Tampere University

Performance of coatings under demanding industrial conditions

Thermally sprayed coatings for demanding wear and corrosion conditions

Tommi Varis, Tampere University

Elina Huttunen-Saarivirta, VTT Technical Research Centre of Finland Ltd

Tampere University

WC-CoCr

<u>Adv.:</u>

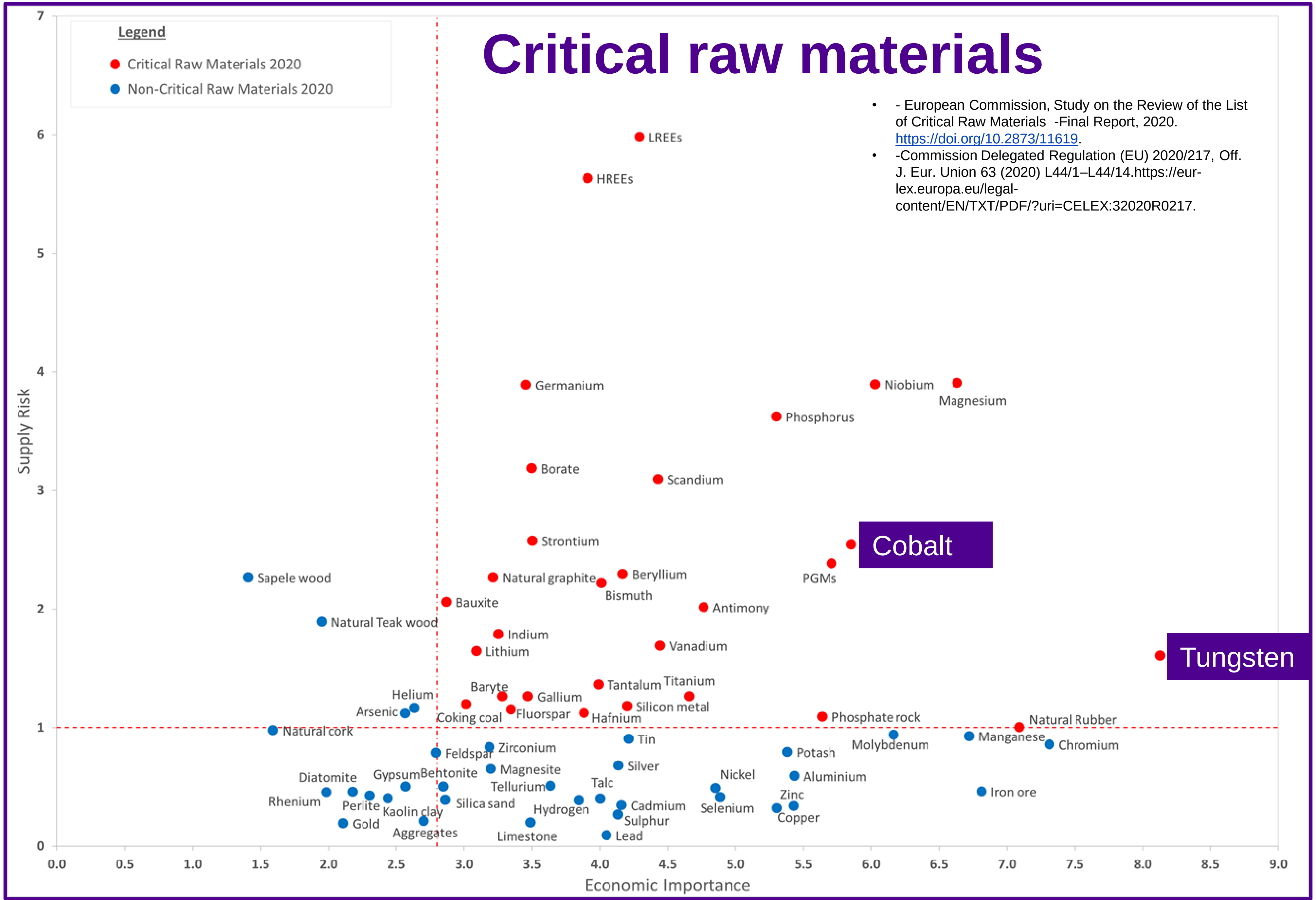
- Wetting between cobalt and tungsten carbide is almost perfect
- Extreme good wear resistance

<u>Sustainability issues:</u>

- Cobalt is associated with health risks
- Localized source of Co (65% from Democratic Republic of the Congo) and W (78% from China)
- Batteries now account for over 50 % of global cobalt consumption and with electric vehicle sales predicted to increase from 6.5 million in 2021 to 66 million by 2040

Critical raw materials

- - European Commission, Study on the Review of the List of Critical Raw Materials -Final Report, 2020. https://doi.org/10.2873/11619.
- -Commission Delegated Regulation (EU) 2020/217, Off. J. Eur. Union 63 (2020) L44/1–L44/14.https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32020R0217.



Challenges of TS coatings in demanding combined wear and corrosion applications

Demanding low temperature corrosion applications:

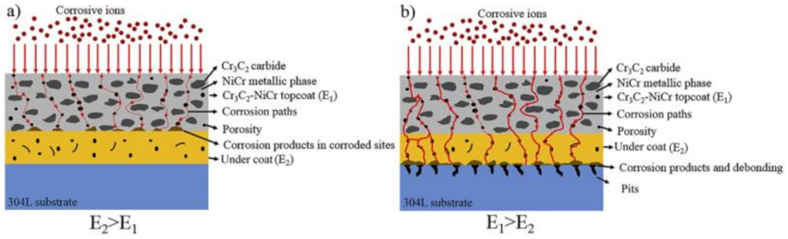
- Sea water
- Paper manufacturing processes
- Acid leach etc.

- Generally, more corrosion resistant thermally sprayed coatings needed
- Combined effect of wear and corrosion challenging to test

Challenges of TS coatings in demanding combined wear and corrosion applications

Corrosion aspects

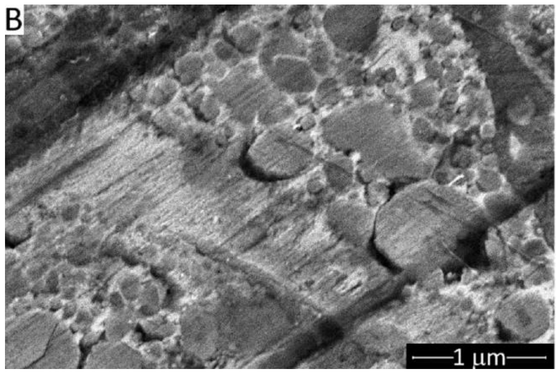
- Overall corrosion of the coatings may be reduced due to processing
- Density of coatings and corrosion of substrate
- Corrosion between hard phase and matrix



E. Sadeghimeresht et al.: Microstructural and electrochemical characterization of Ni-based bi-layer coatings produced by the HVAF process Surface & Coatings Technology 304 (2016) 606–619

Wear aspects

- WC-CoCr hard to beat
- Understanding the effect of coating structure, defect density on wear mechanism



G. Bolelli, et al. TiC–NiCr Thermal Spray Coatings as an Alternative to WC-CoCr and Cr3C2–NiCr, *Wear*, Elsevier B.V., 2020, **450–451**(March).

Tampere University

Challenges for TS coatings in demanding combined wear and corrosion applications

Corrosion aspects

- Overall corrosion of the coatings may be reduced due to processing
- Density of coatings and corrosion of substrate
- Corrosion between hard phase and matrix

Improved processing with high kinetic lower temperature processes
- HVAF
- Cold spray

Alloy design
- Use of more noble matrixes and
- Iron based hard alloys etc.

Wear aspects

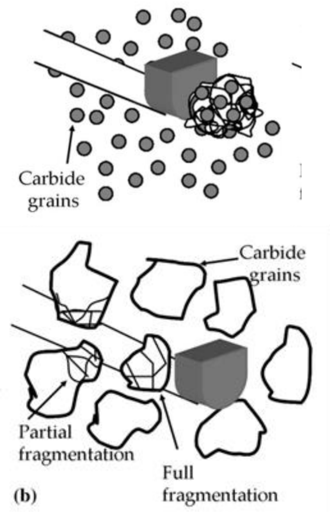
- Replacement candidates for WC-CoCr limited
- Understanding the role of coating defect density and related wear mechanism

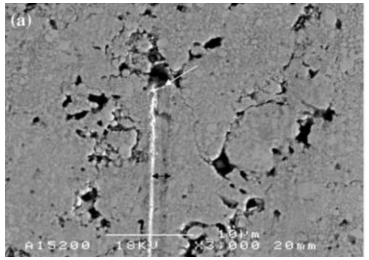
Alloy design and Processing
- Wetting between harphase and matrix
- Lamellar cohesion
- Carbide content

Linking the experimental testing with computational approaches

Wear mechanisms

Three body abrasion



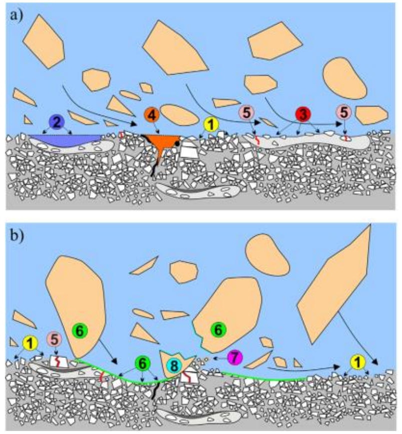


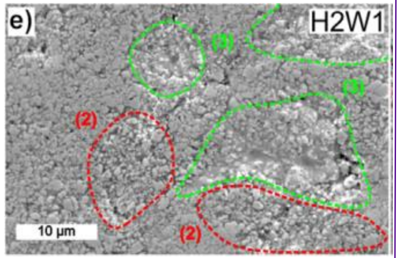
- Cutting of the coating with the group of carbides
- Fragmentation of carbides

- Hardness, carbide content
- Carbide size
- Surface porosity

A. Ghabchi: Behavior of HVOF WC-10Co4Cr Coatings with Different Carbide Size in Fine and Coarse Particle Abrasion. J. Therm. Spray Technol., 2010, 19(1–2), p 368–377

Slurry erosion

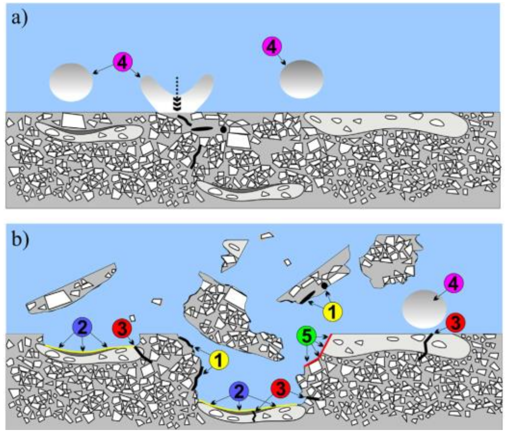


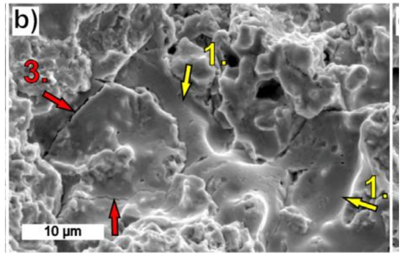


- Selective removal of the soft matrix
- Wear of the weak regions, defects

- Carbide content
- Even distribution of carbides and matrix
- Mean free bath of matrix
- Lamella cohesion, weak areas

Cavitation erosion



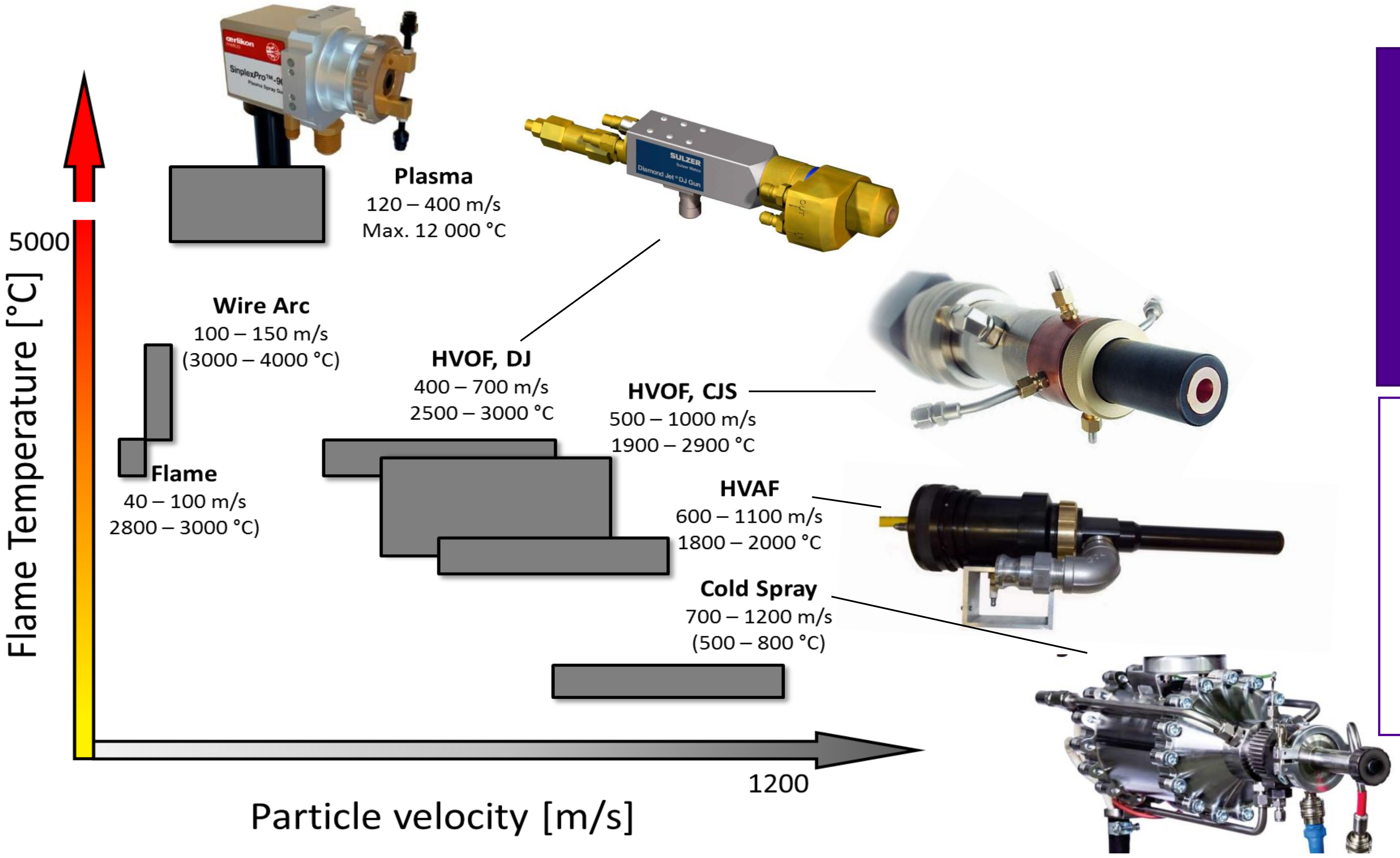


- Fatigue crack growth and and the removal of the fractured areas

- Lamellae cohesion
- Strain hardening of matrix
- Residual stresses

V. Matikainen: Erosion Wear Performance of WC-10Co4Cr and Cr3C2-25NiCr Coatings Sprayed with High-Velocity Thermal Spray Processes, *Surf. Coatings Technol.*, 2019, **370** p 196–212

Thermal Spray Processes



Thermal spraying includes different processes

Wide variety of properties for same coating material

Tampere University

Test coatings

Reference carbides, (Commercial)

1. WC-CoCr
2. Cr_3C_2-NiCr

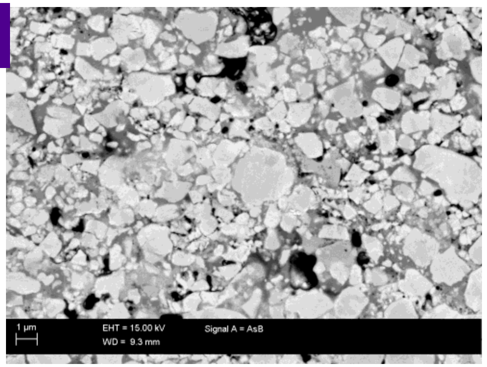
Alternative carbides with corrosion resistant matrix

3. WC-15NiMoCrFeCo (Hastelloy C 276)
4. Cr_3C_2-50NiCrMoNb (Inconel 625)
5. CrC-42WC-16Ni
6. TiC-25FeCrAl
7. TiC-40NiCr

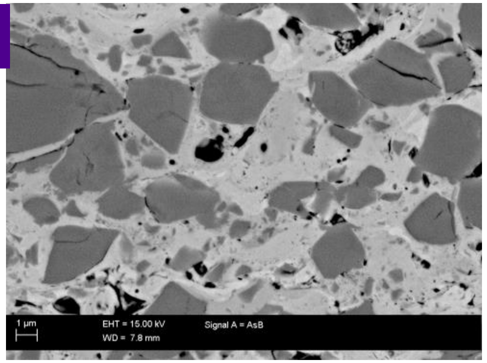
Iron based atomized alloys

8. Fe-31Cr-12Ni-3.6B-0.6C (Commerc.)
9. Fe-28Cr-4.5Mo-16Ni-1.5Si-1.75C (Com.)
10. Fe-5Cr-9V-8W-2B-1Ti-2.4C (Experim.)
11. Fe-11.5Cr-1V-0.7Mo-1.55C (Experim.)
12. Fe-12V-5Cr-1.5Mo-2.4C (Experim.)

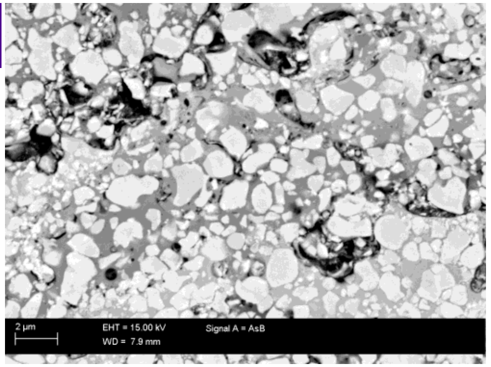
1



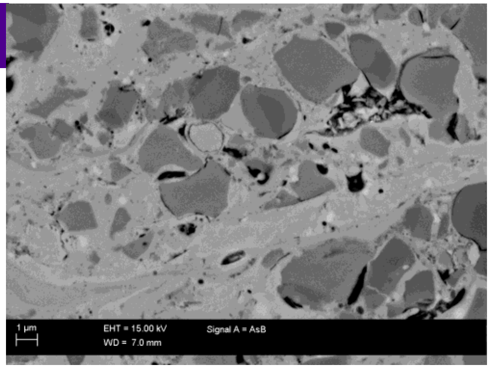
2



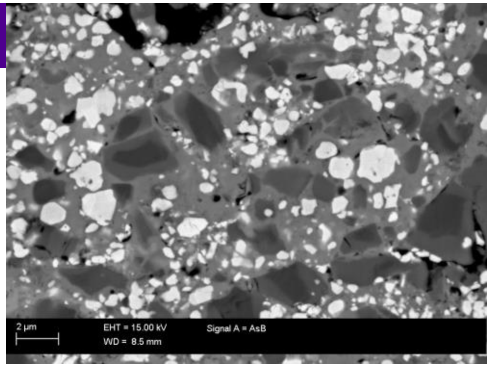
3



4



5



Tampere University

Test coatings

Reference carbides, (Commercial)

1. WC-CoCr
2. Cr3C2-NiCr

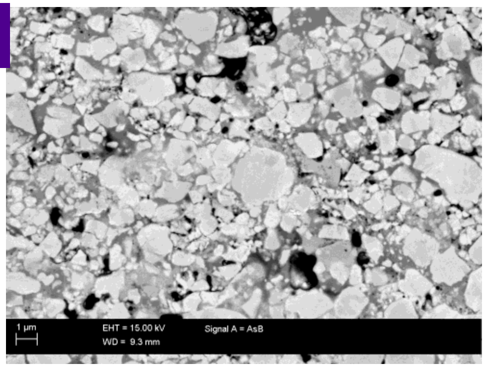
Alternative carbides with corrosion resistant matrix

3. WC-15NiMoCrFeCo (Hastelloy C 276)
4. Cr3C2-50NiCrMoNb (Inconel 625)
5. CrC-42WC-16Ni
6. TiC-25FeCrAl
7. TiC-40NiCr

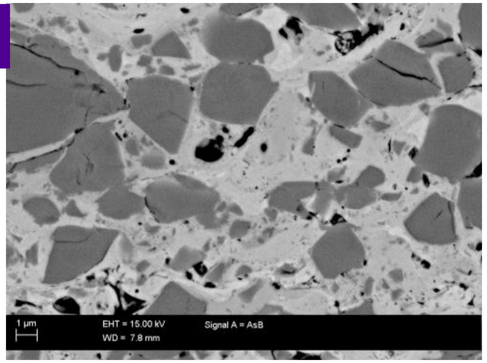
Iron based atomized alloys

8. Fe-31Cr-12Ni-3.6B-0.6C (Commerc.)
9. Fe-28Cr-4.5Mo-16Ni-1.5Si-1.75C (Com.)
10. Fe-5Cr-9V-8W-2B-1Ti-2.4C (Experim.)
11. Fe-11.5Cr-1V-0.7Mo-1.55C (Experim.)
12. Fe-12V-5Cr-1.5Mo-2.4C (Experim.)

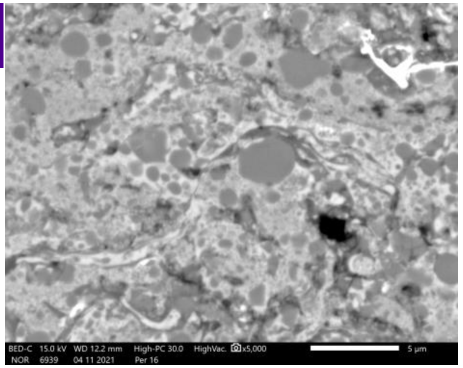
1



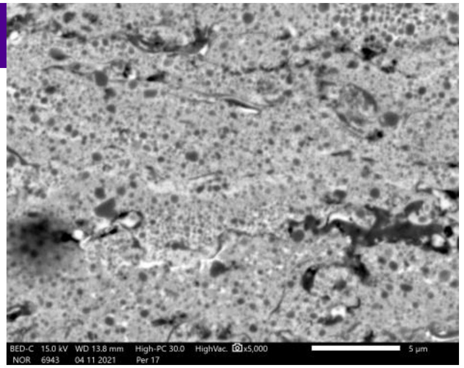
2



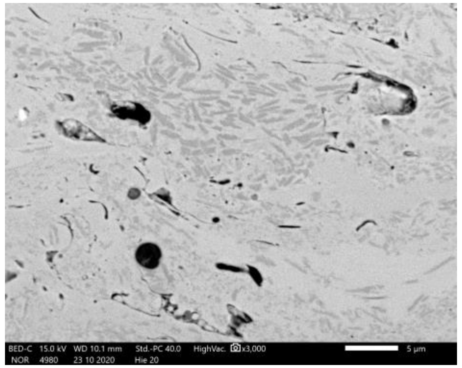
6



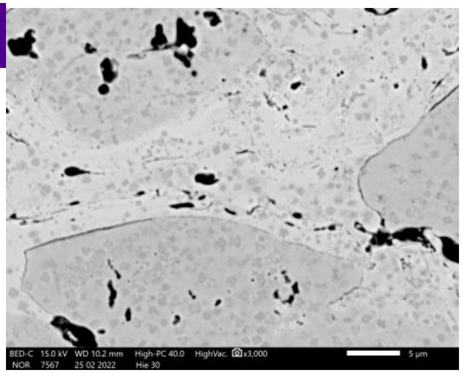
7



9



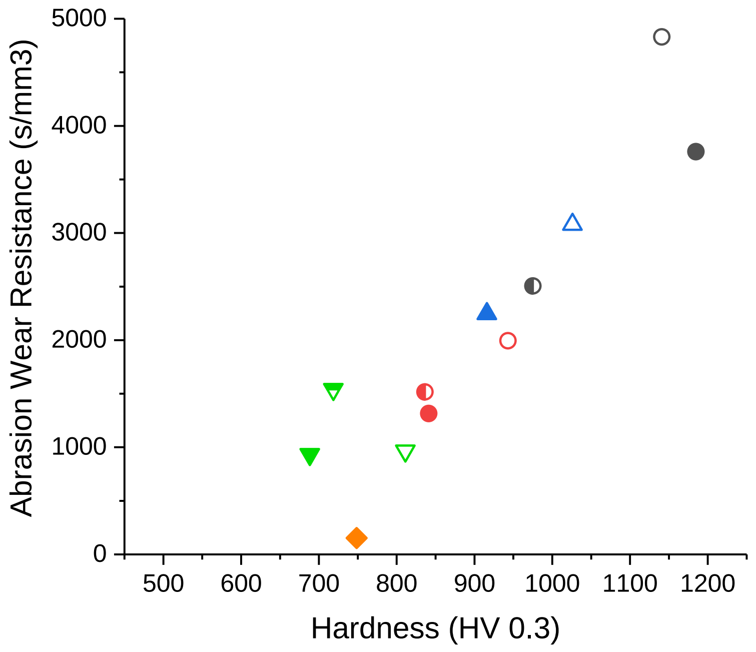
10



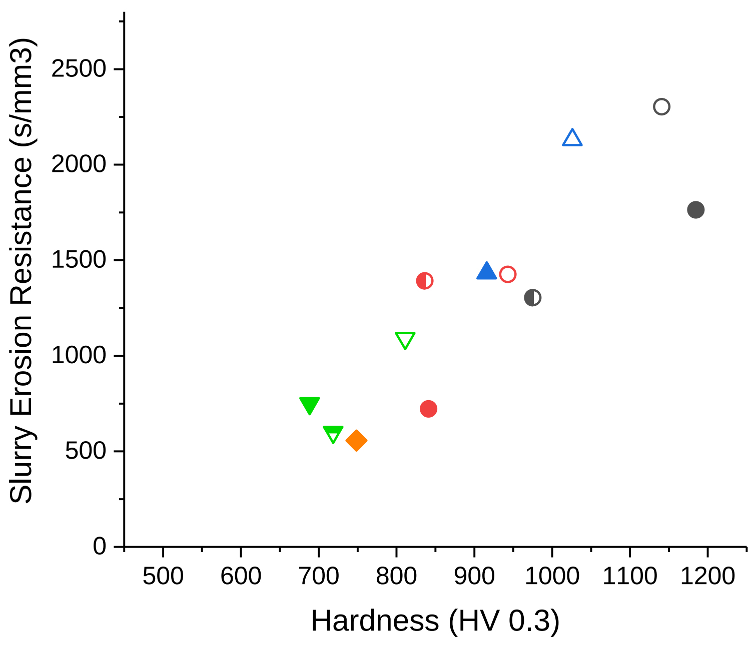
Tampere University

Wear – hardness maps

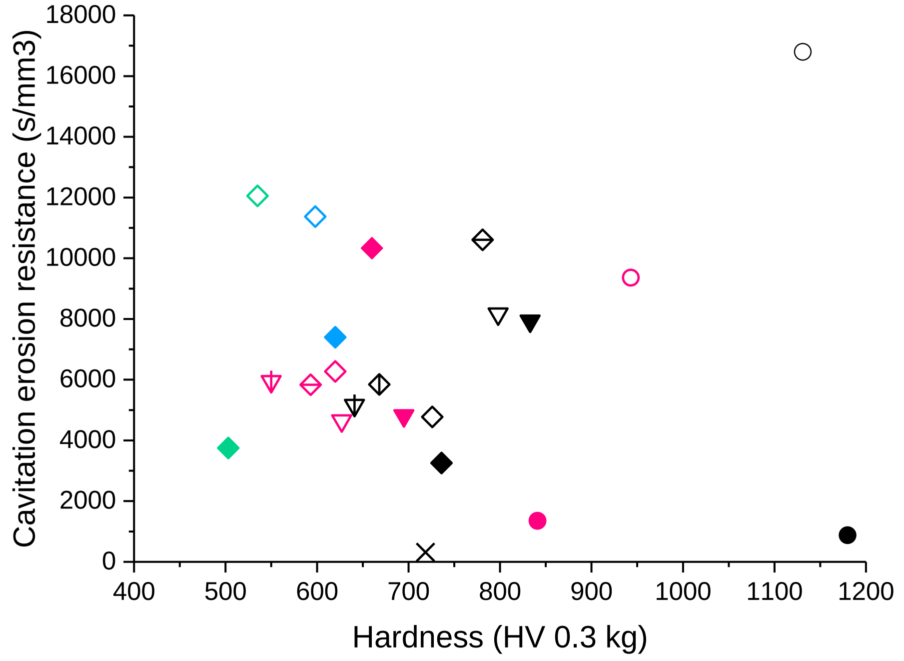
Three body abrasion



Slurry erosion

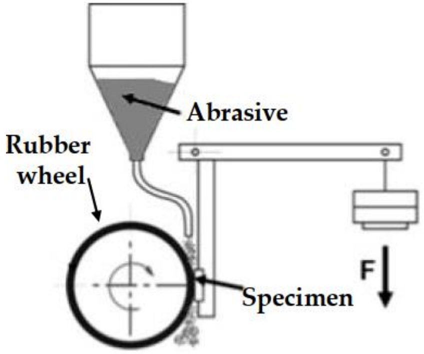


Cavitation erosion

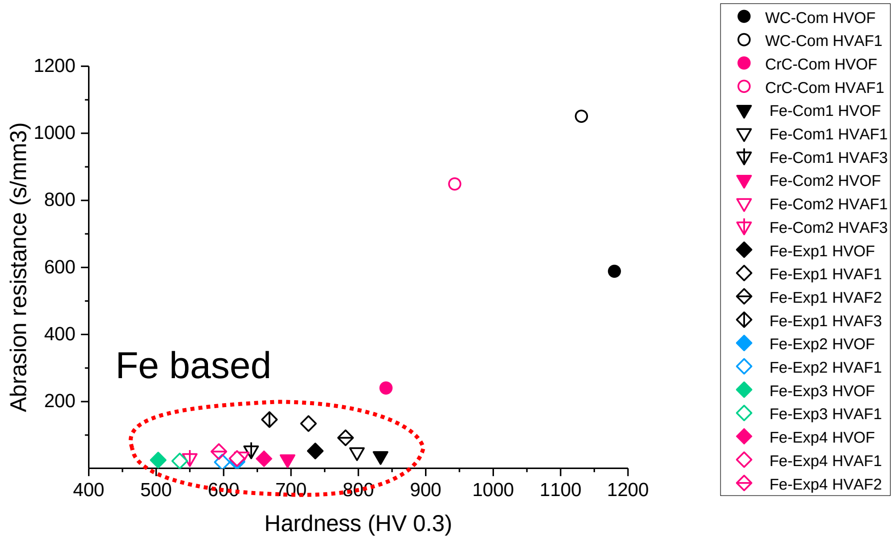


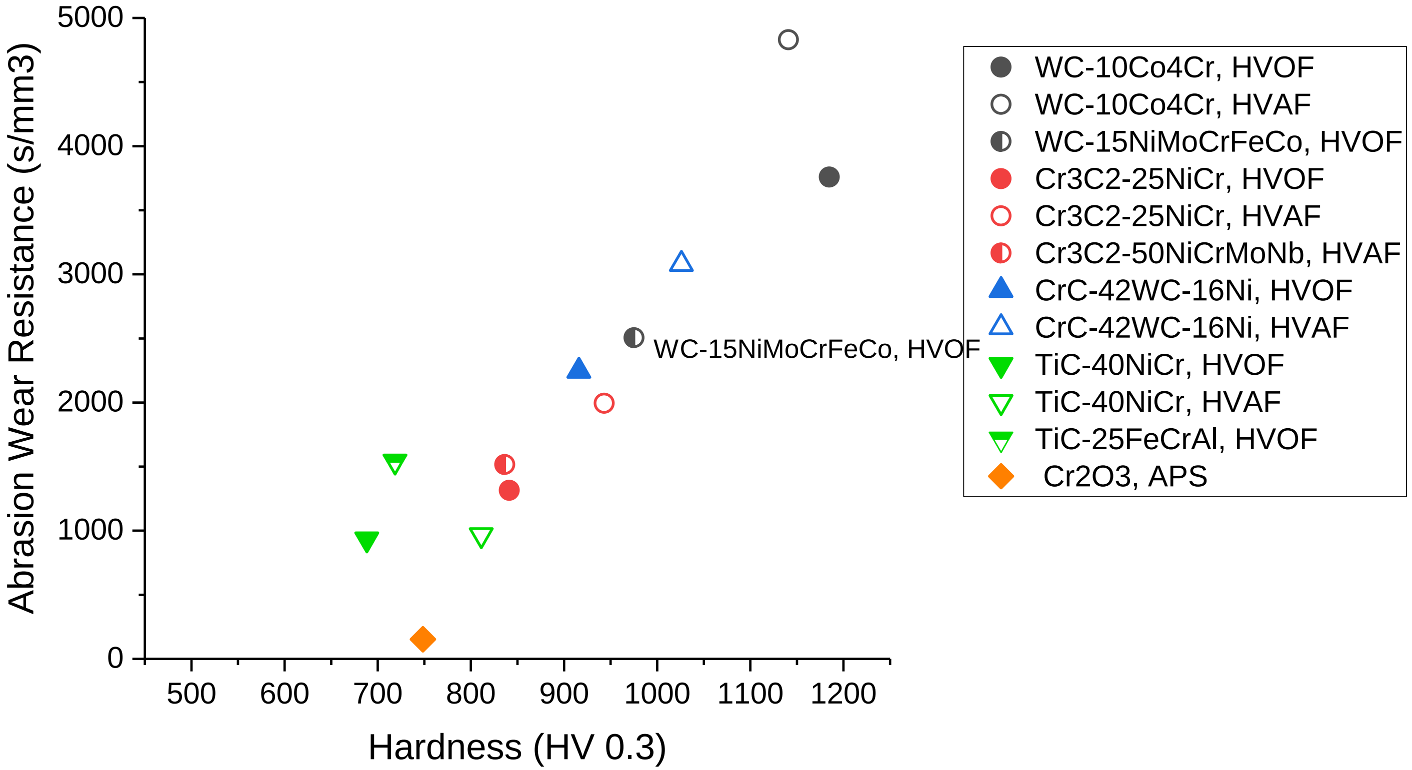
Three body abrasion – hardness maps

- WC-CoCr hard to beat
- Alternative matrixes sufficient abrasion wear
- Fe alloys no good



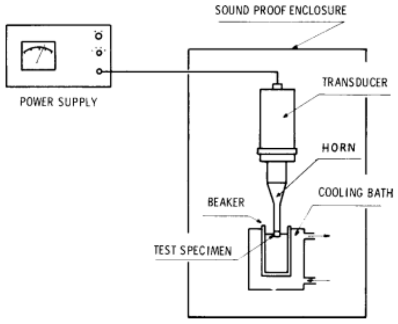
ASTM G 65





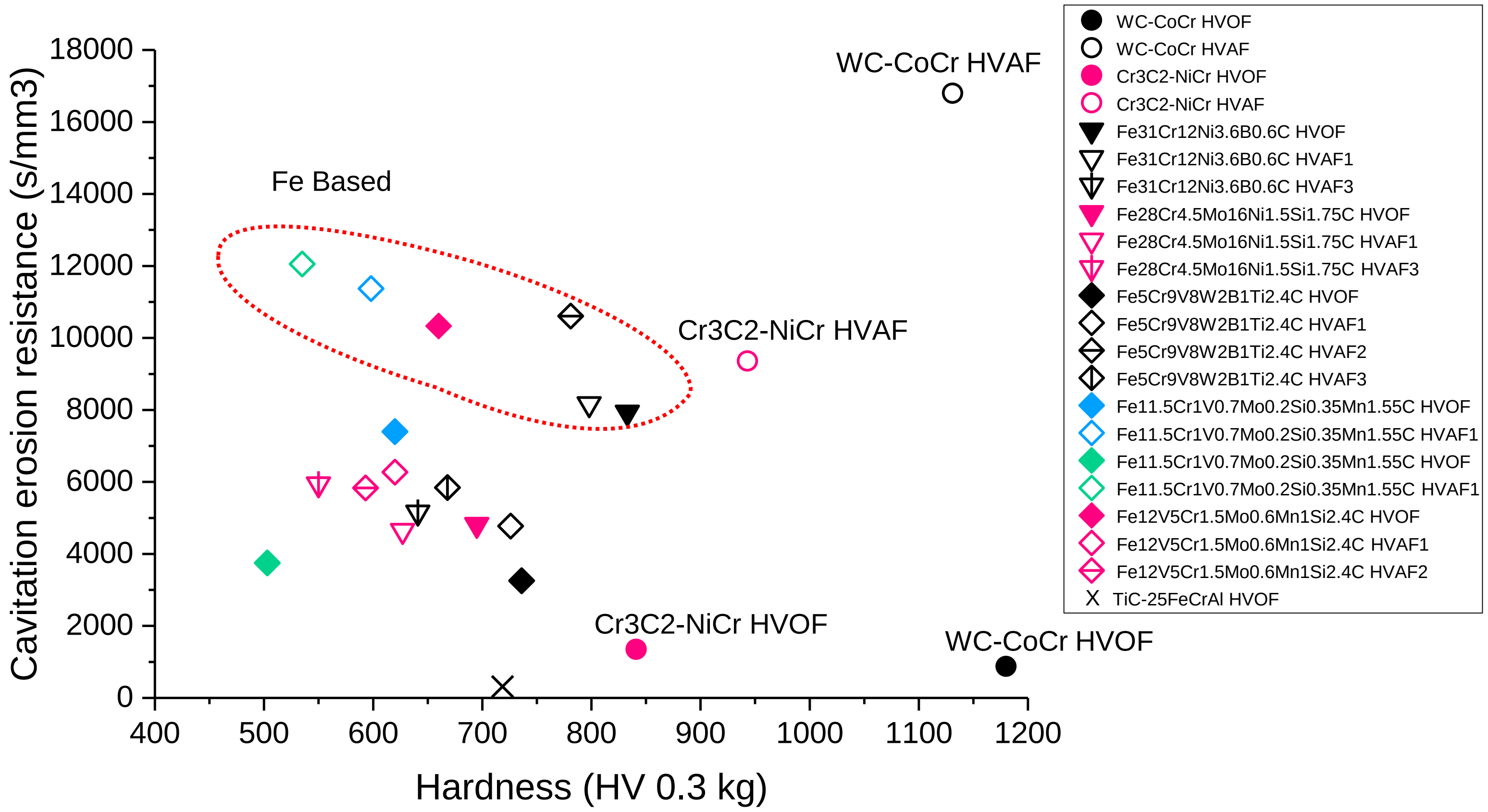
Tampere University

Cavitation erosion – hardness map

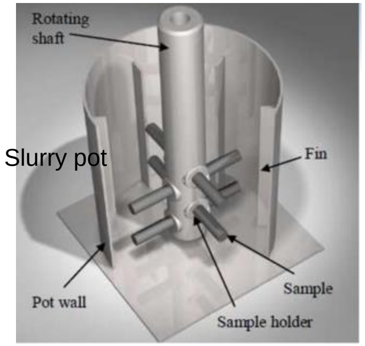


ASTM G 32

- Fe-alloys may offer promising solution
- Hardness less important, lamella cohesion
- WC-CoCr and Cr_3C_2-NiCr huge difference in cavitation erosion → residual stresses important



Slurry erosion – hardness map



Slurry pot

- Alternative matrixes does not significantly reduce slurry erosion wear
- CrC-42WC-16N as well good
- TiC based suffered in this case from poor powder quality