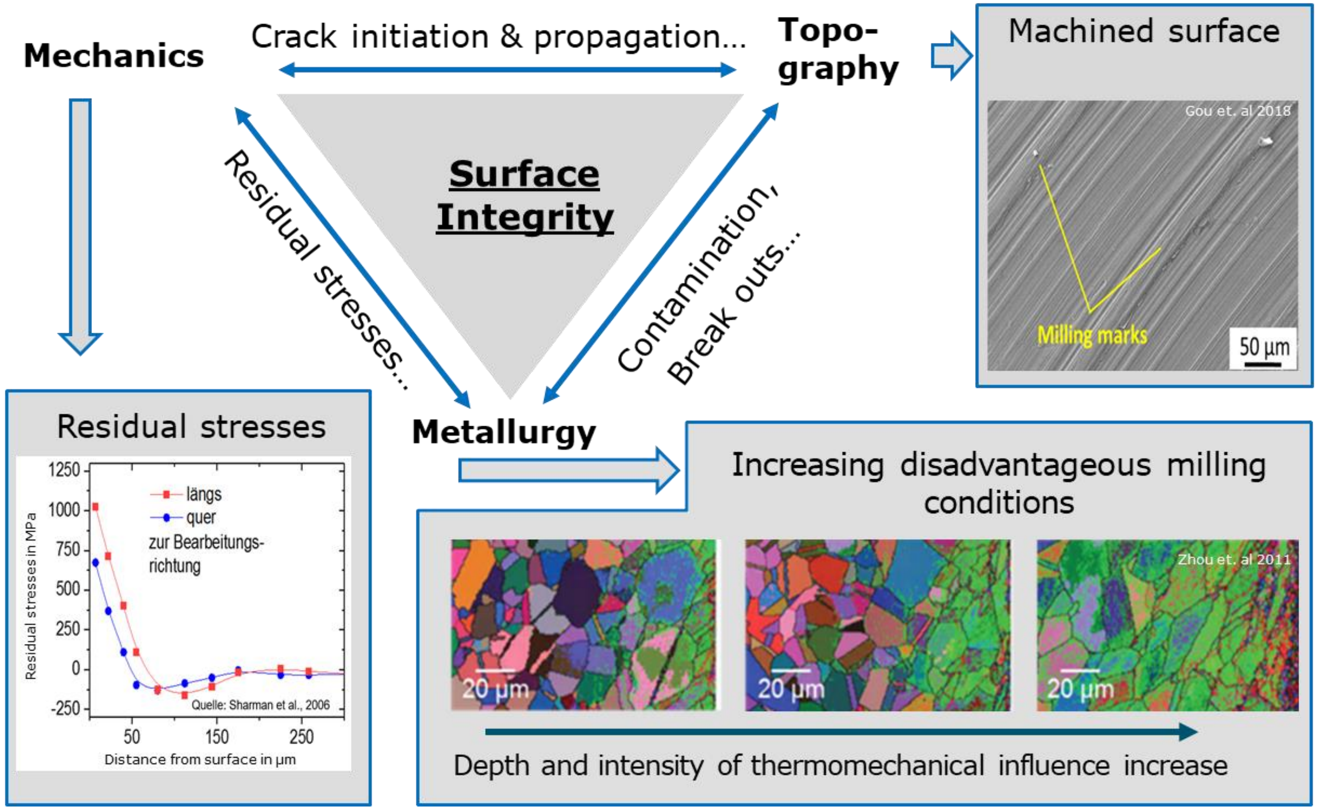
X-ray inspection reveals cracking

Optimized para-meters (RPM, Welding speed)

Nearly defect-free

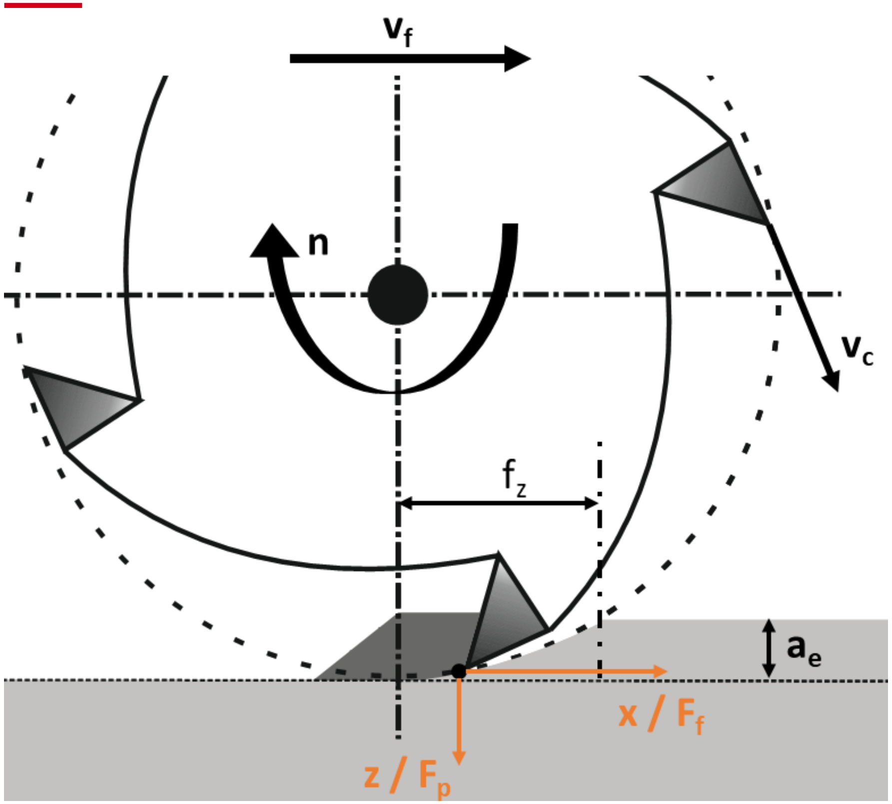
Machinability and surface integrity

- Machinability characterized by: cutting force, tool wear & life, chip formation and **surface integrity**



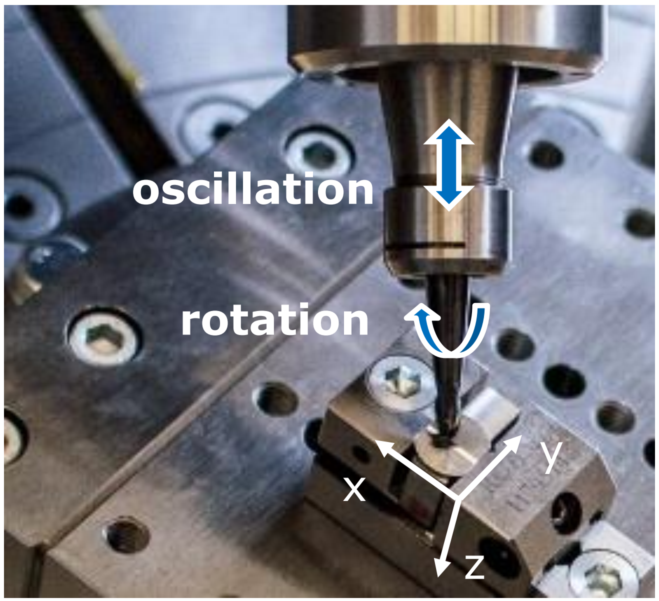
→ Surface integrity is the key challenge for machinability of components in highly stressed or safety-relevant areas

Machinability and surface integrity
Parameters for milling tests

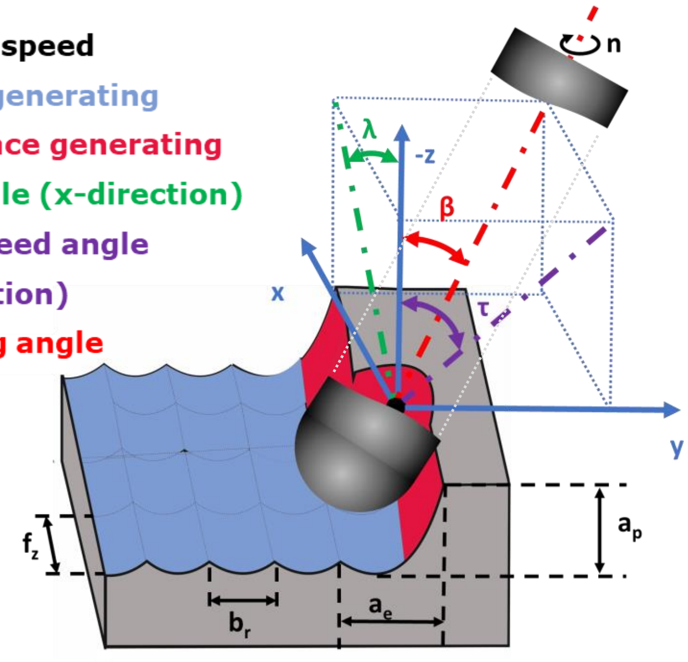


v_c	**cutting speed**
f_z	**feed rate per cutting edge**
n	rotational speed
v_f	feed rate
a_e	cutting depth
F_f	feed force in feed-/ x-direction
F_p	passive force in depth-/ z-direction

Machinability and surface integrity
Regarded parameters for milling tests



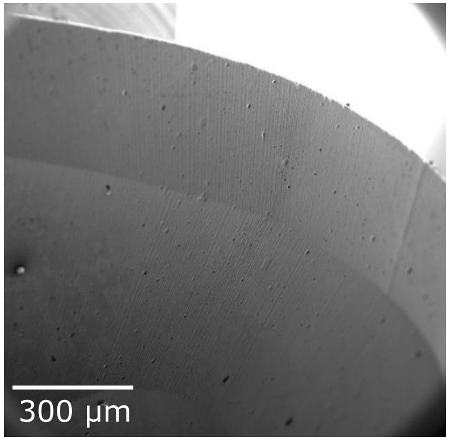
n	**Rotation speed**
(blue)	**Surface generating**
(red)	**Not surface generating**
λ	**Feed angle (x-direction)**
τ	**Normal feed angle (y- direction)**
β	**Resulting angle**

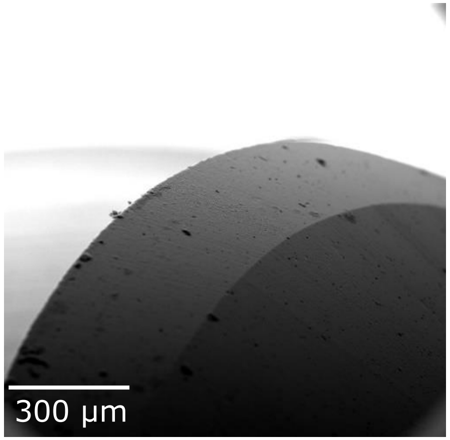


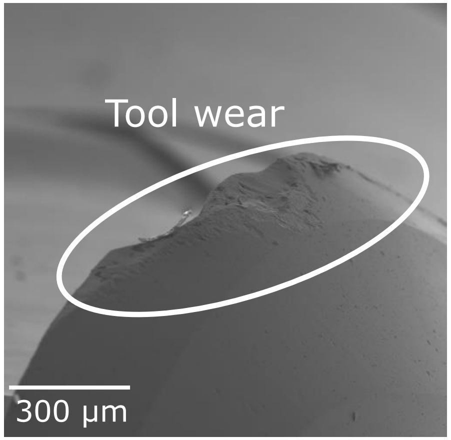
- 6 mm ball nose end milling tool with 4 cutting edges (cemented carbide / PVD coated)
- Ultrasonic assisted milling (USAM modified 5-axis machining portal)
- 3D-cutting force analysis with a dynamometer (Kistler)

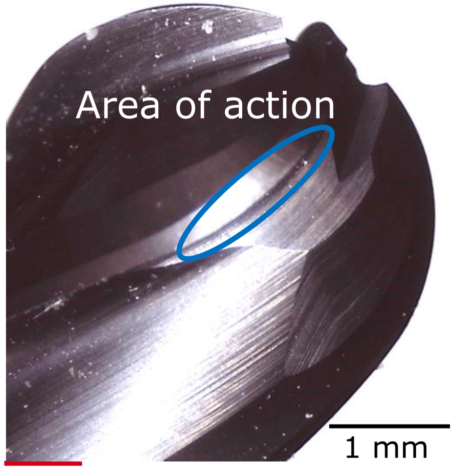
Machinability and surface integrity
Tool wear - Comparison HEA and MEA

Unused cutting edge (as delivered)	Used cutting edge HEA-tests	Used cutting edge MEA-tests









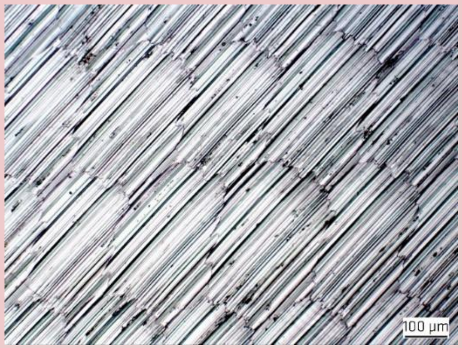
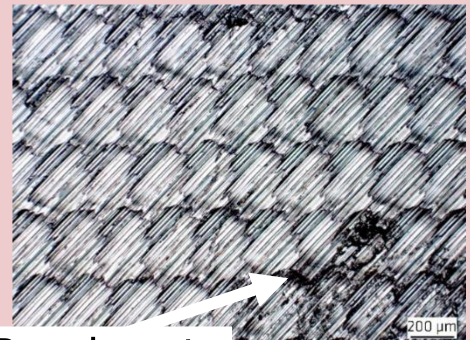
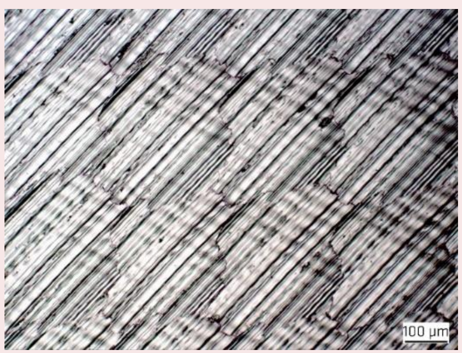
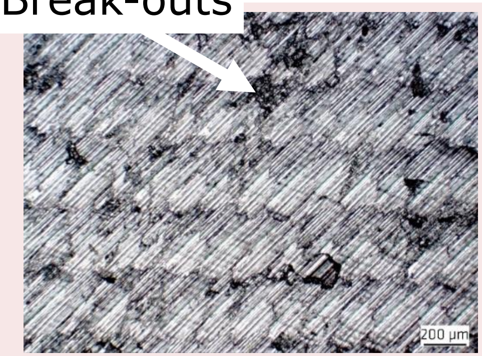
- Cutting edges almost “as good as new” after machining experiments at HEA specimens

→ **Very low tool wear with HEA (CoCrFeMnNi)**

- Severe wear marks and breaks at the tool tip after machining experiments at MEA specimens

→ **Applied cutting tool not suitable for MEA (CoCrNi)**

Machinability and surface integrity
Topography/Defects - CoCrNi-Alloy

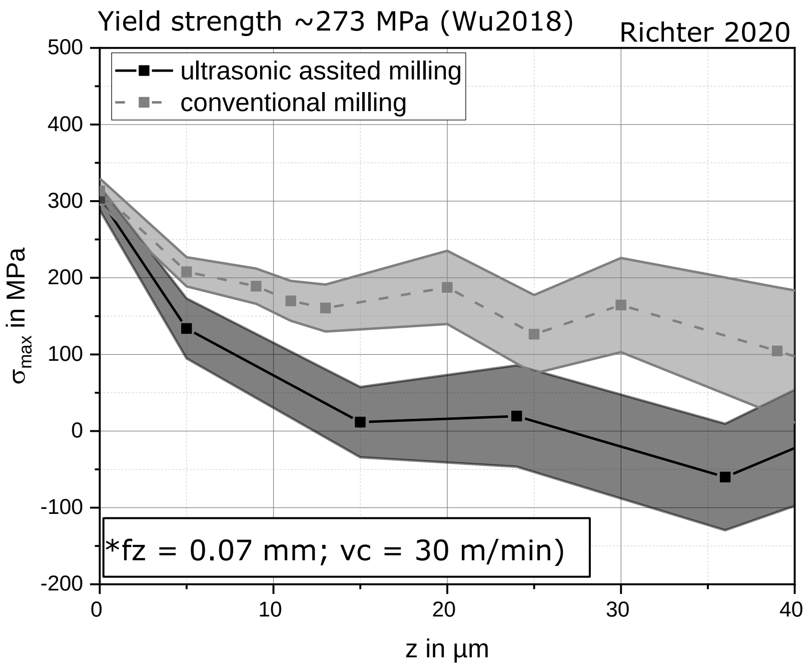
	First test		Last test	
Conven-tional		v_c= 70 m/min f_z = 0.055 mm		v_c= 70 m/min f_z = 0.055 mm
USAM		v_c= 110 m/min f_z = 0.07 mm		v_c= 110 m/min f_z = 0.04 mm

- First tests: high surface quality, almost free of defects
- Significant influence of tool wear on the generated surface

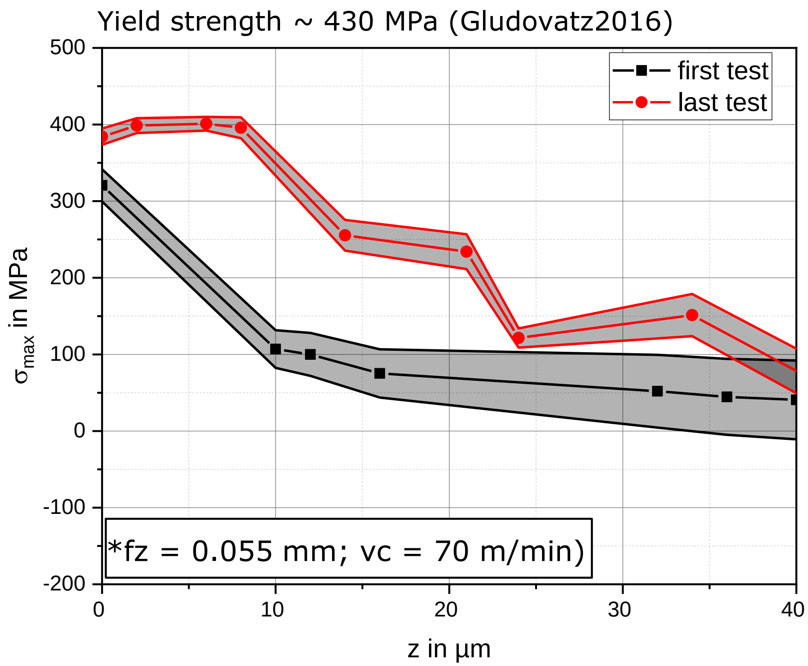
→ **Worn tool causes extensive surface defects (break-outs)**

Machinability and surface integrity
Residual Stresses (XRD) - Comparison HEA and MEA

CoCrFeMnNi-HEA



CoCrNi-MEA



- USAM causes reduced detrimental tensile residual stresses below the surface in the CoCrFeMnNi-HEA compared to conventional milling

→ **Improved residual stress condition due to application of USAM**

- With the CoCrNi-MEA the continuously increasing tool wear has a predominant influence on the residual stress state

Summary and conclusions

Basic research on HEAs/MEAs:

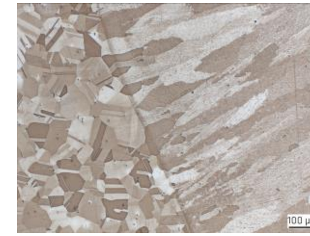
– Weldability/Machinability:
  - TIG fusion welding results in cracking of HAZ, Solid-state FSW promising technique → general weldability is ongoing work
  - Cracks perhaps originate from Cu-slags from EDM-cutting → in-depth characterization of different weld zones and properties necessary
  - Ultrasonic assisted milling for improved surface integrity and reduced reaction forces

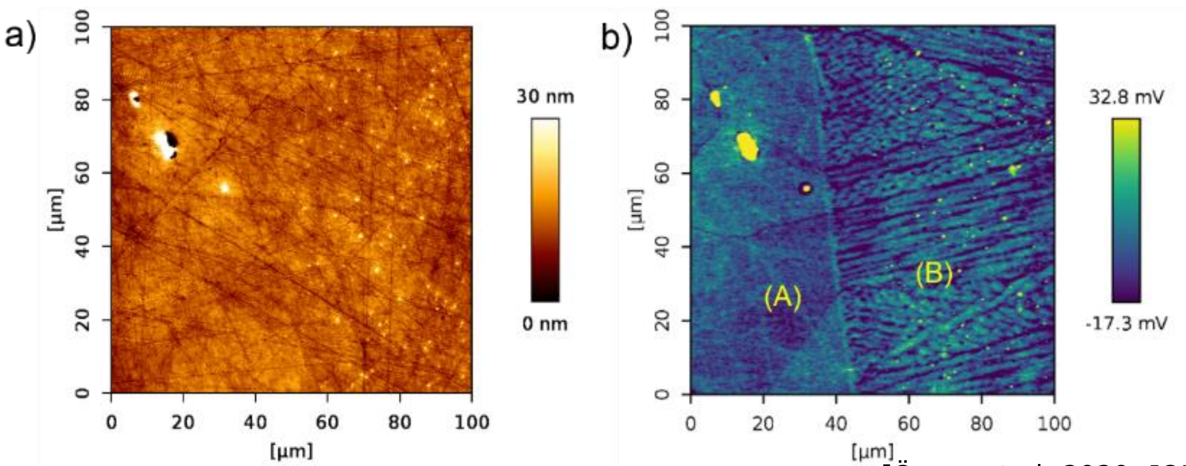
Processing influence on application properties

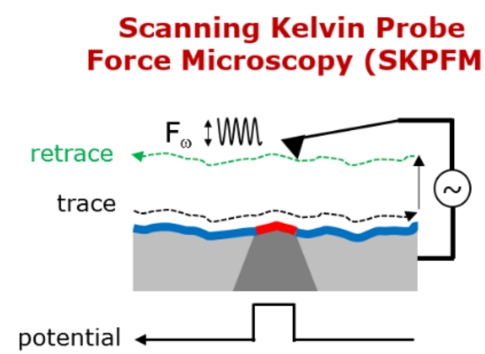
– *Mechanical performance of welded joints still open*
– *Surface integrity → electrochem. and high-temperature corrosion experiments are in progress*
– *Hydrogen diffusion and adsorption experiments in progress*

Further topcis:
Electrochemical corrosion properties

- Micro-segregations of elements during laser welding
- Investigated with scanning kelvin probe force microscopy
- Visualization of local Volta-potential







[Öczan et al. 2020, IOP Science]

- Epitaxial growth of dendrites from fusion line during solidification

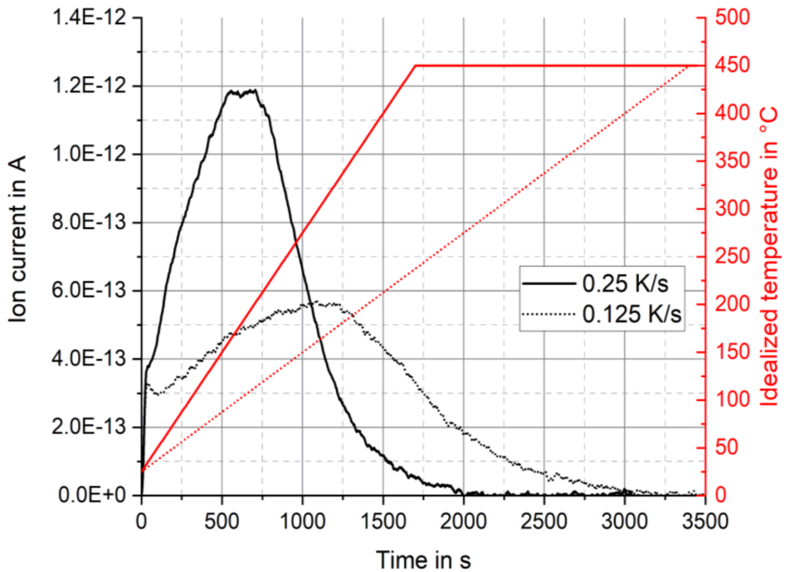
→ Segregations of elements → increased pitting susceptibility

- Dissolution and reprecipitation of Al-rich impurities (due to processing)

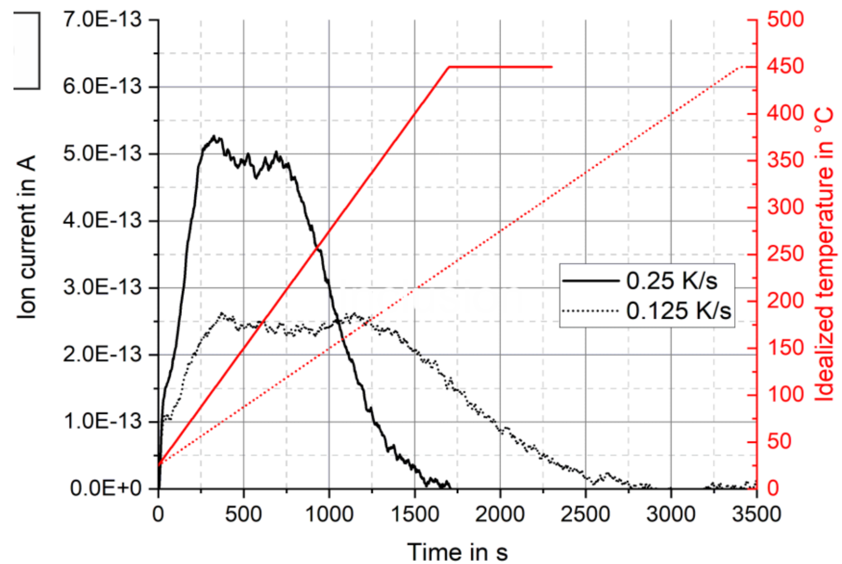
→ Smaller difference potential → galvanic corrosion risk decreases in WM

Further topics:
Hydrogen diffusion in HEAs/MEAs

– CoCrFeMnNi-HEA



– CoCrNi-MEA



[Rhode et al. 2020, IOP Science]

– Similar diffusion behavior, i.e. active traps at respective temperatures
– CoCrFeMnNi: significantly higher hydrogen concentration (higher effusion rate!)

→ Concern for hydrogen assisted (weld) cracking

Thank you for your kind attention!

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