TAMPERE UNIVERSITY OF TECHNOLOGY

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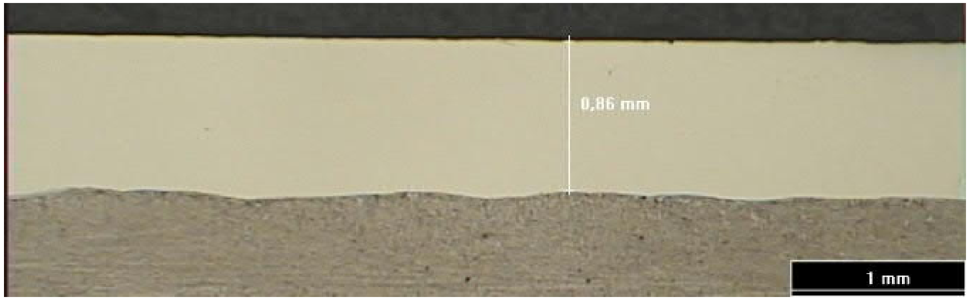
CMT project highlights – Results and implementation

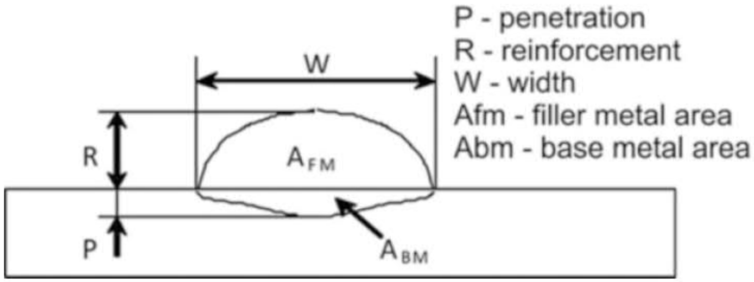
J. Tuominen, Dr.Tech.
Tampere University of Technology
Laboratory of Materials Science
Laser Application Laboratory

Outline

- Project overview
- Facilities at TUT
- Metal deposition
  - Cladding
  - Additive manufacturing
  - Welding
- Properties:
  - Rubber wheel abrasion
  - High-speed dry-pot erosion
  - Solid particle erosion
  - Hammer-mill impact
  - Pin-on-disc sliding
- Publications



- Fusion bond
- Low dilution (single layer)



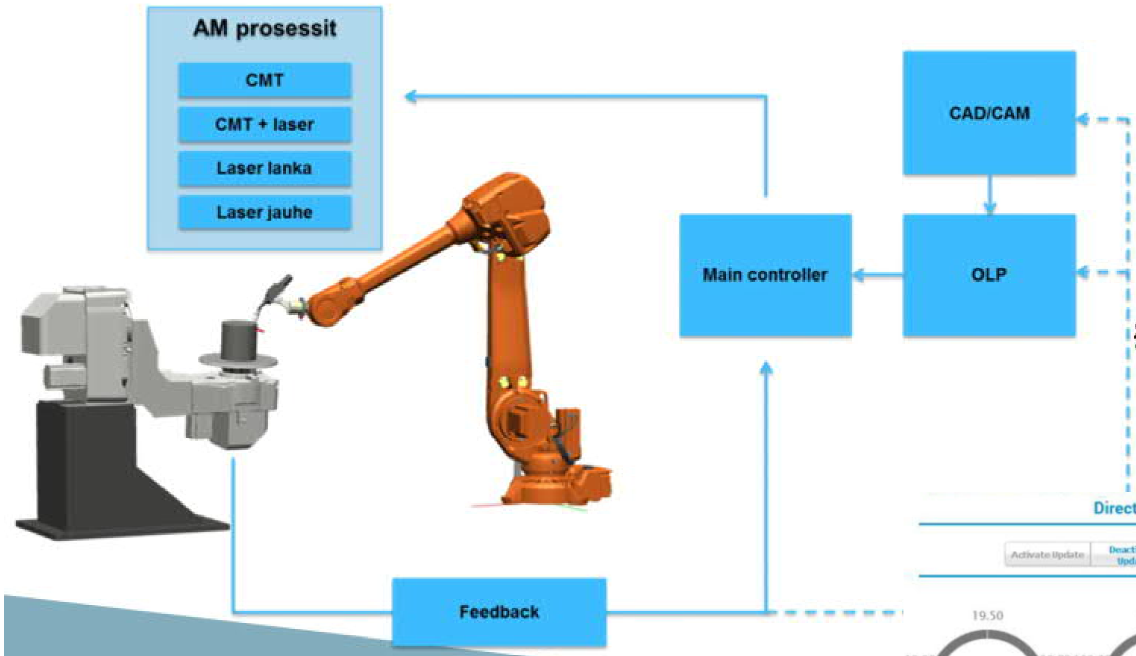
$$D = \frac{A_{BM}}{A_{BM} + A_{FM}} \times 100$$

D = dilution

CMT – Nordic business opportunities from coating and additive manufacturing

- Total budget 1.4 MEur
- Period 1.6.2015 – 30.4.2018
- Funded by:
  - European Regional Development Fund (ERDF)
  - Regional Council of Lapland
  - Länsstyrelsen Norrbotten
  - Kokkolanseudun Kehitys Ltd
  - Troms fylkeskommune
  - Wärtsilä Finland Oy, Rolls-Royce Oy, Gestamp HardTech Ab
  - Kokkola LCC Oy, Ab A. Häggblom Oy, Duroc Laser Coating Ab, Metasphere Technology Ab, Alfamat Oy

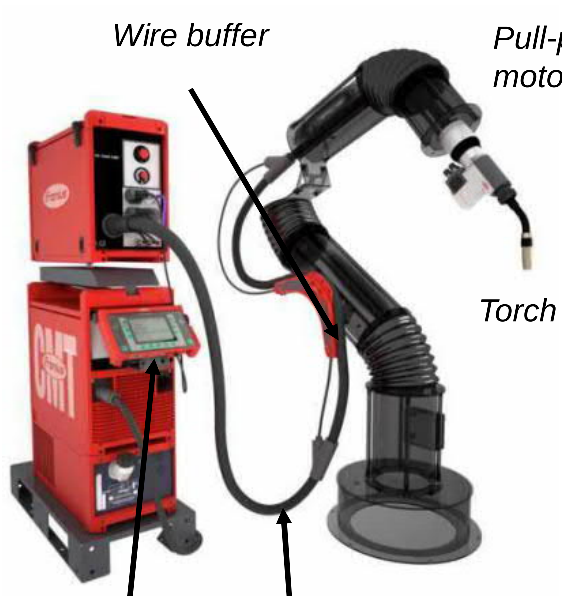
CMT at TUT

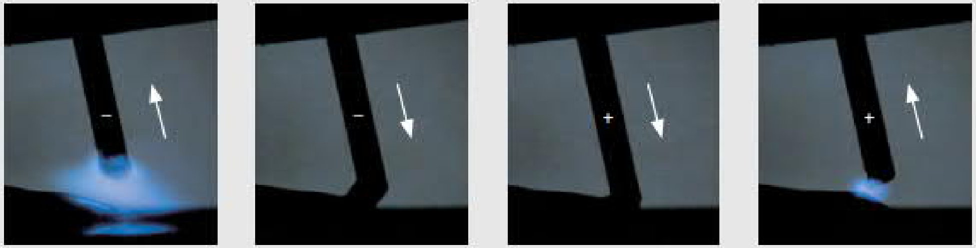


- Fronius CMT Advanced 4000R single wire
  - *400A (50%), 320A (100%) duty cycle*
- ABB IRB 4600-40/2.55 (40kg) + ABB IRBP A-750 turn table (700kg)
- 1-colour pyrometer to control interpass temperatures
- Heatmasters heat treatment unit
- Minac induction heater

Process monitoring, 10ms (100Hz) (Stjerna 2017)

CMT Advanced



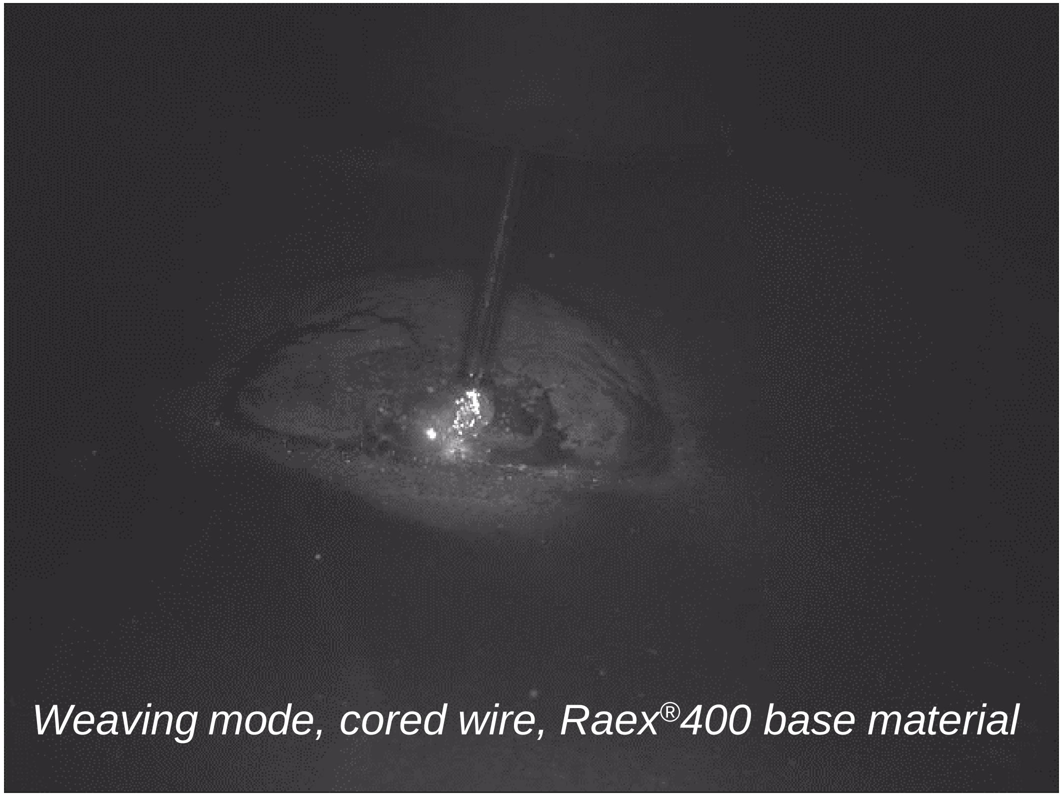


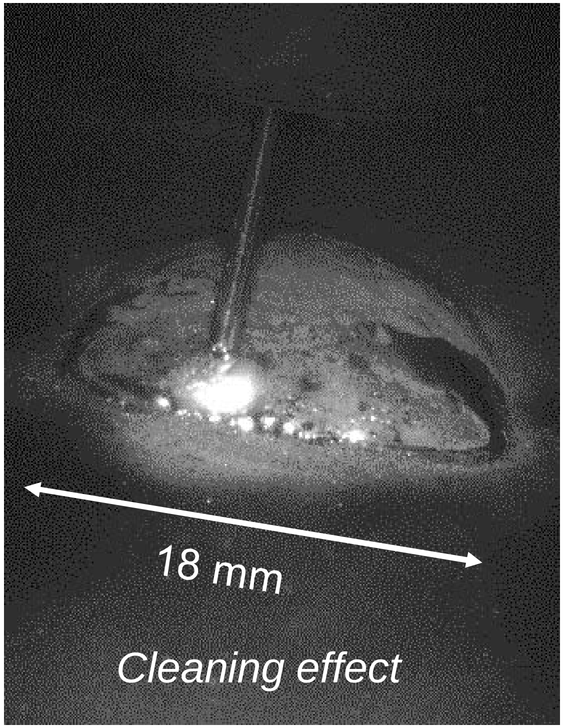
/ CMT-negatiivinen   / CMT-negatiivinen   / Käyttöönotto   / CMT-positiivinen

CMT Advanced: polarity change during short circuit

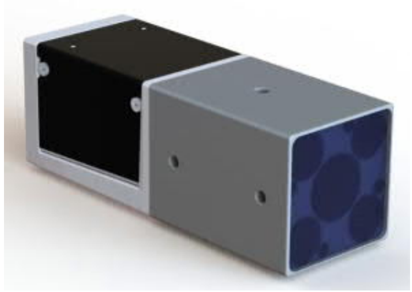
- *Synergy lines available to Al- alloys*
- *Beneficial for MMCs, solid lubricants etc.?*

Camera-based monitoring

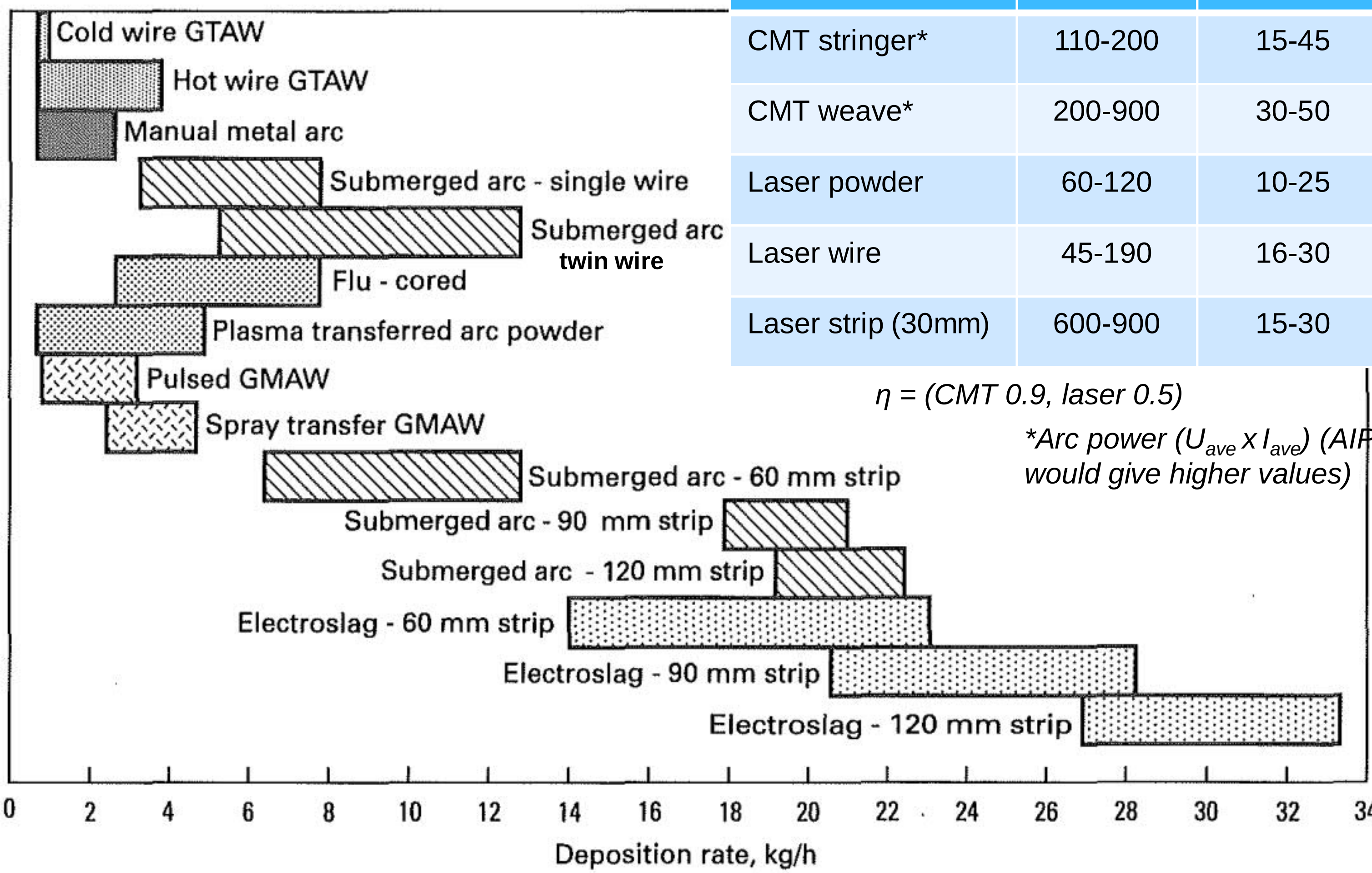




Cavitar Welding Camera (Camera and integrated laser illumination, 29 x 29 x 85 mm^3)



Weld surfacing: productivity & HI



Method	HI (J/mm)	HI (J/mm^2)	DR (kg/h)
CMT stringer*	110-200	15-45	3-5
CMT weave*	200-900	30-50	3-5
Laser powder	60-120	10-25	0.5-2
Laser wire	45-190	16-30	2-6
Laser strip (30mm)	600-900	15-30	6-8

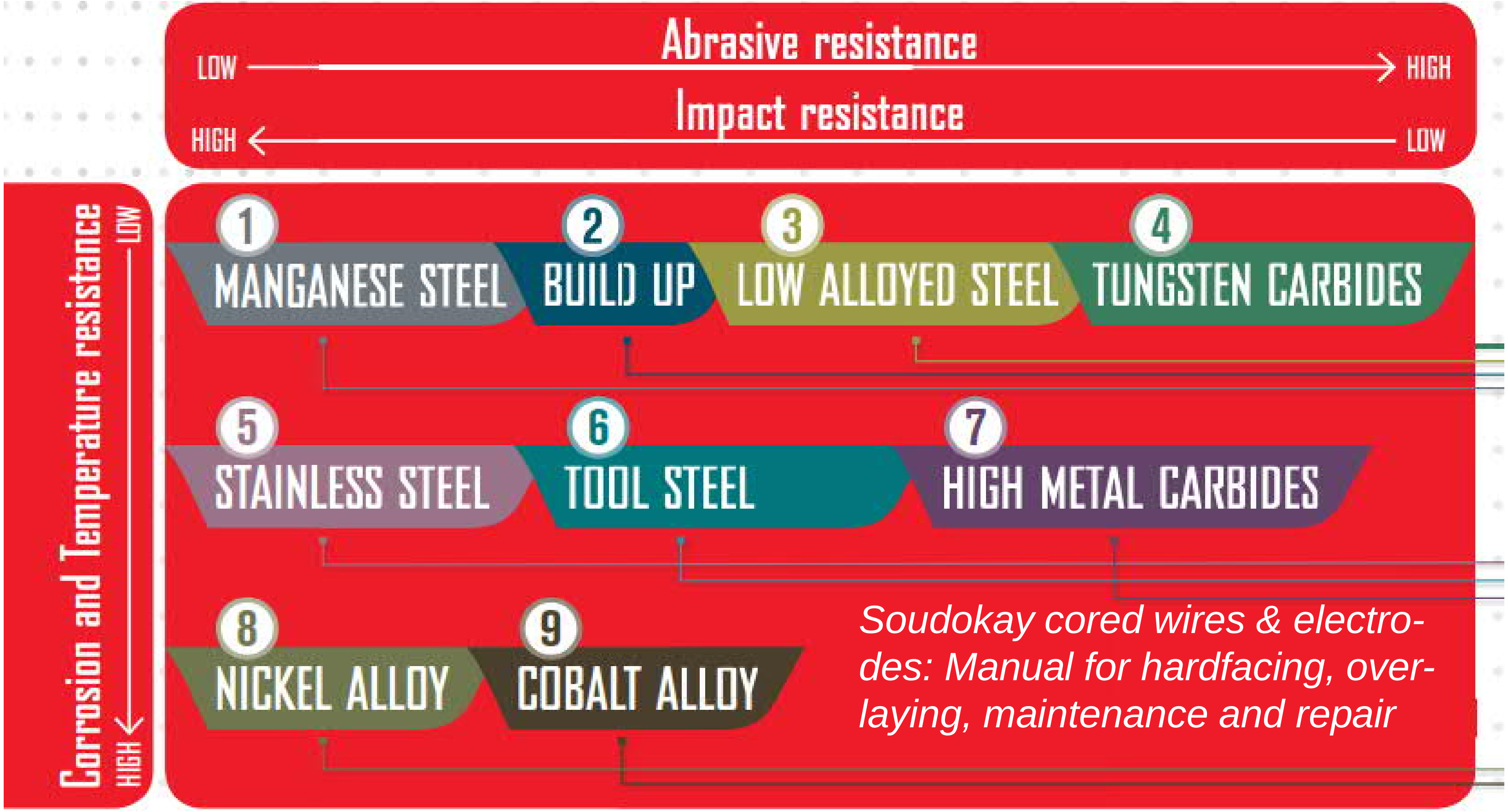
η = (CMT 0.9, laser 0.5)

**Arc power (U_{ave} x I_{ave}) (AIP method would give higher values)*

Davis 1994

Hardfacing alloys

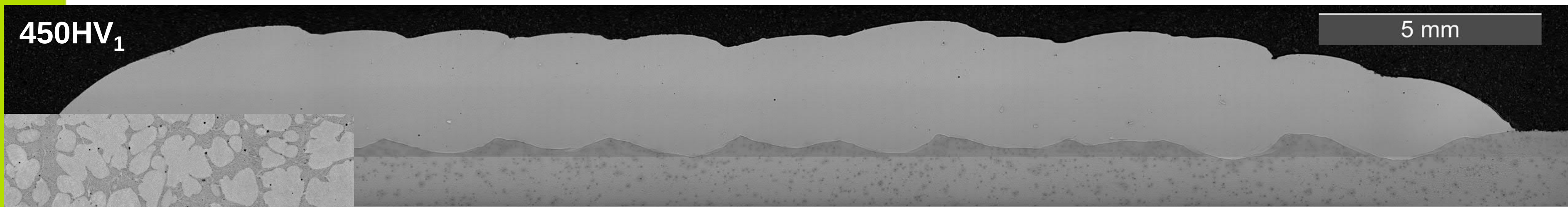
Cobalt containing and Stellites for cavitation-erosion

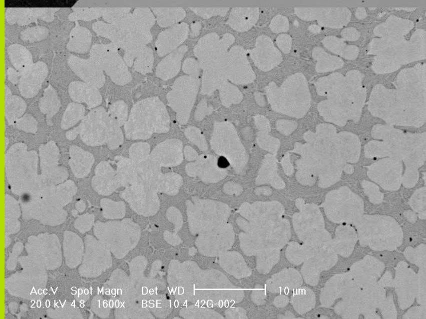


Soudokay cored wires & electrodes: Manual for hardfacing, overlaying, maintenance and repair

EN 14700:2014 'Welding consumables. Welding consumables for hard-facing.'
ISO/TR 13393:2009 'Welding consumables – Hardfacing classification – Microstructures'

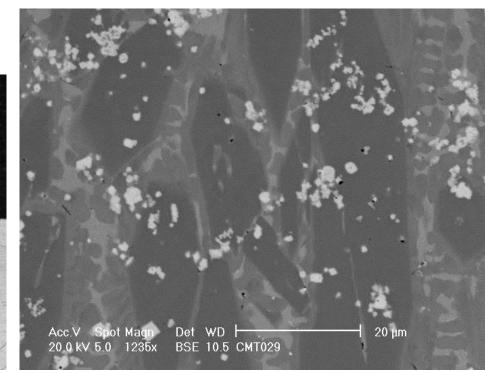
Fe-base hardfacing alloys





Fe-28Cr-3Ni-0.8Mo-1.9C / S355, geometrical dilution 12.0%, 2.5kg/h

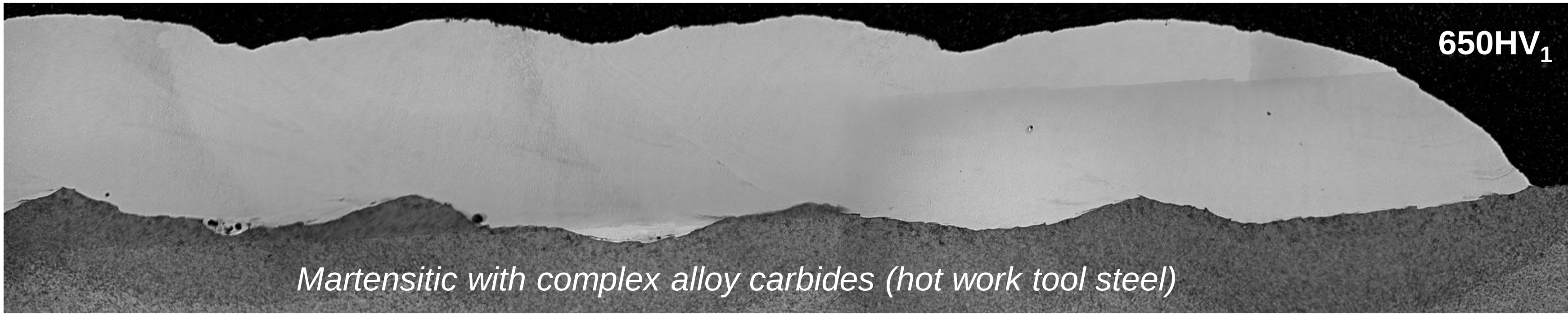
Primary austenite with austenite-carbide eutectic ($M_{23}C_6$)



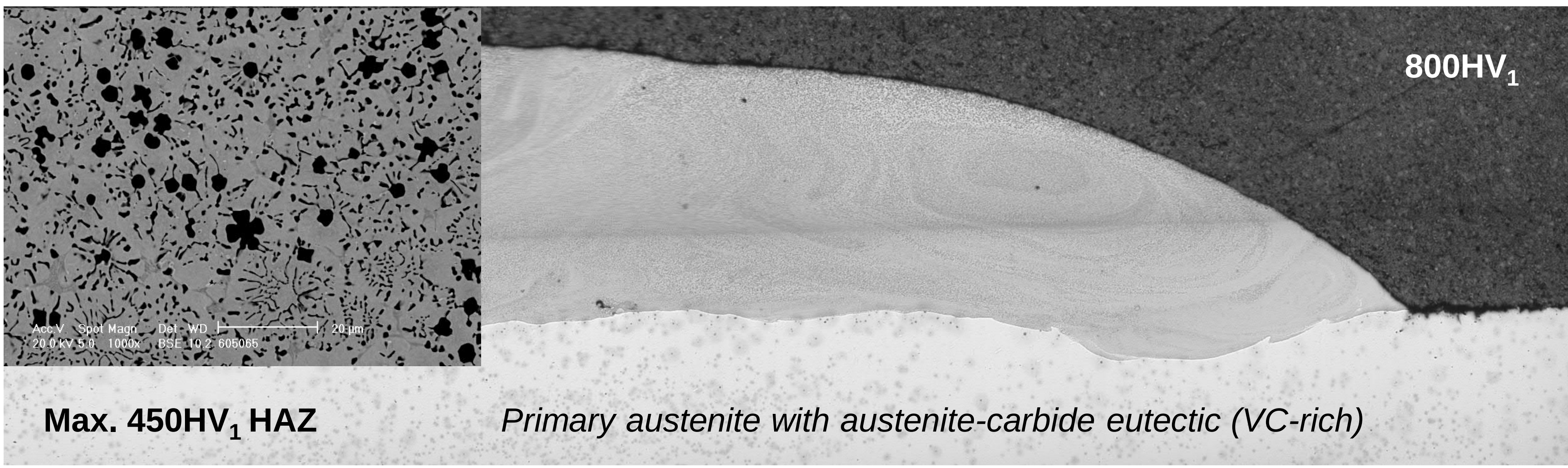
Fe-28Cr-7Mo-7Nb-2W-1V-5.2C / 304L, geometrical dilution 8.4%

Primary carbides (M_7C_3) and smaller alloy carbides (Mo-Nb) in an eutectic austenite/carbide ($M_{23}C_6$) matrix

Tool steels

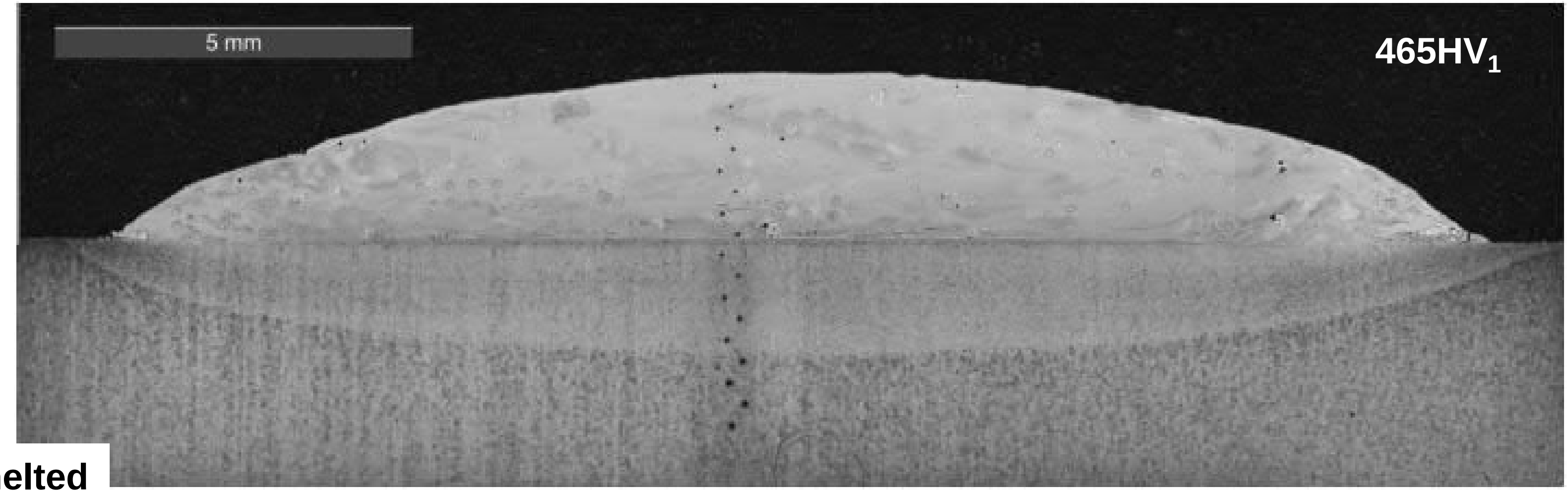


Fe-5.5Cr-1.4Mo-1.6W-0.5V-0.45C / S235, geometrical dilution 15.6%, 3.6kg/h



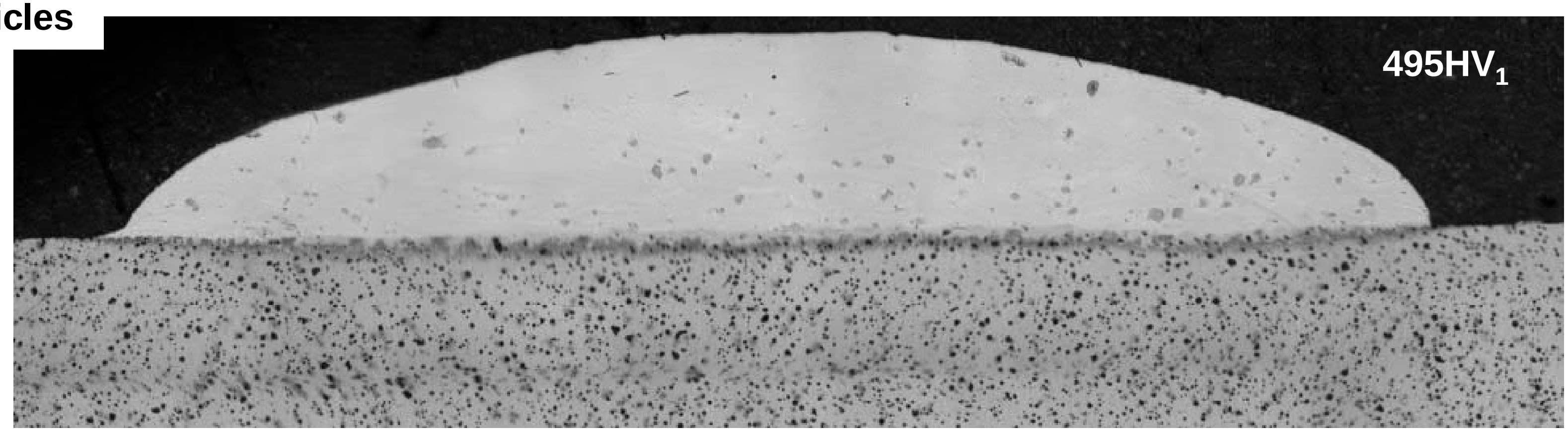
Fe-7.5Cr-1.2Mo-11.5V-2.6C / Raex®400, geometrical dilution 10.9%

Co-base hardfacing alloys



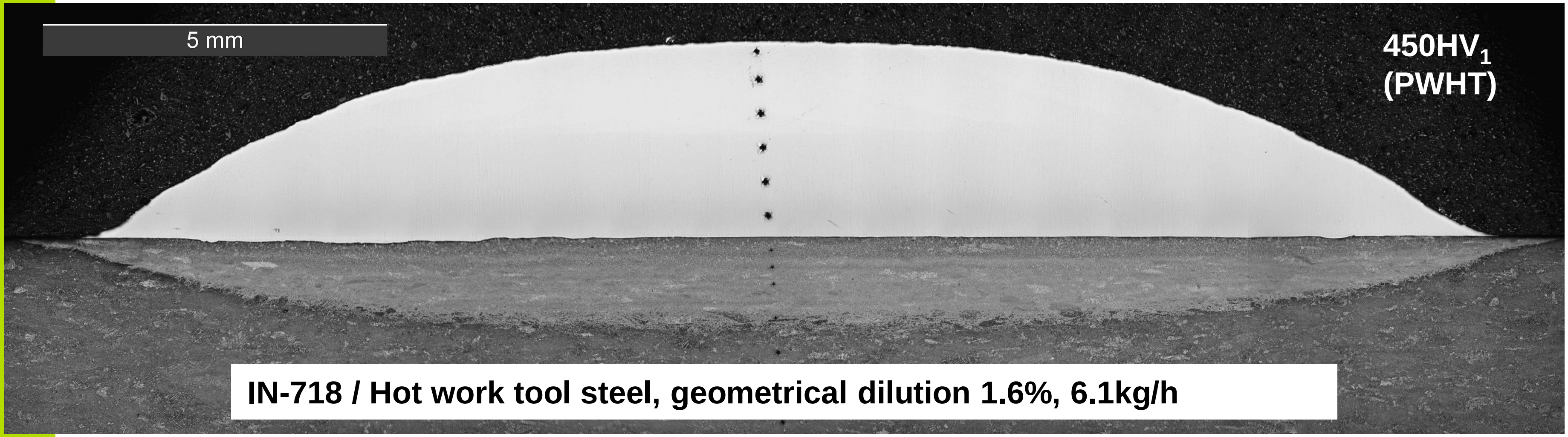
Unmelted W and Cr particles

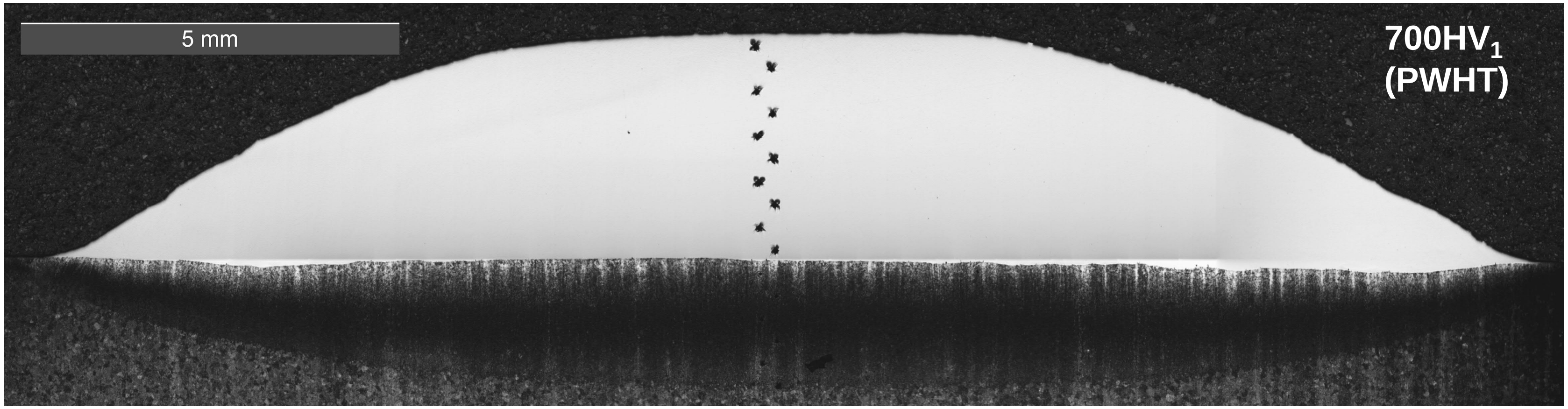
St12 / Mart. SS, geometrical dilution 1.7%, 3.0kg/h



St12 / Spheroidal graphite cast iron, geometrical dilution 3.8%, 2.4kg/h

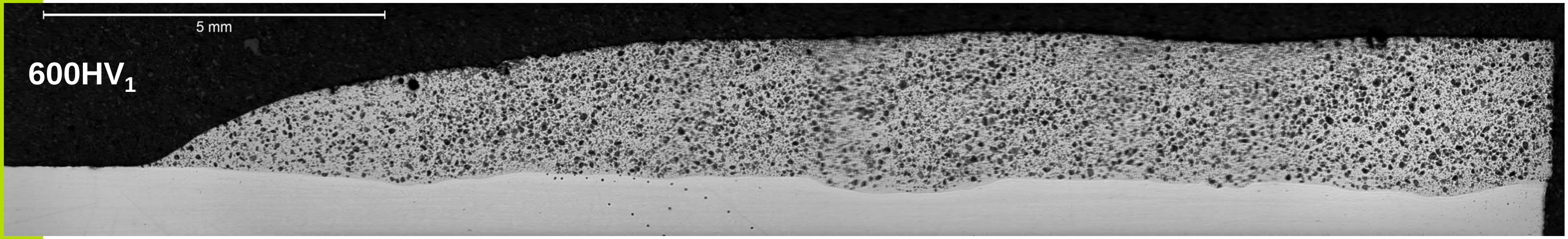
Ni-base hardfacing alloys





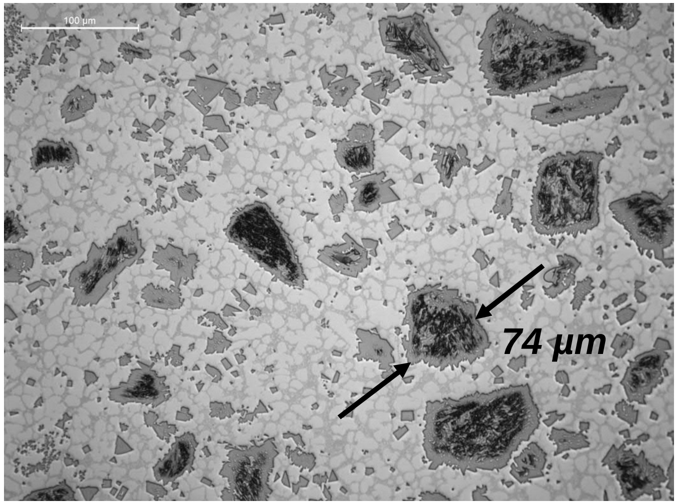
Ni-38Cr-4Al / Mart. SS, geometrical dilution 2.8%, 5.8kg/h

Metal matrix composites

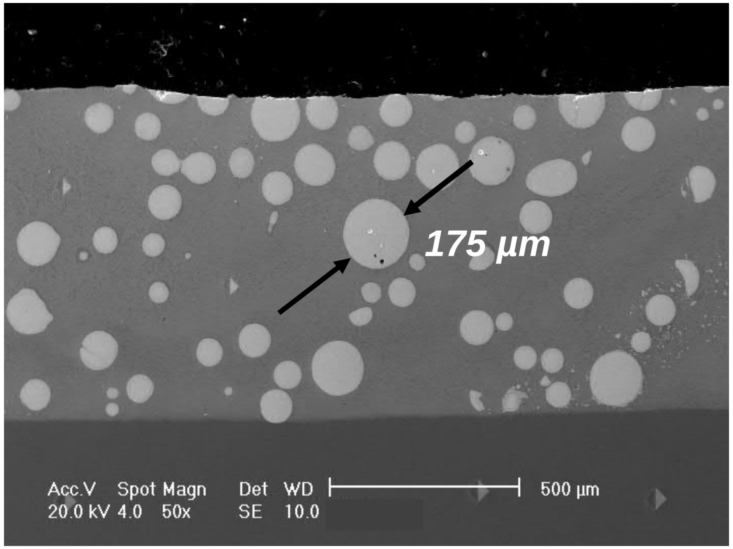


NiCrBSi + 60% Fused Tungsten Carbide (WC/W_2C) / 304L, geometrical dilution 11%

Dissolution of WC/W_2C to be avoided!

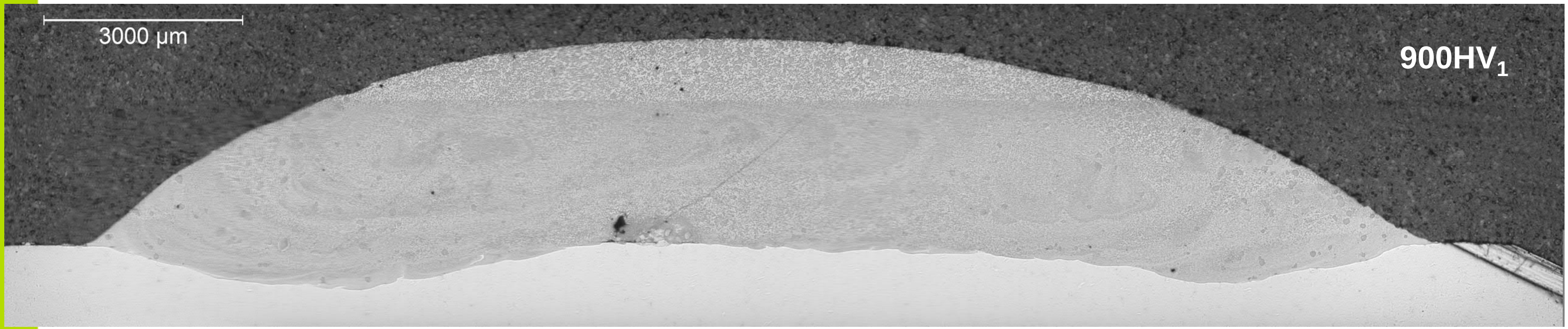


Primary carbide 2500$HV_{0.3}$ (~20 vol.%)
Matrix 530 $HV_{0.3}$



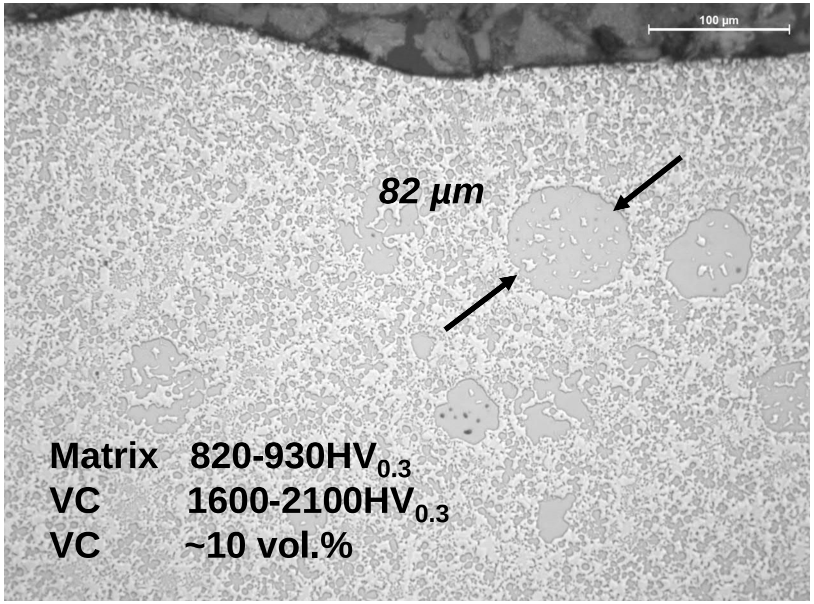
Primary carbide 2500$HV_{0.3}$ (~20 vol.%)
Matrix 260 $HV_{0.3}$

Metal matrix composites



Fe-7.5Cr-1.2Mo-11.5V-2.6C + VC (50-150µm) (externally added) / S355, geometrical dilution 11.1%

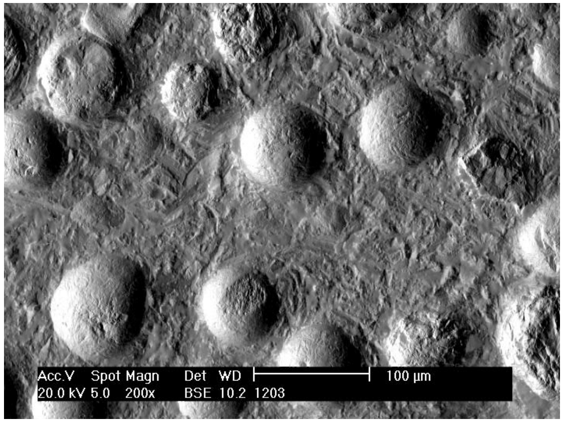
4.0kg/h

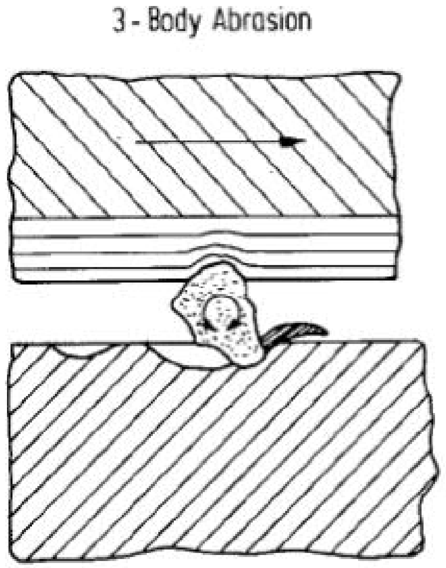


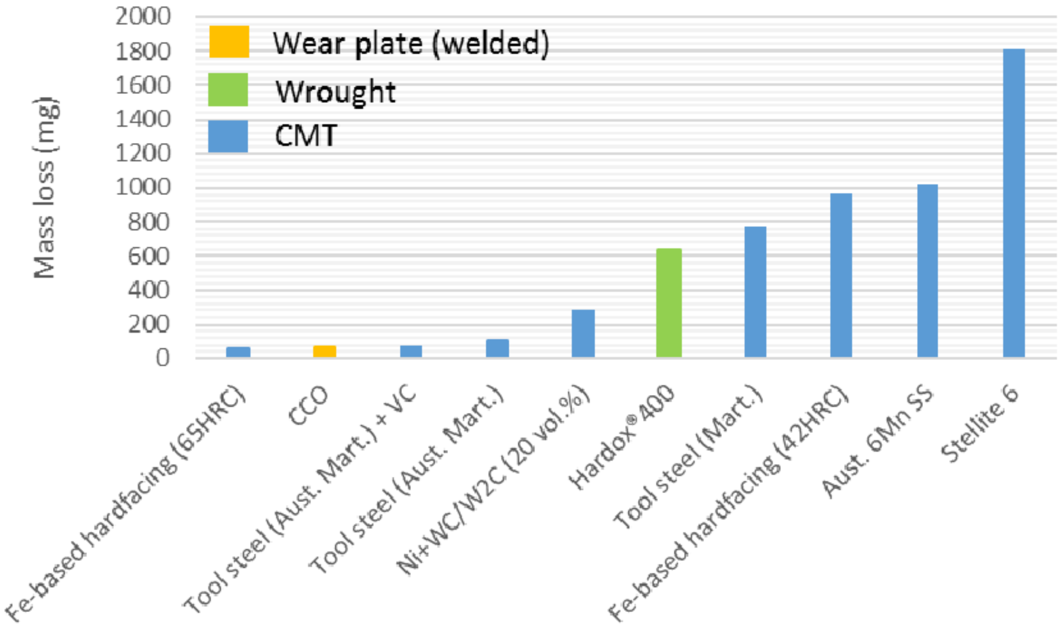
External addition of particulates

Rubber wheel abrasion

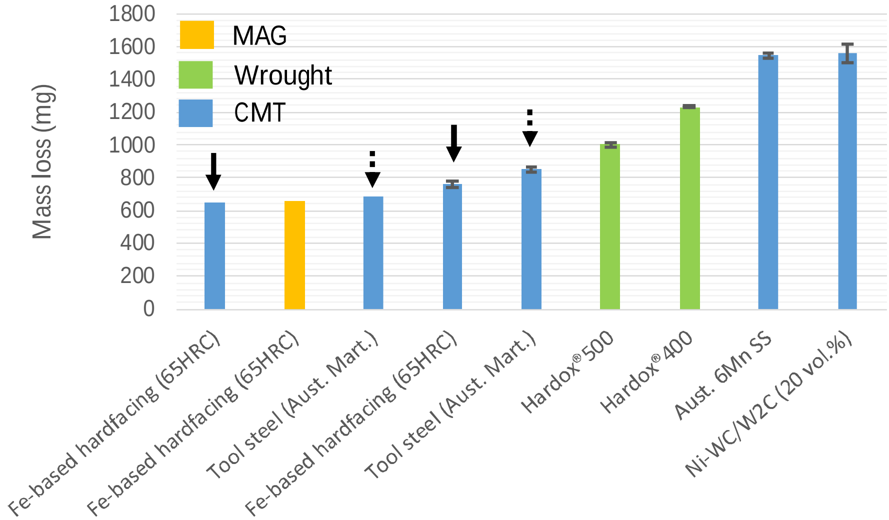
- Low-stress 3-body rubber wheel abrasion
- Crushed dry quartz sand (0.1-0.6 mm)
- Abrasive feed rate 20-30 g/min per specimen
- Load 23 N
- Surface speed of wheel 1.64 m/s
- Testing time 60 min







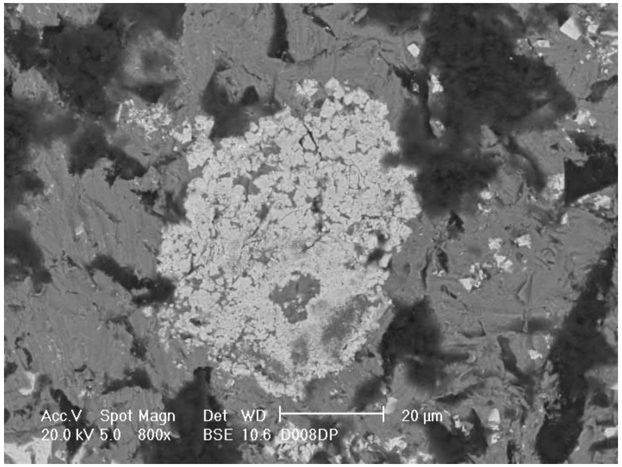
High-speed dry-pot erosion

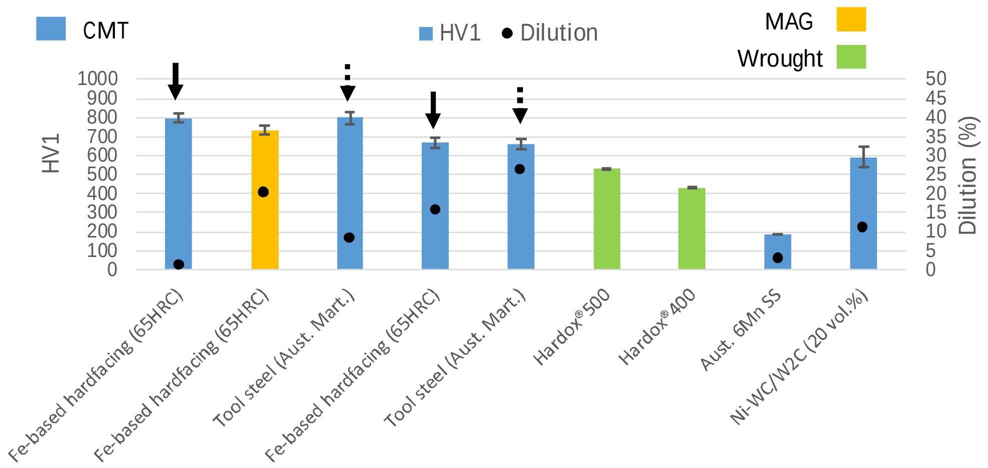


High-speed slurry/dry-pot erosion tester

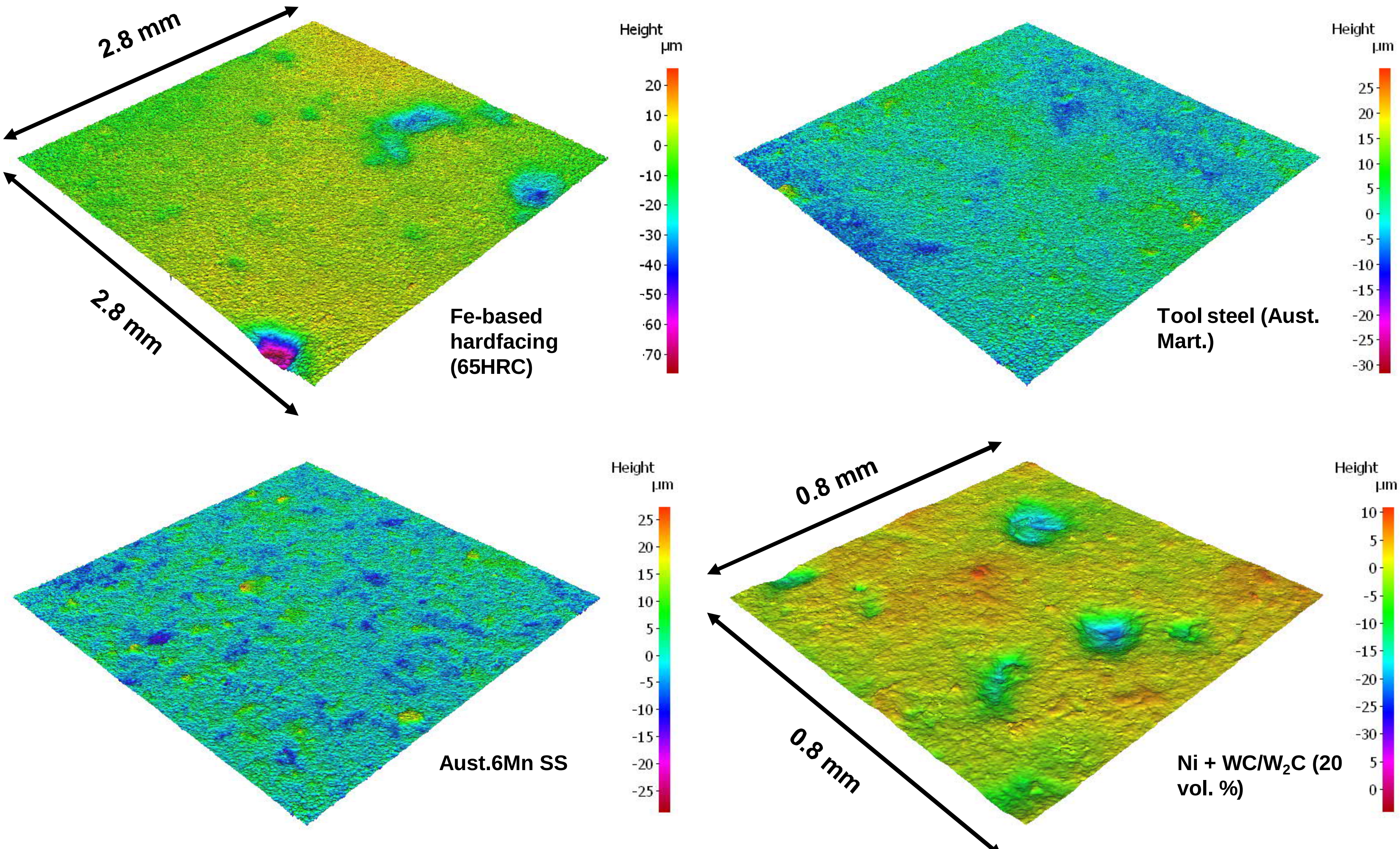
Abrasive:
Kuru granite
(8-10mm)
High-stress conditions

Fragmented
WC/W_2C
after the test



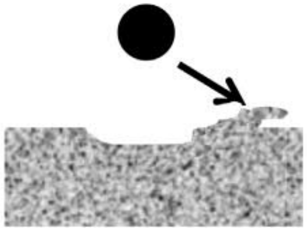


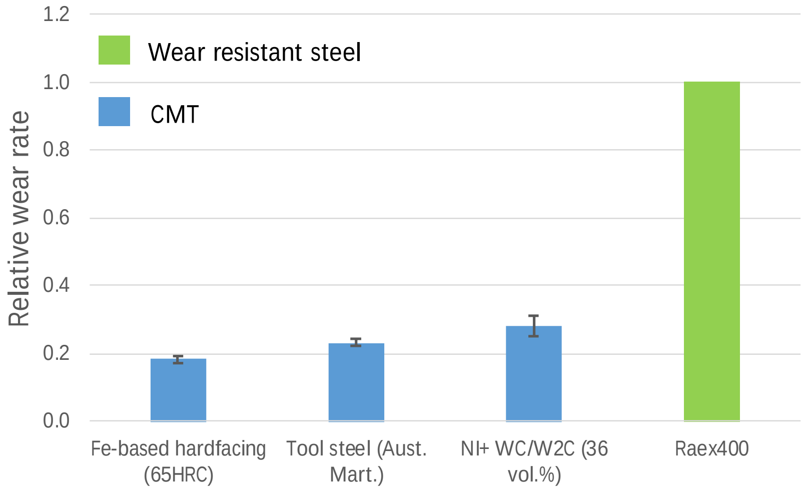
High-speed dry-pot erosion

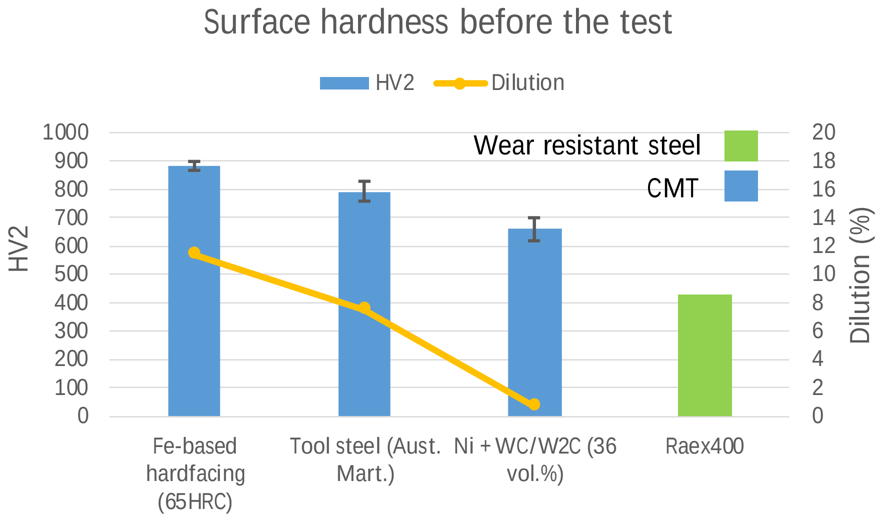


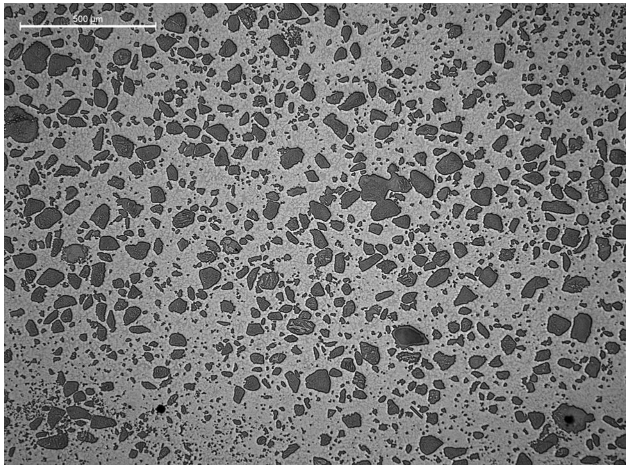
Solid particle erosion

- Pulsating jet erosion test (PulseJET)
- Rock drilling debris (<4 mm)
- Airjet pressure 6 bar
- Impact angle ~0°
- Max. Speed 80 m/s



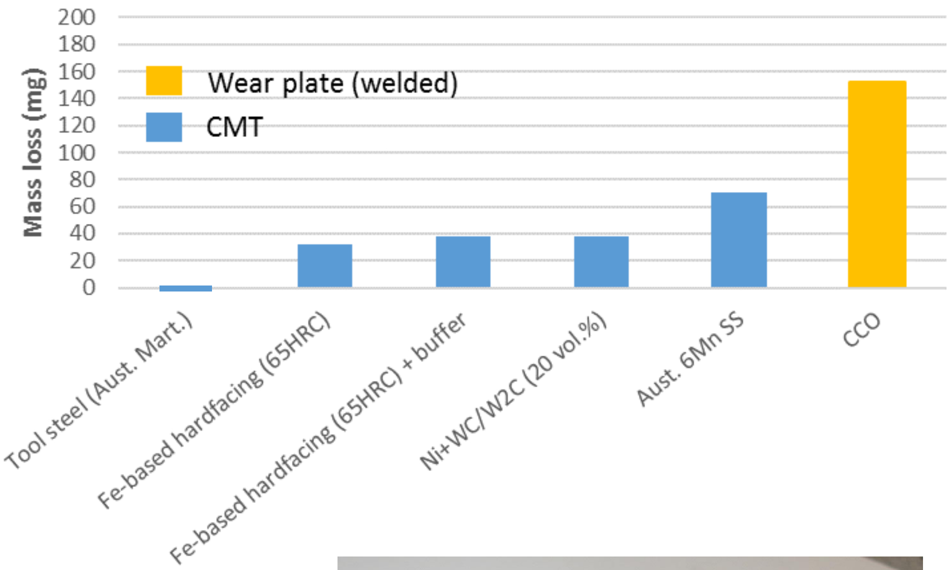


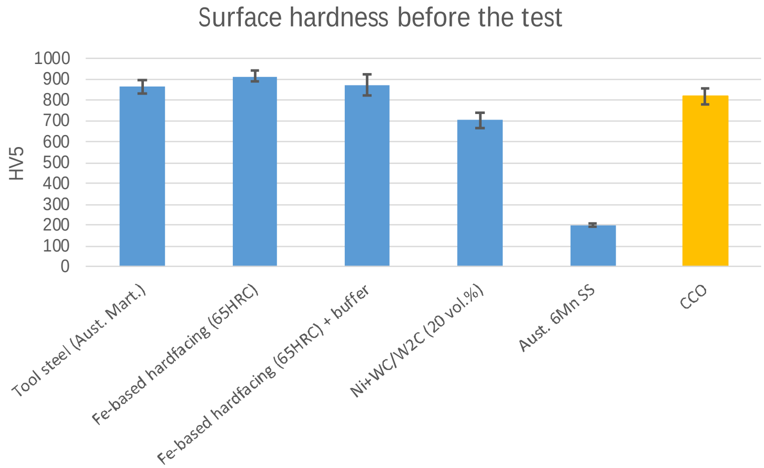


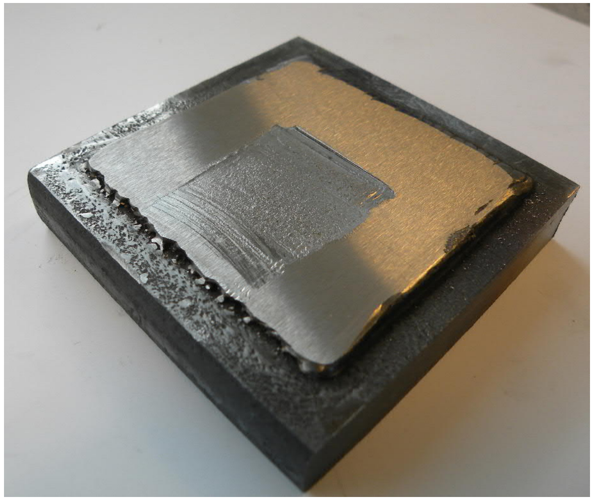


Primary carbide 2300HV$_{0.3}$ (~36 vol.%) (≤80 µm)
Matrix 410 HV$_{0.3}$

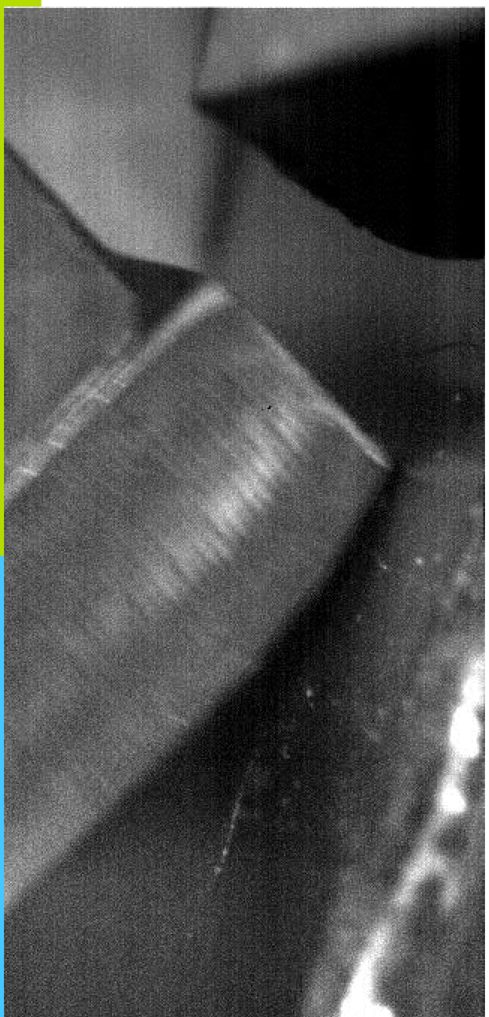
Hammer-mill impact wear

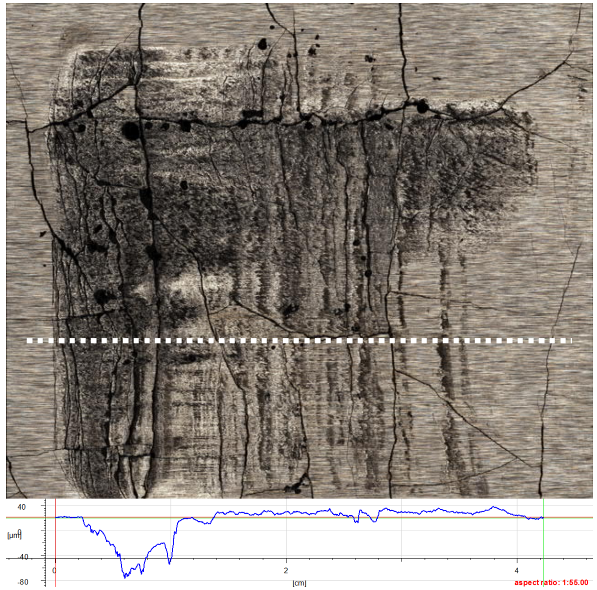


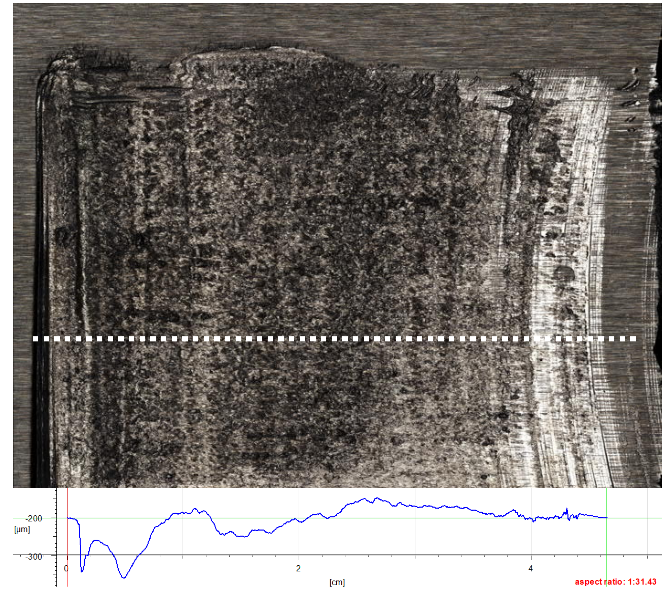




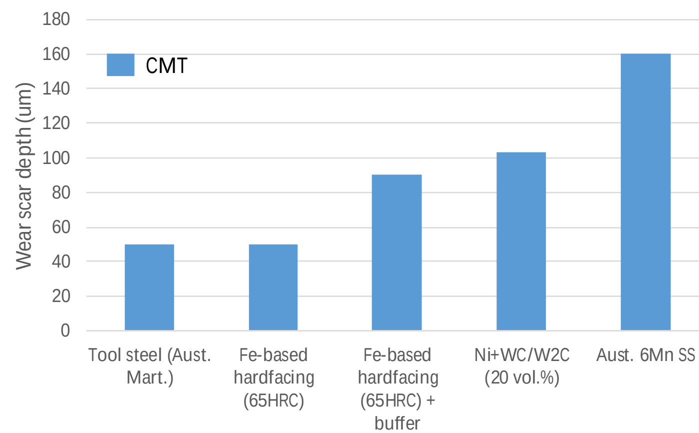
Hammer-mill impact wear



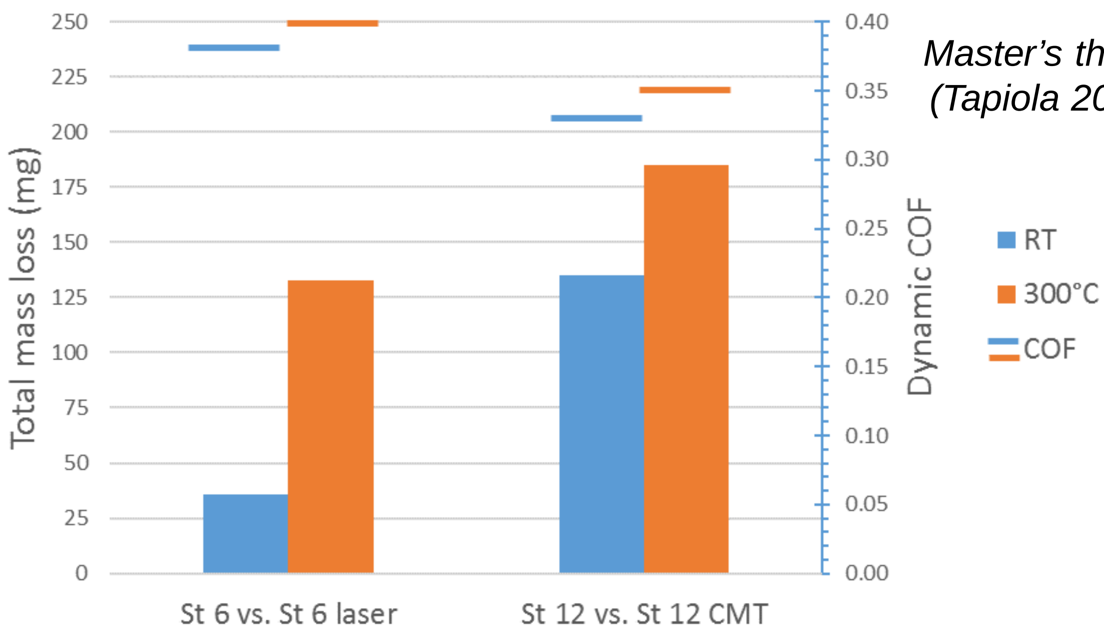




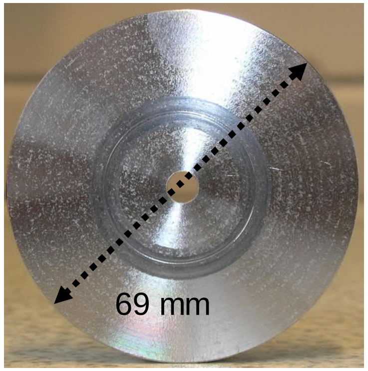
Fe-based hardfacing
(65HRC)
Video length 160 ms

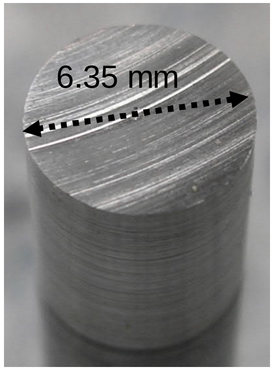


Pin-on-disc sliding wear



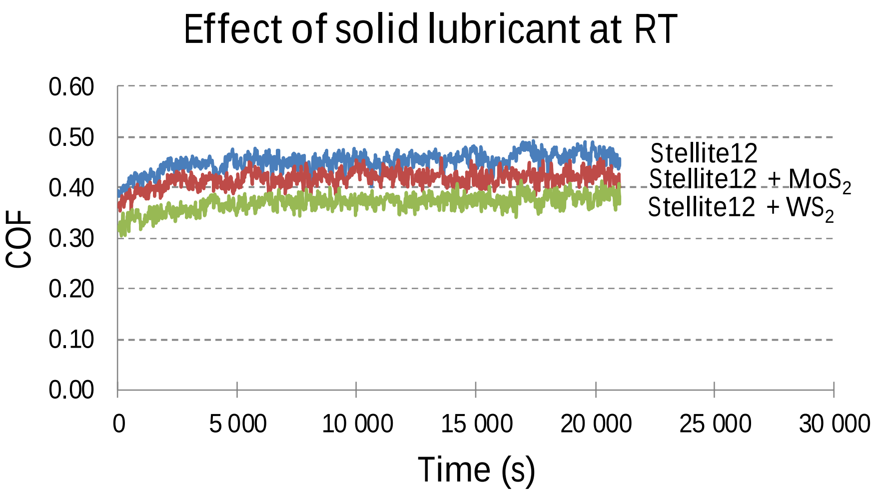
Master's thesis (Tapiola 2017)

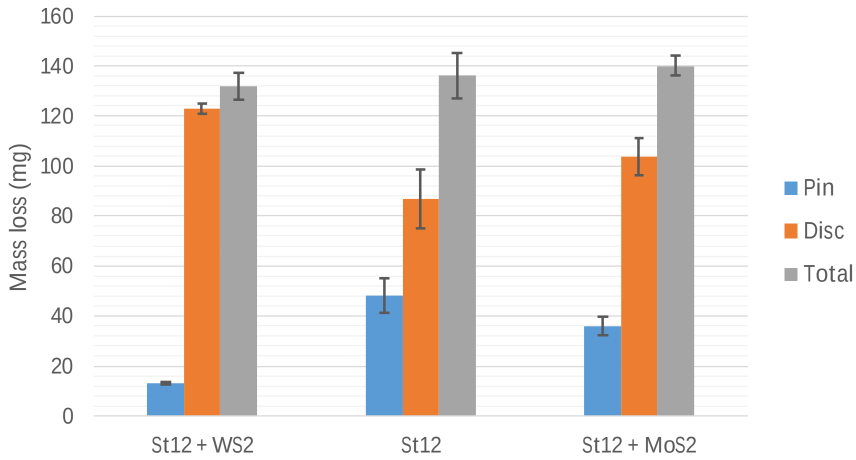


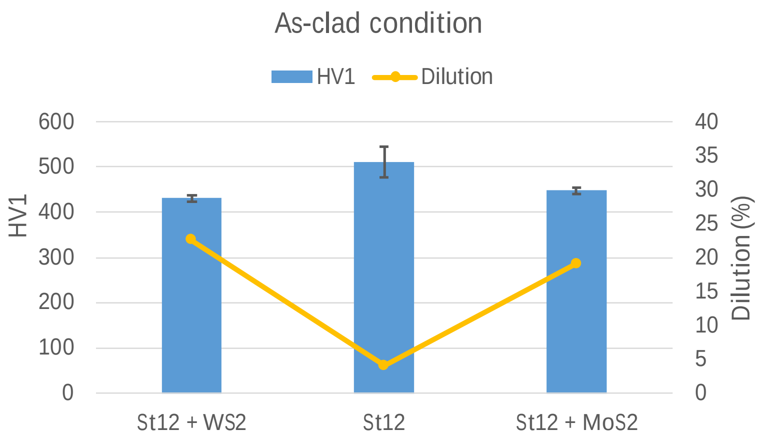


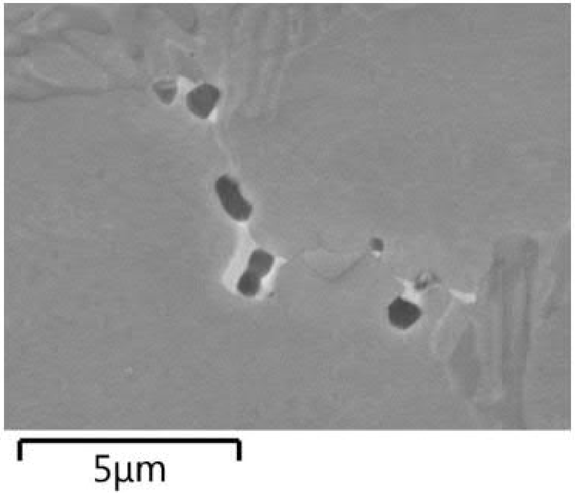
- *CETR UMT-2*
- *Dry conditions*
- *Testing temperature RT and 300°C*
- *Load 150N*
- *Surface speed 2400 mm/min*
- *Test duration 6h*
- *ASTM G99-95a*

Solid lubricants (POD)



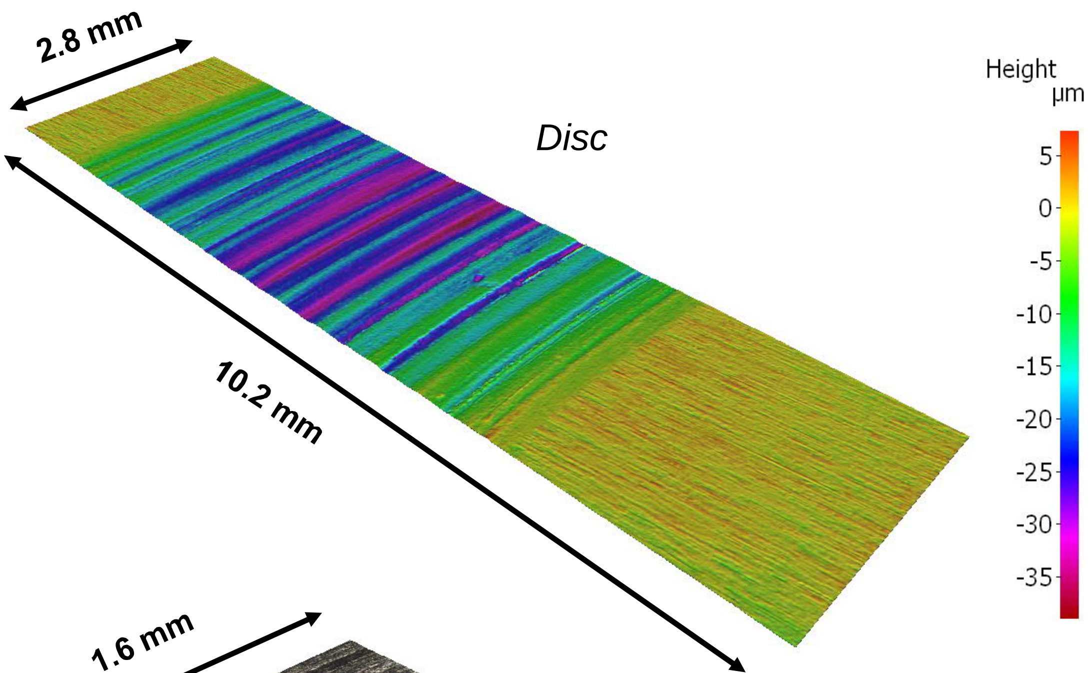


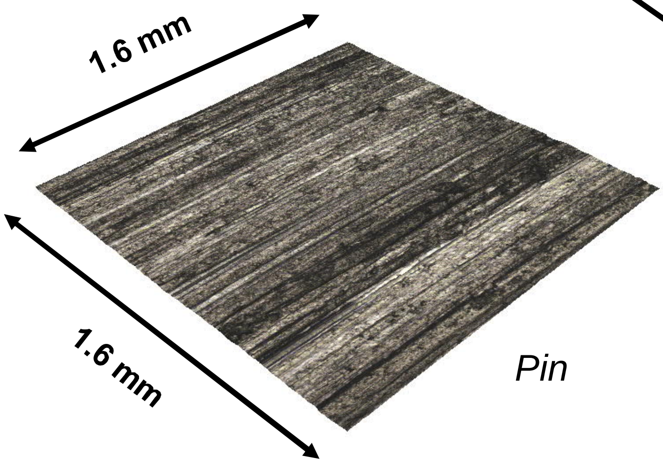




Very small MnS surrounded by W in interdendritic regions

Solid lubricants (POD)





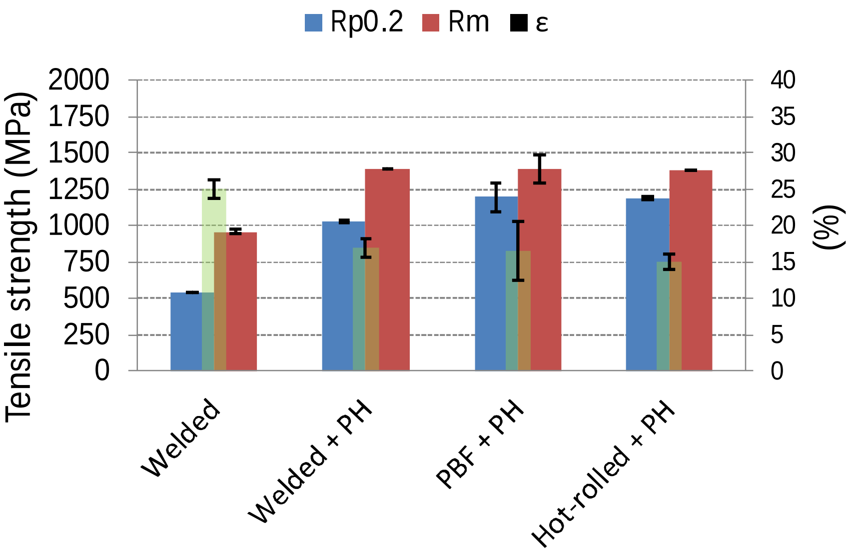
Sulfur and oxidation detected on the wear scar. Formation of lubricuous sulfides?

Wear scar of pin

Solid lubricants (video)

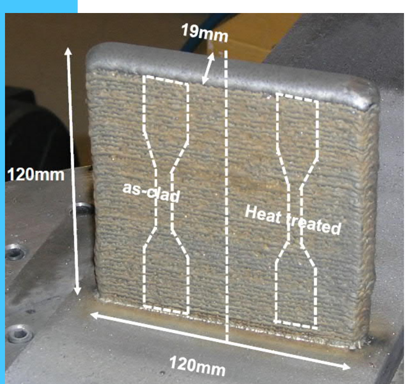
- Stellite 12 / Spherical graphite cast iron
- Solid lubricants inside the wire Ø1.6mm
- Fundamental problem: solid lubricants tend to segregate out from the melt pool to the surface

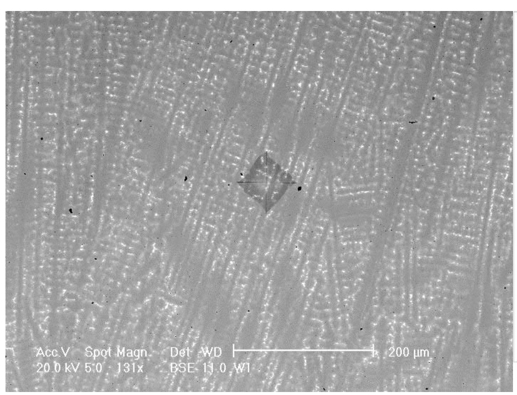
AM: IN-718

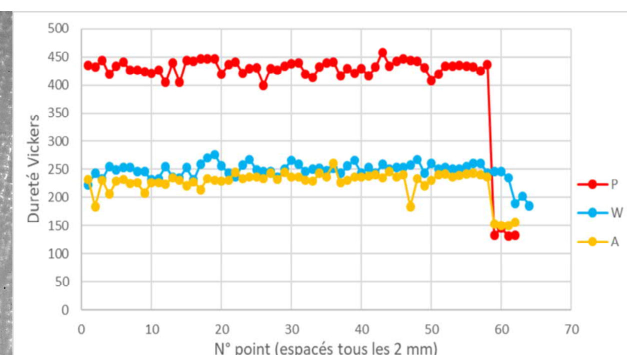


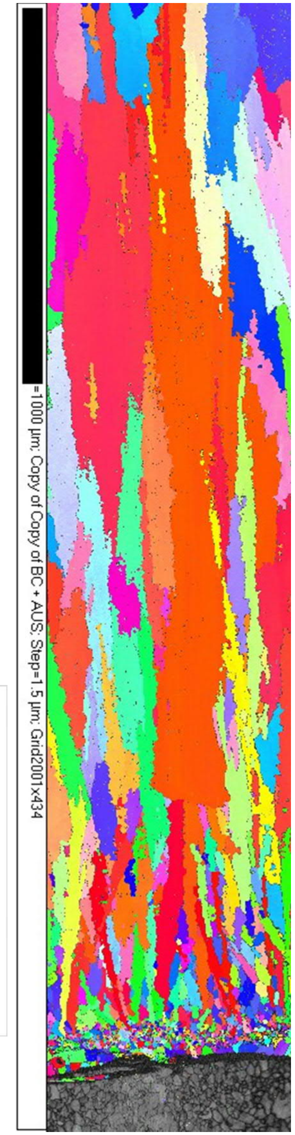
Phases (XRD)
γ-Ni
γ' ($Ni_3(AlTi)$)
γ'' (Ni_3Nb)
NbC
η (Ni_3Ti)

γ''(Ni_3Nb) -> δ(Ni_3Nb)









Welding/repairing

- Cracked steel belt, t = 1 mm, 460 – 470 HV_1
- Repaired with CMT and Ø = 0.8 mm wire
- Fusion zone ~320 HV_1, HAZ ~350 HV_1

Travelling & visits

- Fronius International GmbH, Wels, Austria (Oct 2016)
- Cranfield University, Cranfield, UK, (Jan 2017)
- TWI, Cambridge, UK, (Jan 2017)

Tuominen, Jari

has attended the following training:

INDIVIDUAL TRAINING

Duration: 22 hours
Start: 18.10.2016 08:00
End: 20.10.2016 14:00

Content of training:

/ Theoretical part: CMT

/ Practical part: different materials, geometries and welding positions

/ Cladding: overview with CMT and applications

Publications

- Pajukoski et al., High performance corrosion resistant coatings by novel coaxial cold- and hot-wire laser cladding methdos, Journal of Laser Applications, 02/2016
- Tuominen et al., Microstructural and abrasion wear characteristics of laser-clad tool steel coatings, Surface Engineering, 06/2016
- Tuominen J., Directed energy deposition – Advances in surfacing, remanufacturing & additive manufacturing, Kokkola Material Week, 11/2016
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THANK YOU!