stam

Science and Technology in Advanced Manufacturing

SchuF

innovative valves, precision engineering

esa

European Space Agency

ADVANCED SPACE ADDITIVE MANUFACTURING APPLIED TO HIGH TECH CONTROL VALVES

4000137618/22/NL/GLC/idb

Closing meeting (31st of May 2023)

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http://www.schuf.ie/
https://www.tcd.ie/mecheng/research/stam/

Trinity College Dublin
Coláiste na Tríonóide, Baile Átha Cliath
The University of Dublin

Meeting Agenda

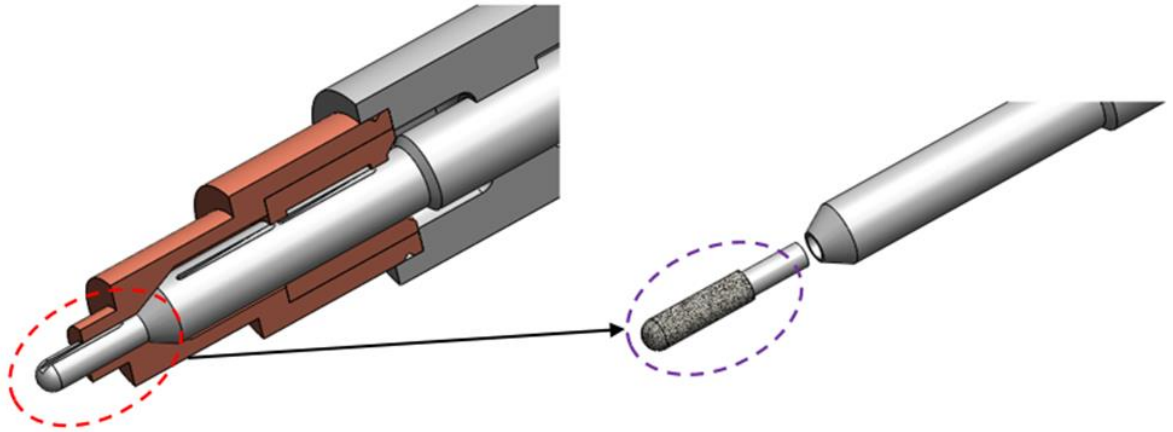
1. Project overview
2. Workflow
3. Work packages
4. Open Discussion

Project Overview

Activity Duration

1st of June 2022 - 31st of March 2023

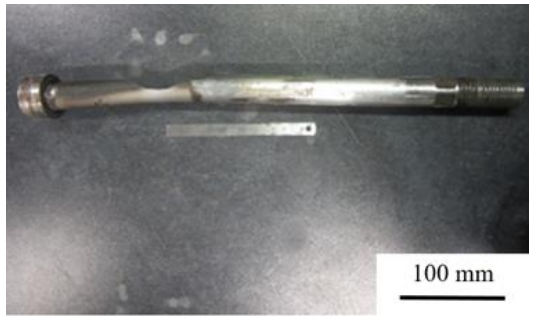
Project background



Conventional design

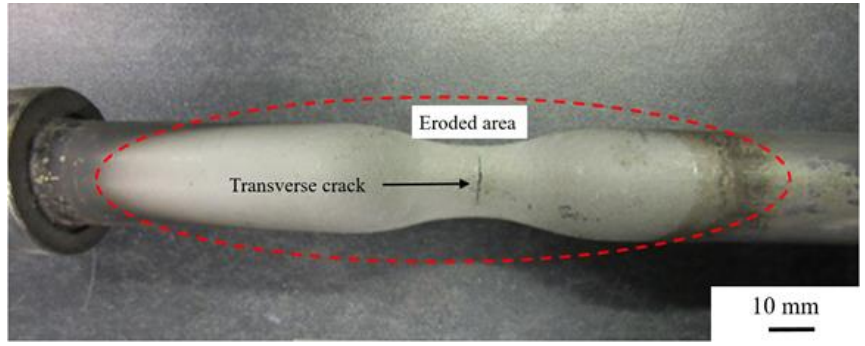
New design

Part 1 (SLM)

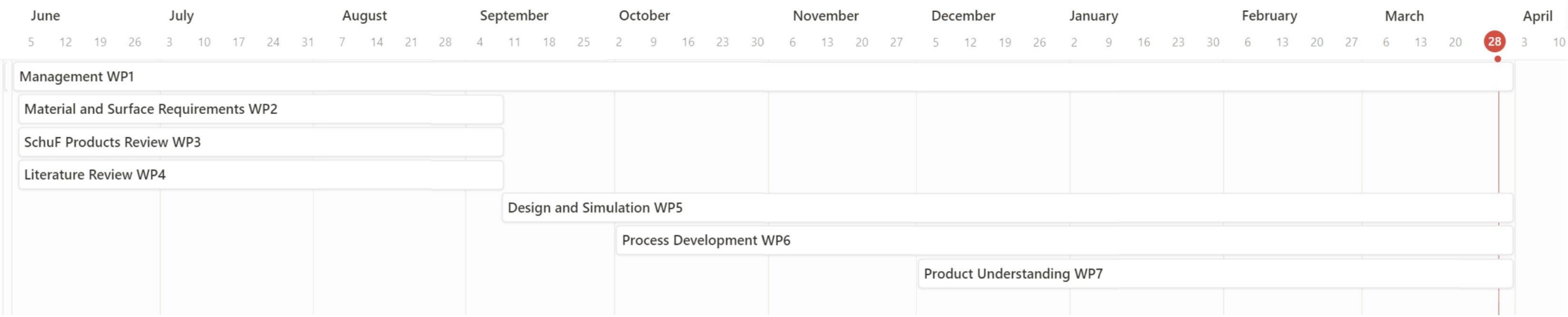


Part 2 (CS)

6 months life improvement



Workflow



Material and surface requirements (WP2)

SchuF products review (WP3)

Literature review (WP4)

Design and simulation (WP5)

Process development (WP6)

Product understanding (WP7)

WP2 - Requirements

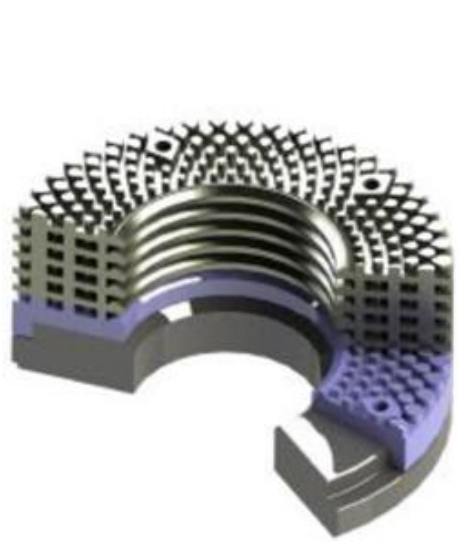
REQUIREMENTS	SPINDLE	PLUNGER TIP
IMPINGEMENT EROSION RESISTANCE	X	
CAVITATION EROSION RESISTANCE		X
CORROSION RESISTANCE	X	X
HARDNESS	High	Not essential
POROSITY	< 1%	< 1%
ROUGHNESS	Machined	Machined
THERMAL STABILITY	Up to 350°C	Up to 350°C
ADHESION STRENGTH	40 – 50 MPa	NA
THERMAL EXPANSION COEFFICIENT	Close to 10.1 µm/m°C (440C)	
DEPOSITION EFFICIENCY	>20%	NA
PROCESSABILITY	Under 900°C 30 bar, N2	Under 300W

WP3 – Product Review

Traditional casting or Additive Manufacturing?

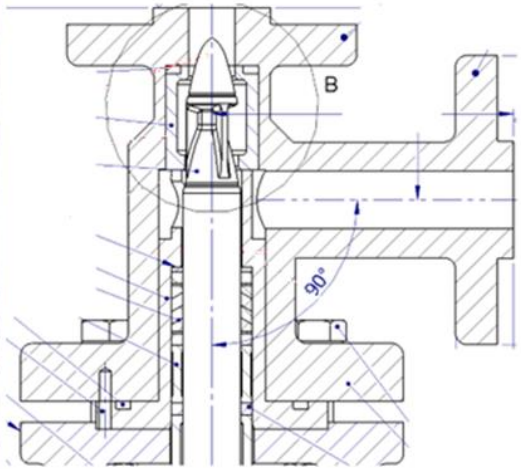
FACTORS:

- **Production volume**
- **Complexity**
- **Customization**
- **Part consolidation**



Cold Spray??

- Erosion protection coating?
- Part restoration?



WP4 – Cold Spray

	Microhardness	Impingement erosion resistance (erosion rate) 30°	Impingement erosion resistance (erosion rate) 90°	Electrochemical corrosion resistance in NaCl medium	Porosity	TEC [µm/(m°C)]	Thermal stability below 350°C	Availability	DE	Parameters Temp [C]	Parameters Press [bar]	Parameters SoD [mm]	Cold sprayability	Score
Inconel625	1.5 (570HV0.3)	-	-	1 (-0.49V)	0.5 (4.2%)	1 (13.1)	ok	3	2	800*	30*	30	0 (He)	9
Inconel718-Ni	0.5 (242HV0.3)	37 mg/min	19 mg/min	0.5 (-0.59V)	3 (0.84%)	1.5 (12.8)	ok	3	2	900	30	30	2	12.5
WC-Co	3 (981HV0.3)	-	-	1.5 (-0.43V)	3 (0.7%)	2 (8.8)	ok	1	1	800	40	40	2	13.5
WC-Ni	1 (335HV0.3)	27 mg/min	15 mg/min	0.5 (-0.63V)	3 (0.9%)	2.5 (9.3)	ok	3	1	850	30	40	3	14
WC-Ti	1.5 (549HV0.3)	-	-	1(-0.5V)	2 (1.8%)	1.5(7)	ok	2	1	550	45	30	3	12
WC-TiC	3 (922HV0.3)	-	-	2.5 (-0.2V)	2.5 (1.2%)	1 (6.5)	ok	2	1	550	45	30	3	15
Diamalloy 5849-AA5083	1.5 (500HV0.1)	-	-	0.5 (-0.6V)	-	0.5 (16.5)	ok	2	1	500			2	7.5
Diamalloy 3004	1.5 (450HV0.3)	-	-	0.5 (-0.59V)	0 (7%)	1.5 (12.2)	ok	3	1	800	40	30	2	9.5
HEA Cantor	1 (351HV0.3)	-	-	3 (-0.07V)	1 (3%)	0.5 (15)	ok	2	2	950	50	50	1	10.5

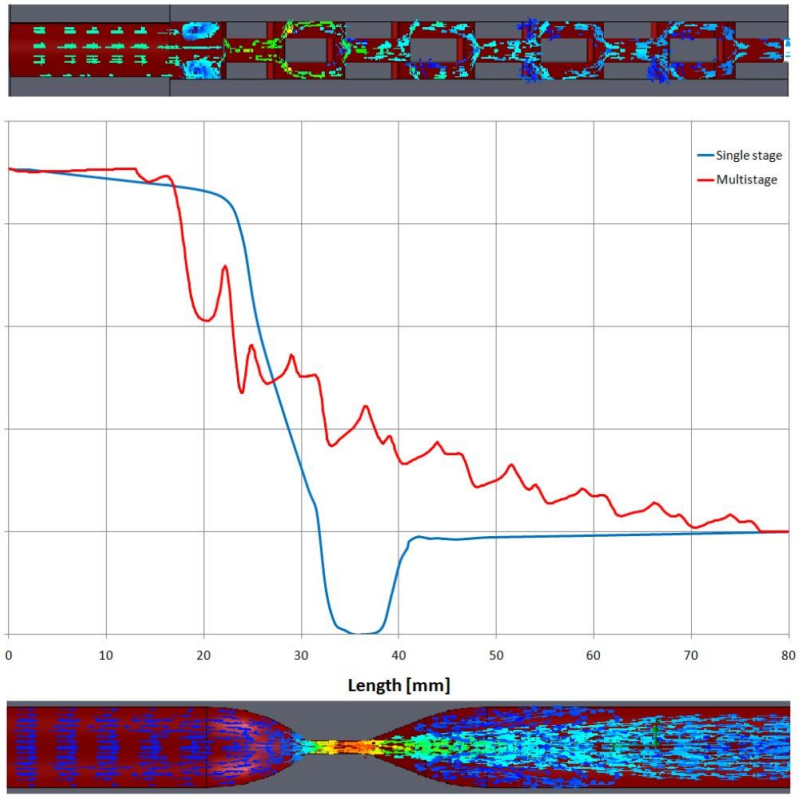
WP4 – SLM

	Cavitation erosion resistance	Electrochemical corrosion resistance in NaCl medium	Porosity	Thermal stability below 350°C	Processability	Availability	Process parameters			Score
							Power [W]	Scan speed [mm/s]	Hatch [um]	
Inconel 625	0.5 (0.160 mg/min)	1 (-0.49V)	2 (1.44%)	ok	2	3	180	500	70	8.5
Inconel 718	1 (0.04 mg/min)	1 (-0.59)	2 (1.3%)	ok	2	3	180	600		9
Maraging steel	-	2 (-0.2V)	2.5 (0.4%)	ok	3	3	380	960	110	10.5
SS316L	3 (0.005 mg/min)	2 (-0.2V)	2.5 (0.6%)	ok	3	3	200	80 µs (exposure time)	60	13.5
Cantor HEA	-	3 (-0.07)	3 (0.07%)	ok	3	2	280	800	60	11

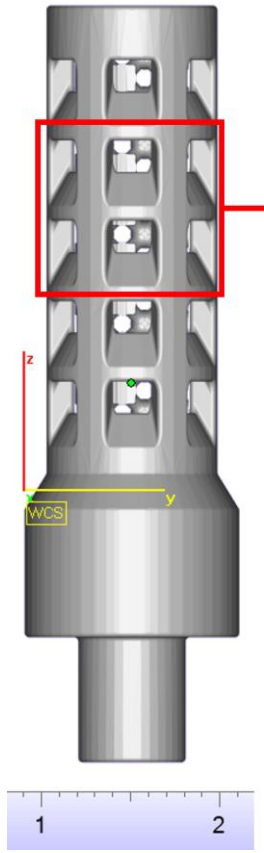
WP4 – Powder Market

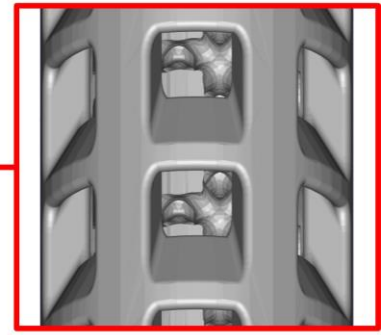
Powder material	Companies	Minimum order [Kg]	Price €/Kg
WC-Ti	MBN Nanomaterialia	5	152
WC-Ni	Hoganas (AMPERIT547)	5	100
HEA Cantor	HC Starck GmbH		100-150
Maraging steel 18Ni300	Hoganas (Amperprint 1556), Carpenter additive (POWDERRANGE M300)	5, 10	100
SS316L	Hoganas, Carpenter additive (POWDERRANGE 316L)	5, 10	80

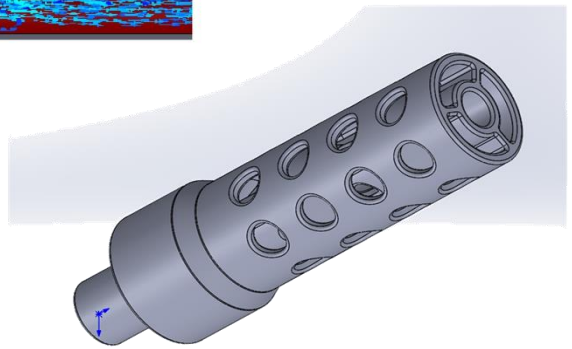
WP5 – Plunger Design



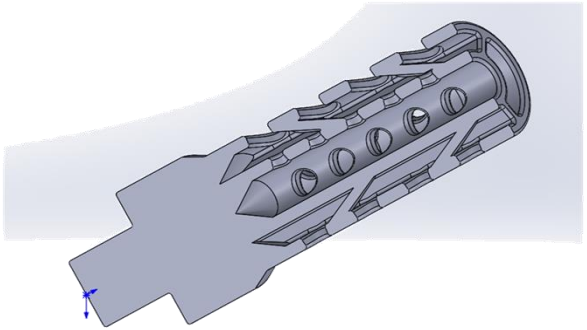
Multistage cage





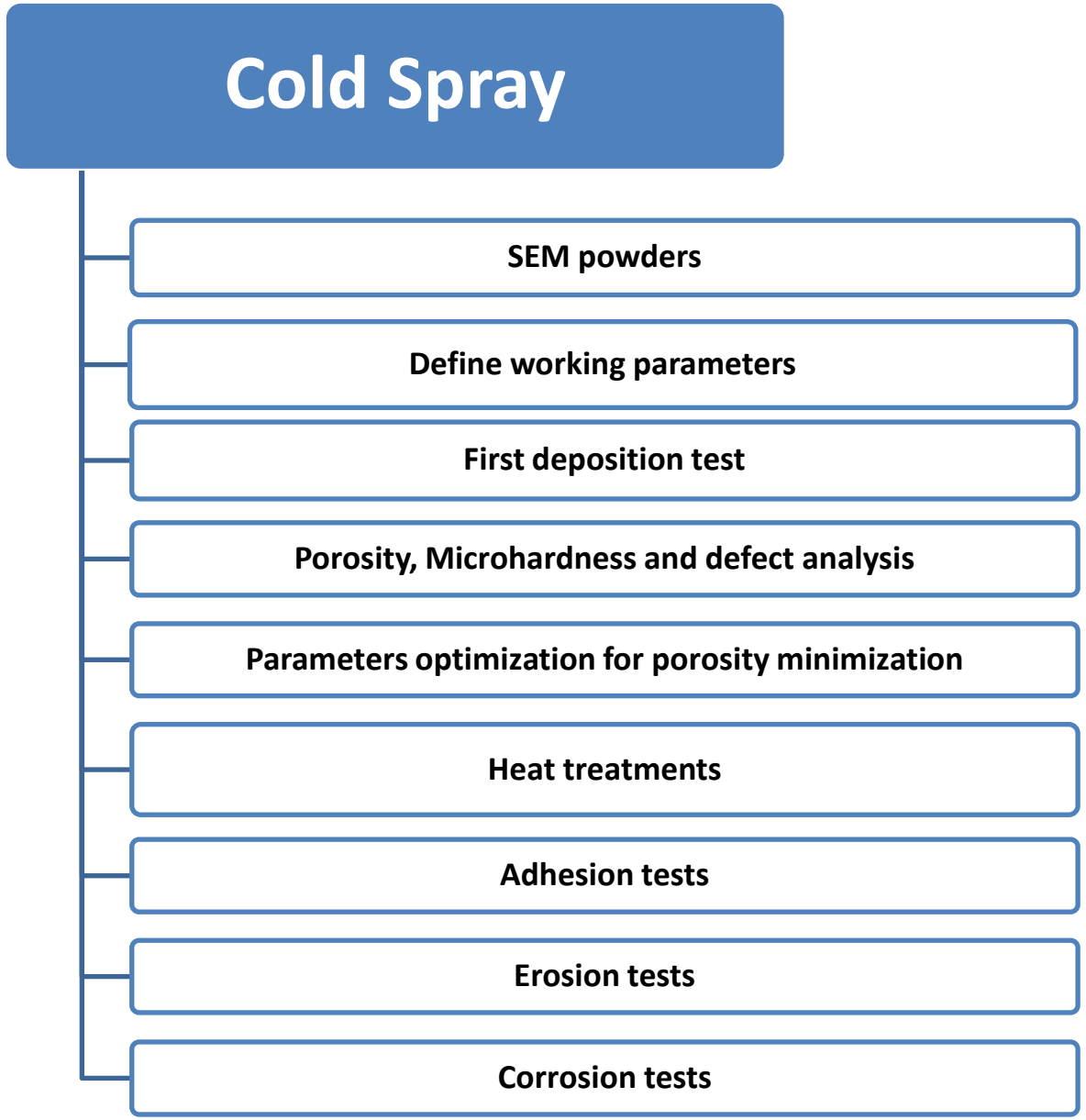


Plunger



Plunger section

WP6 – Cold Spray

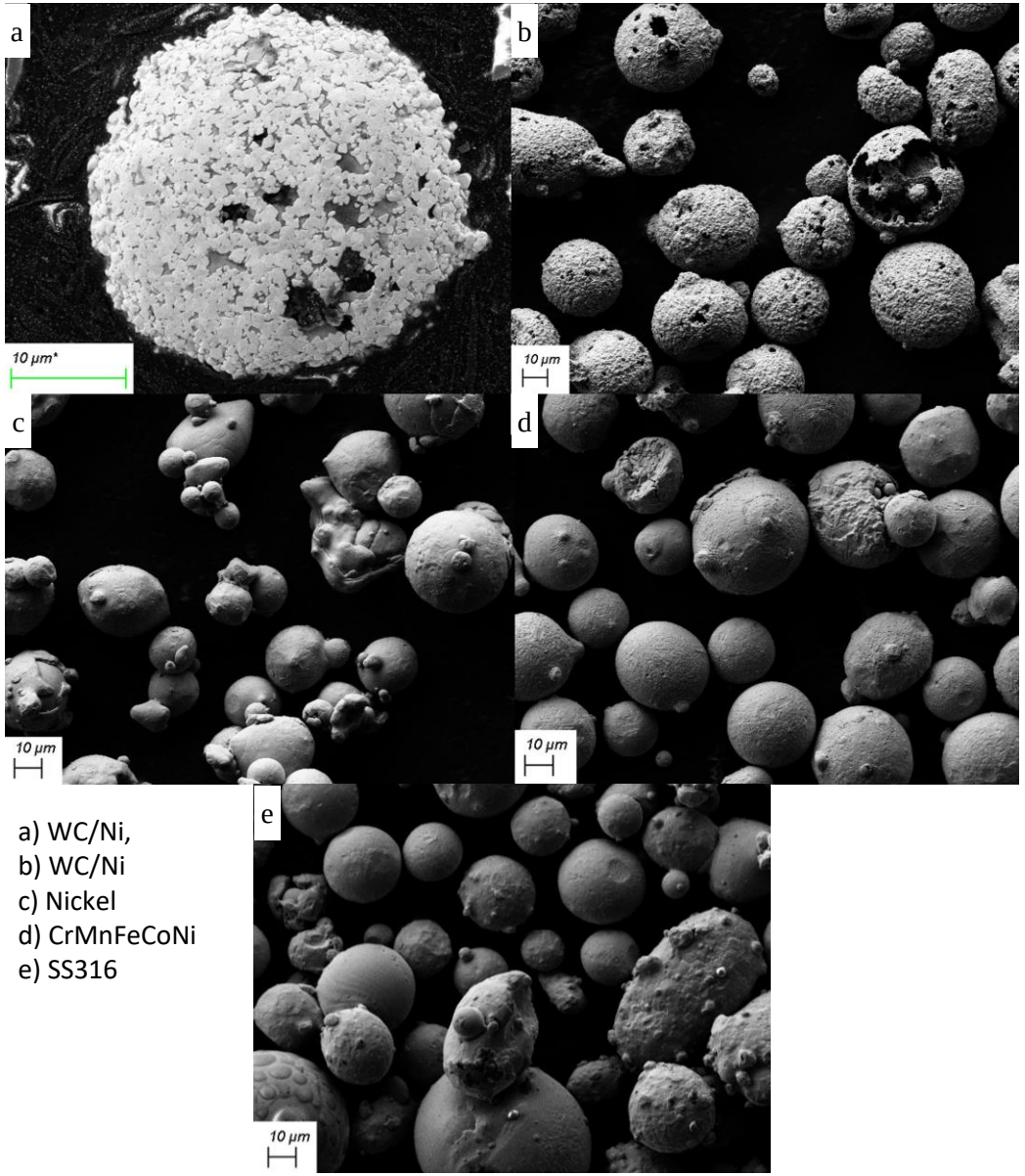


Cold Spray

Tested substrates:

- Annealed 440C (350HV1)
- 2205 duplex stainless steel (310HV1)

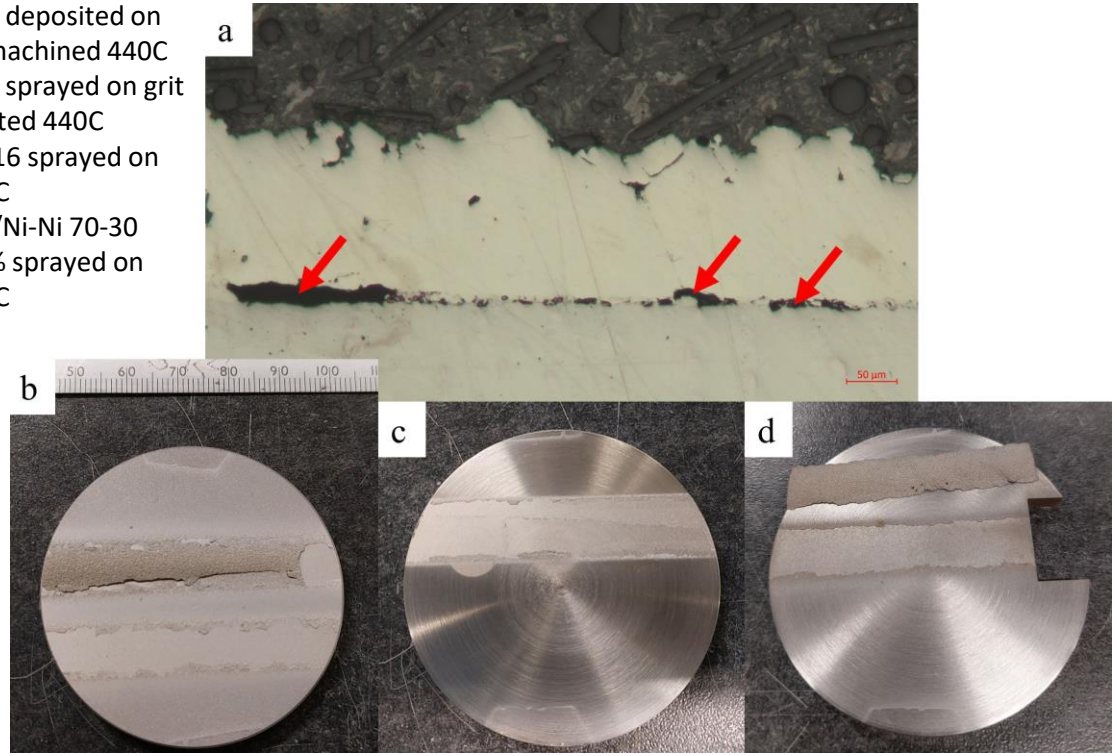
Parameters	Value
Temperature [°C]	900
Pressure [bar]	30
Spray distance [mm]	40
Feed rate [g/min]	80

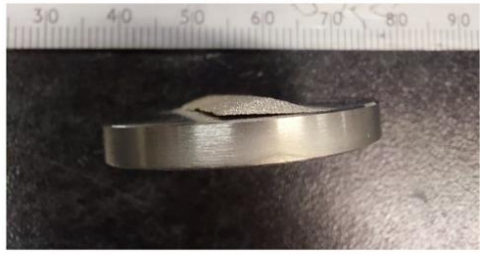


a) WC/Ni,
b) WC/Ni
c) Nickel
d) CrMnFeCoNi
e) SS316

WP6 – Cold Spray

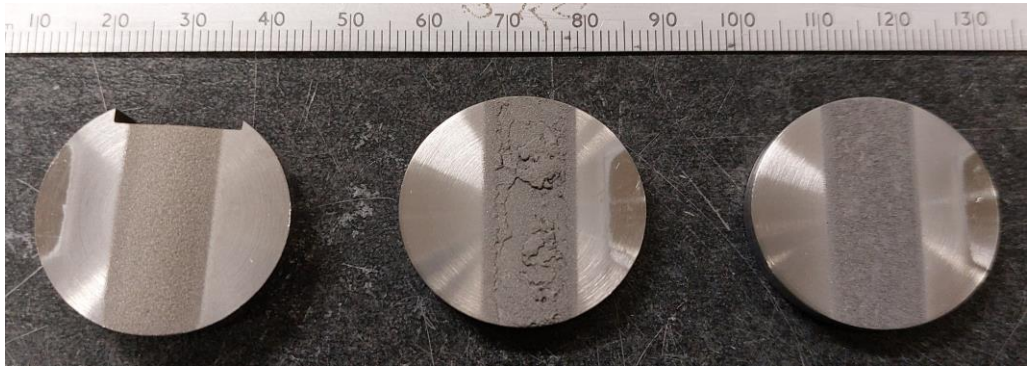
a) HEA deposited on as-machined 440C
b) HEA sprayed on grit blasted 440C
c) SS316 sprayed on 440C
d) WC/Ni-Ni 70-30 vol% sprayed on 440C





HEA sprayed on 2205 duplex stainless steel.

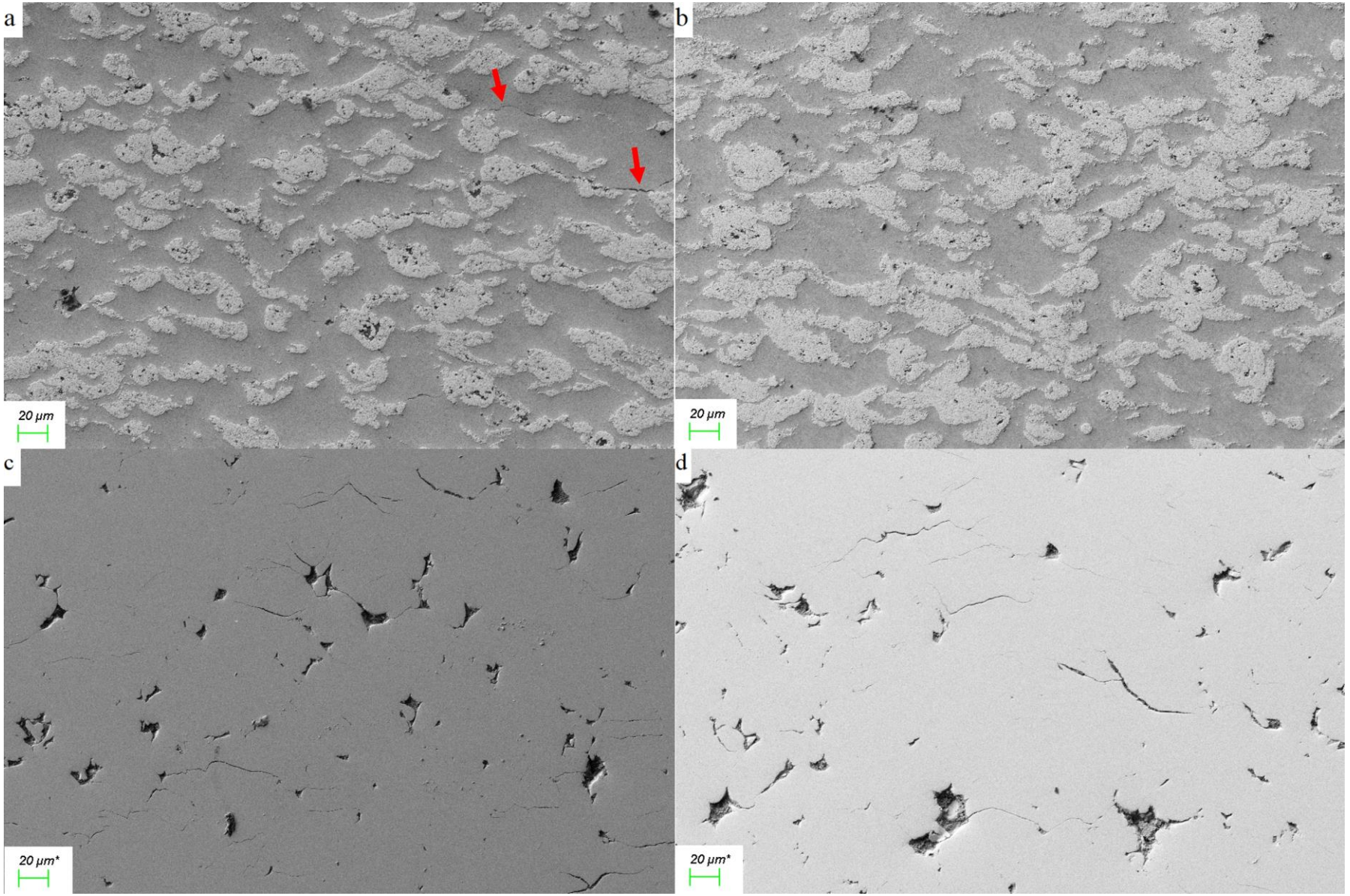
SS316 steel coating deposited on 2205 duplex stainless steel.



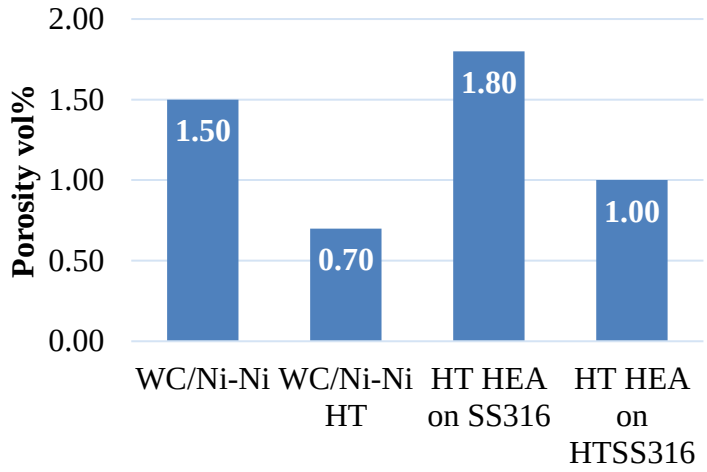
70 – 30 %vol | 80 – 20 %vol | 90 – 10 %vol

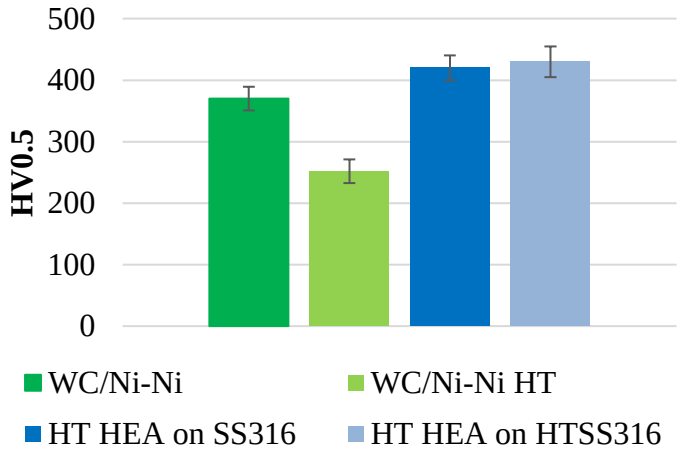
WC/Ni – Ni %vol

WP6 – Cold Spray



a) As-sprayed WC/Ni-Ni
b) Heat treated WC/Ni-Ni
c) Heat treated CrMnFeCoNi HEA on as-sprayed SS316
d) Heat treated CrMnFeCoNi HEA on heat treated SS316

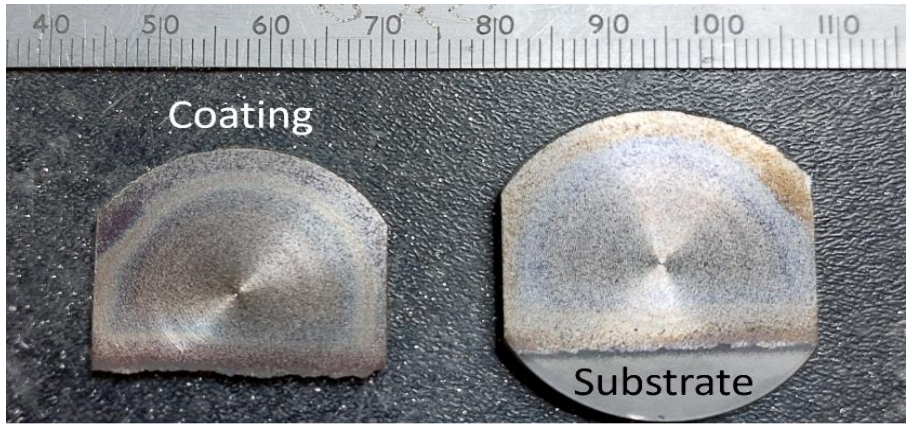




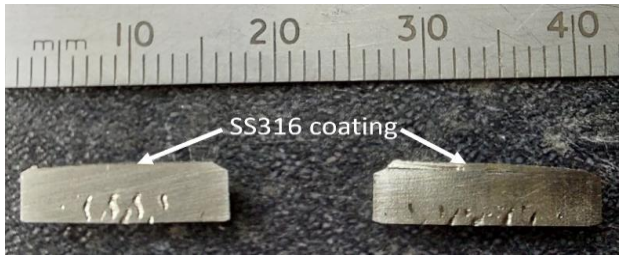
WP6 – Cold Spray

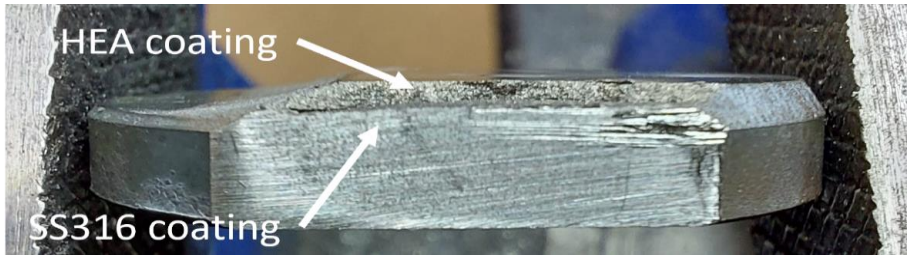
Adhesion test ASTM B571 - 97

HT HEA on SS316



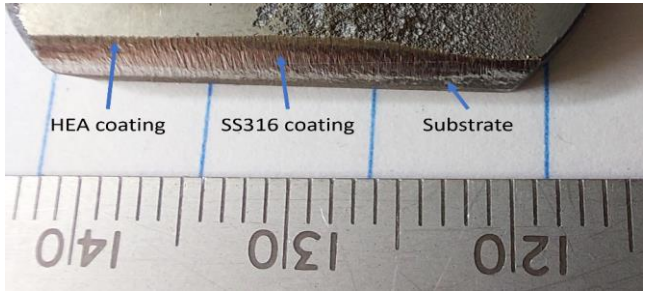
HT HEA on HTSS316



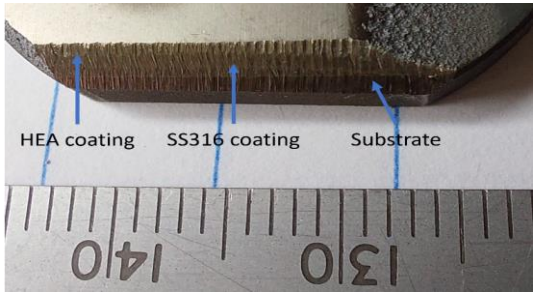


CHISEL TEST

HT HEA on SS316



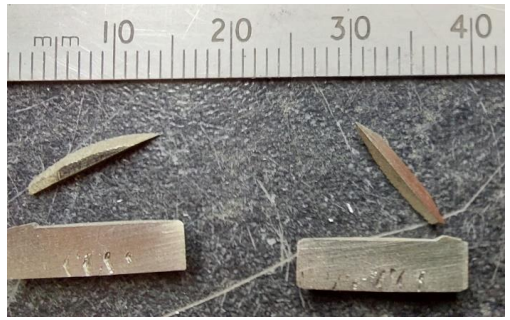
HT HEA on HTSS316

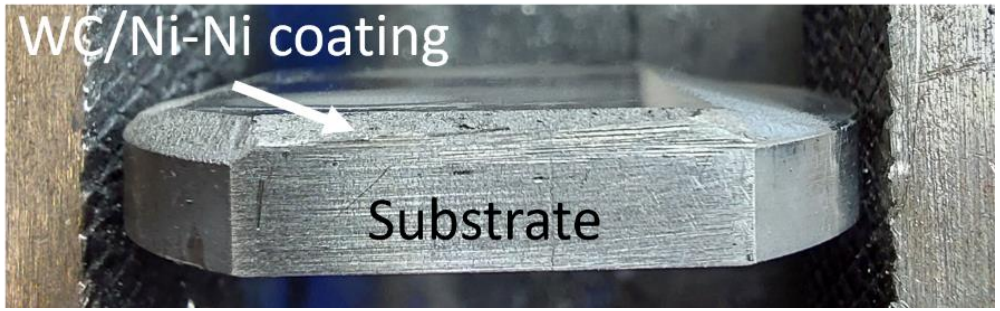


COARSE MILL FILE TEST

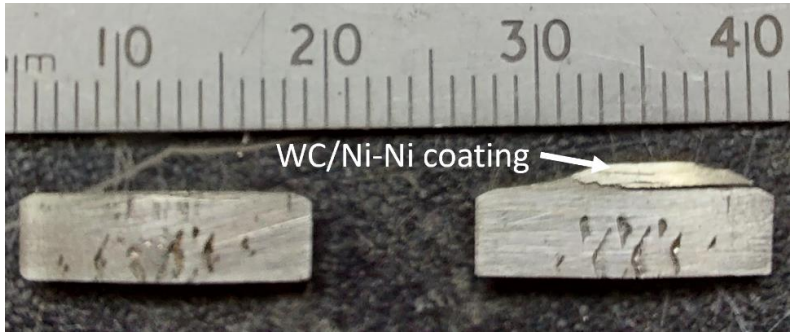
WP6 – Cold Spray

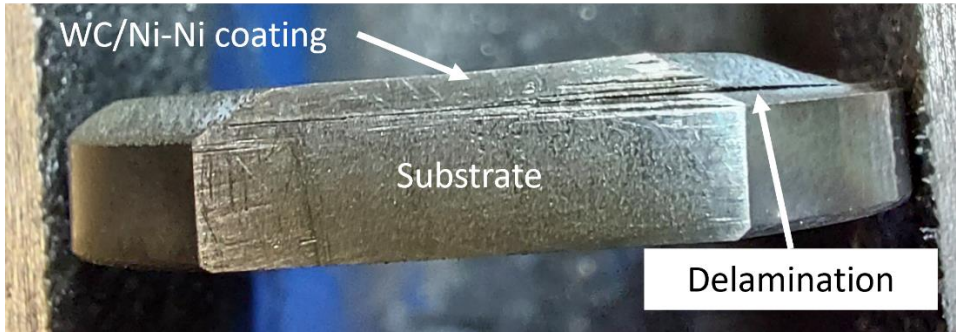
WC/Ni - Ni





HTWC/Ni - Ni

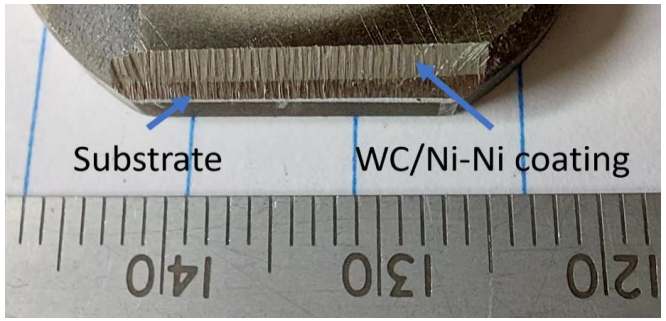


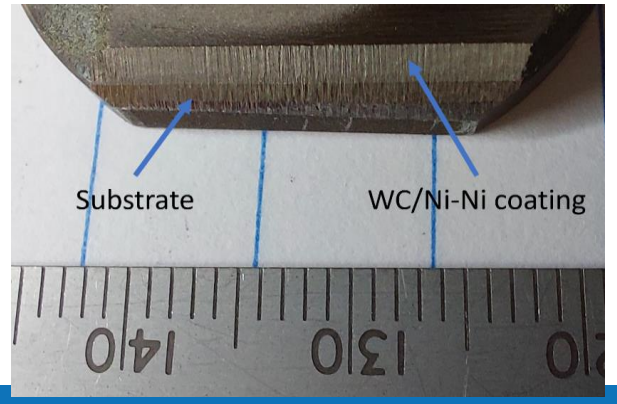


CHISEL TEST

WCNi - Ni

HT WCNi - Ni

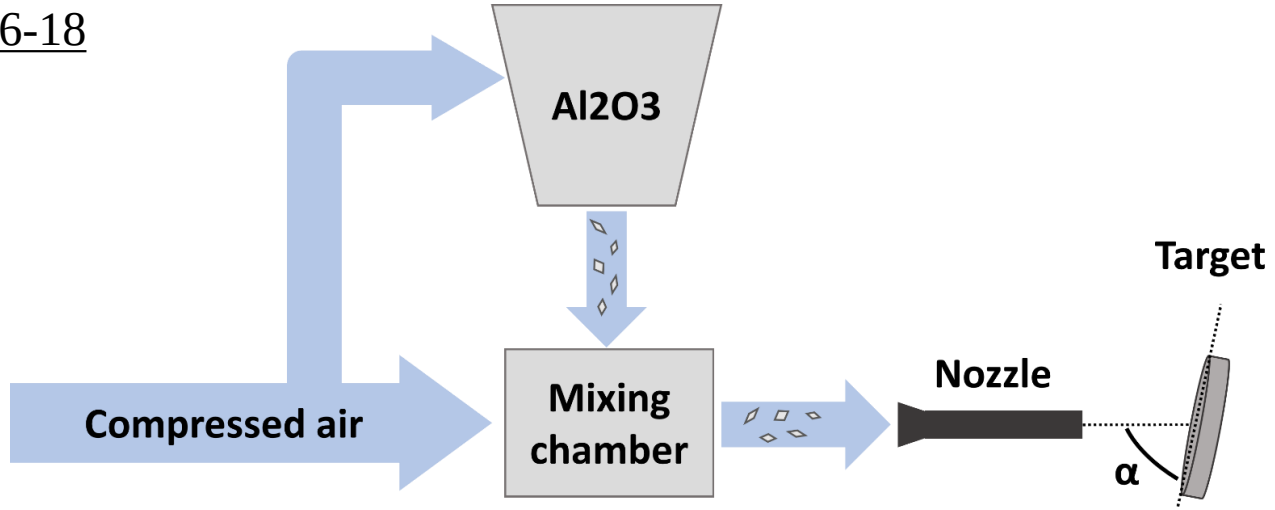




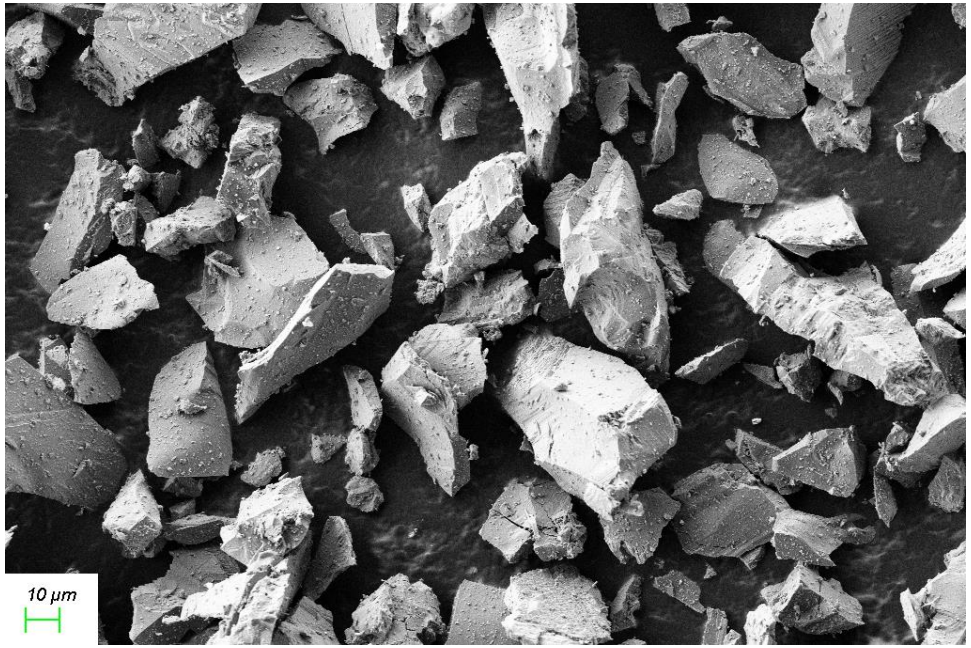
COARSE MILL FILE TEST

WP6 – Cold Spray

Erosion test ASTM G76-18

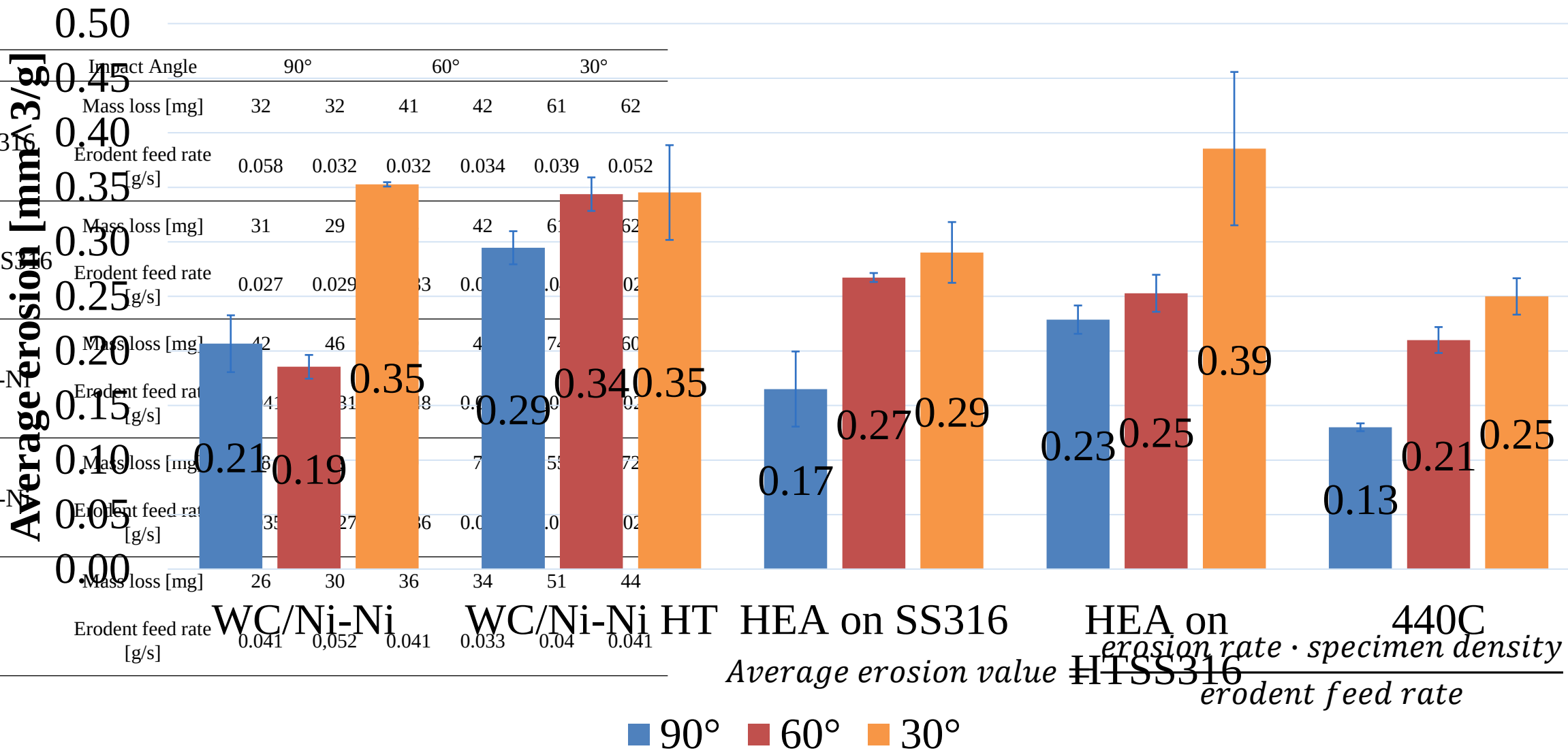


Parameters	Value
Temperature [°C]	20
Pressure [bar]	1.5
Spray distance [mm]	10
Feed rate [g/s]	~ 0.03
Duration [min]	10



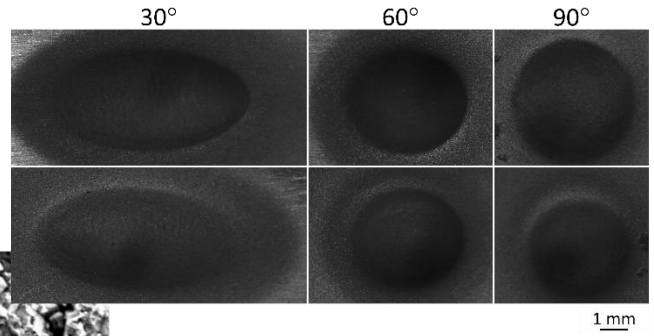
WP6 – Cold Spray

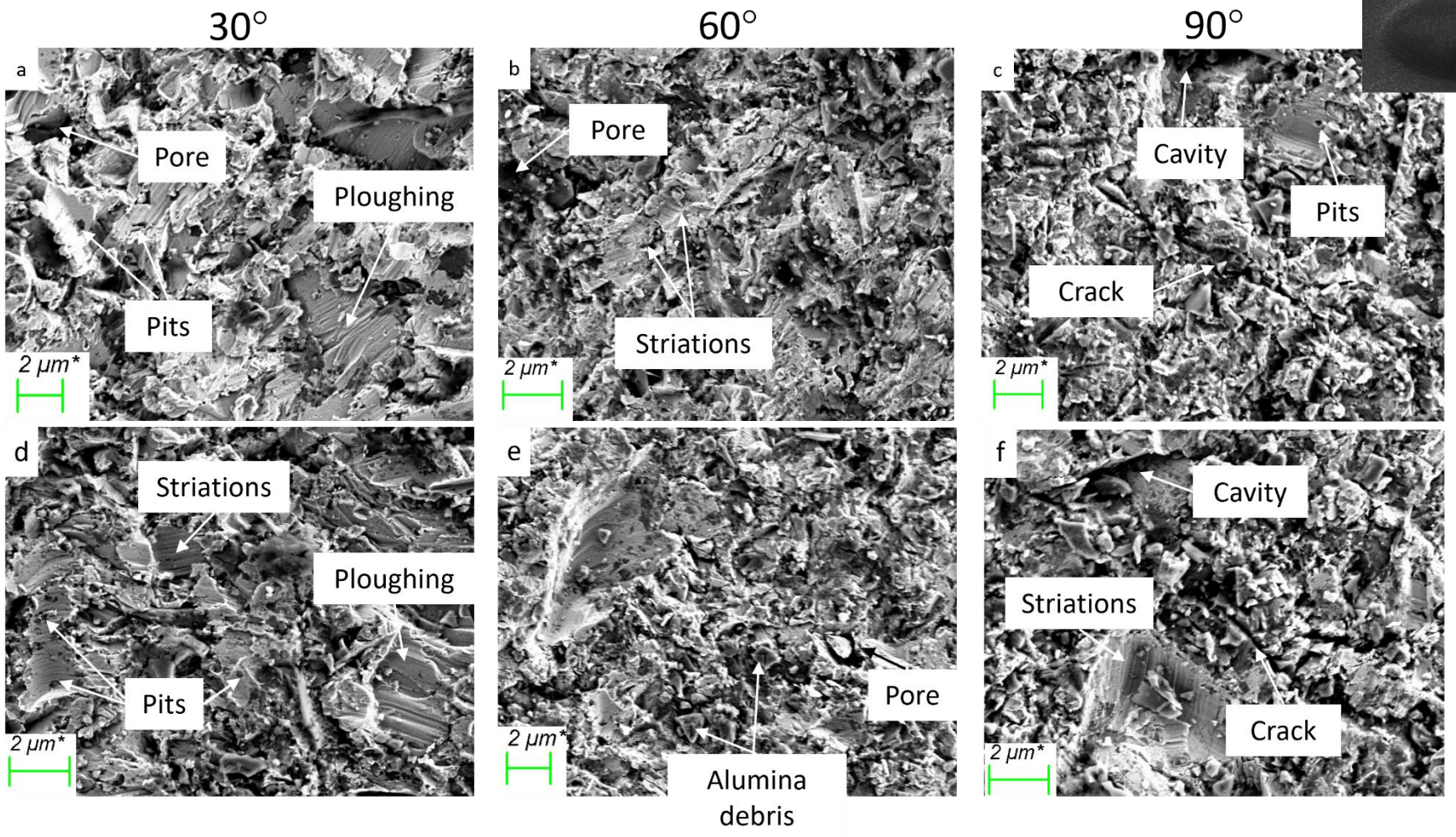
Impact Angle		90°		60°		30°	
HEA on SS316	Mass loss [mg]	32	32	41	42	61	62
	Erodent feed rate [g/s]	0.058	0.032	0.032	0.034	0.039	0.052
HEA on HTSS316	Mass loss [mg]	31	29		42	61	62
	Erodent feed rate [g/s]	0.027	0.029				
AS WC/Ni-Ni	Mass loss [mg]	42	46				
	Erodent feed rate [g/s]						
HT WC/Ni-Ni	Mass loss [mg]						
	Erodent feed rate [g/s]						
440C	Mass loss [mg]	26	30	36	34	51	44
	Erodent feed rate [g/s]	0.041	0,052	0.041	0.033	0.04	0.041



$$\text{Average erosion value} = \frac{\text{erosion rate} \cdot \text{specimen density}}{\text{erodent feed rate}}$$

WP6 – Cold Spray

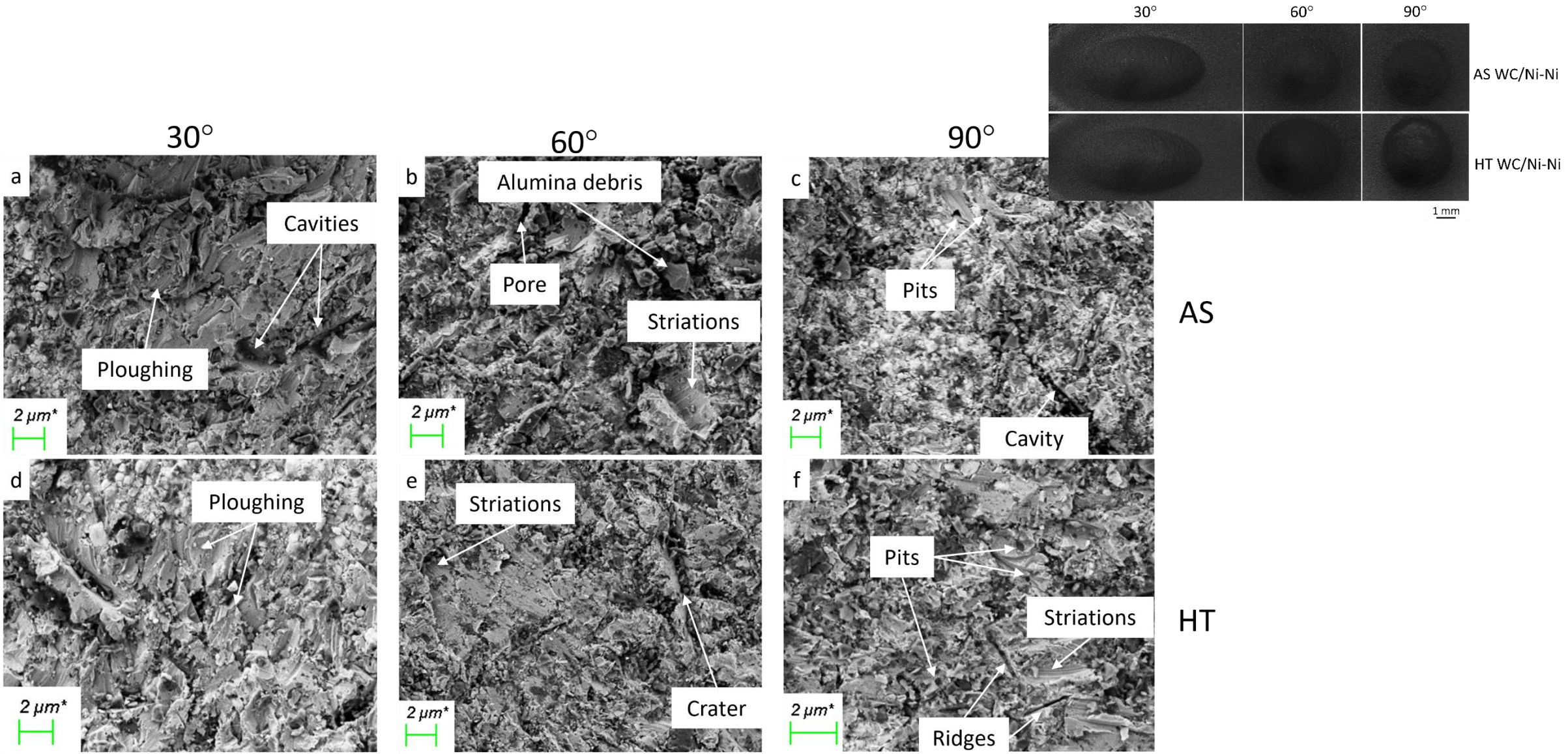




HT HEA on AS SS316

HT HEA on HT SS316

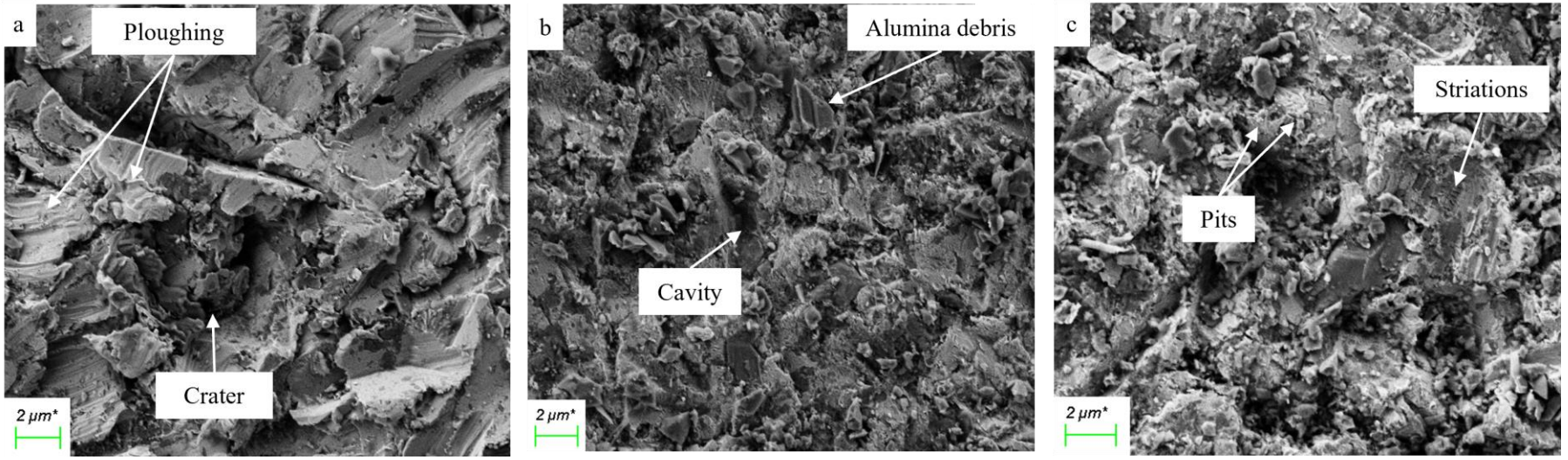
WP6 – Cold Spray



WP6 – Cold Spray

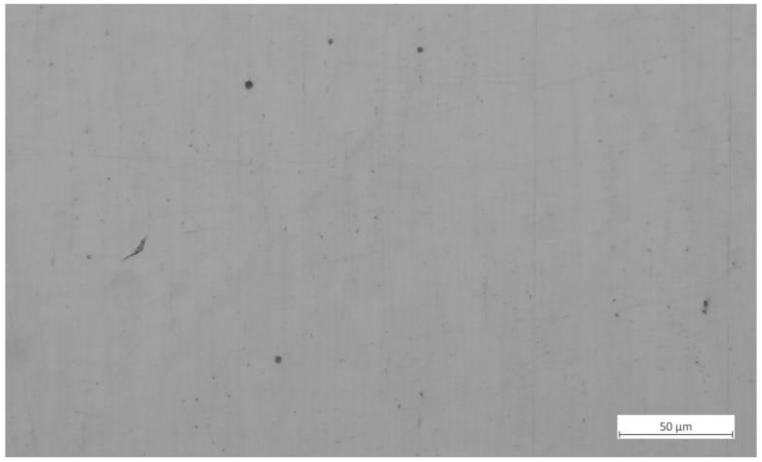
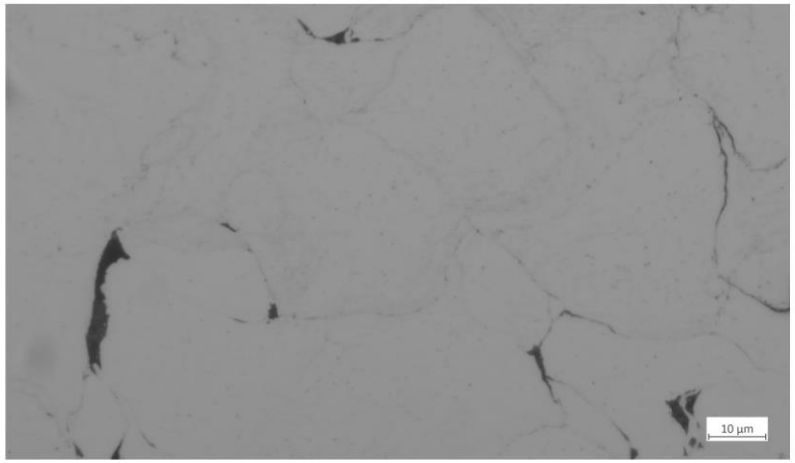
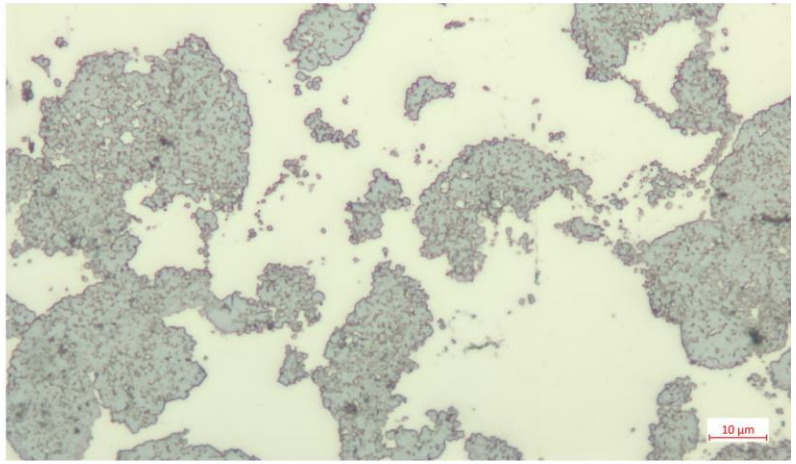
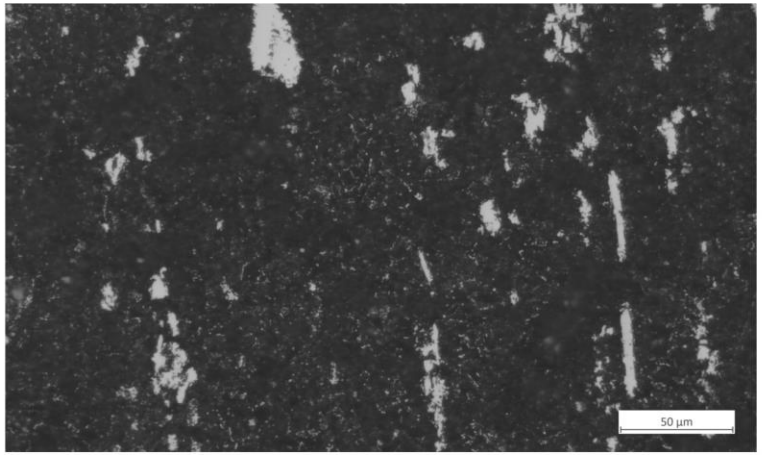
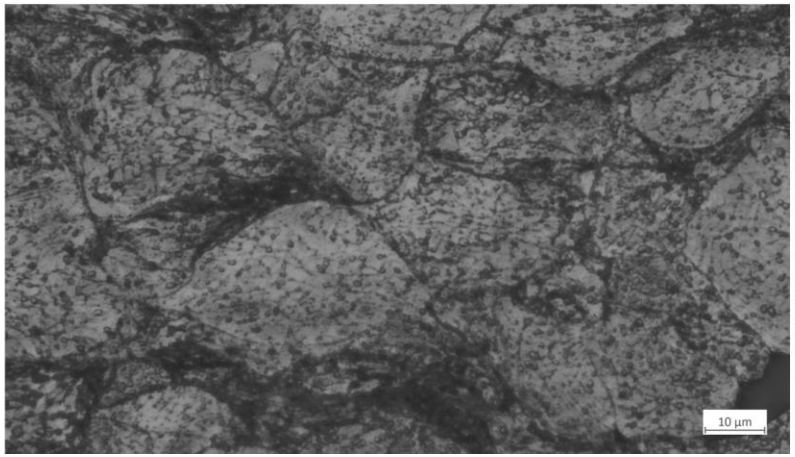
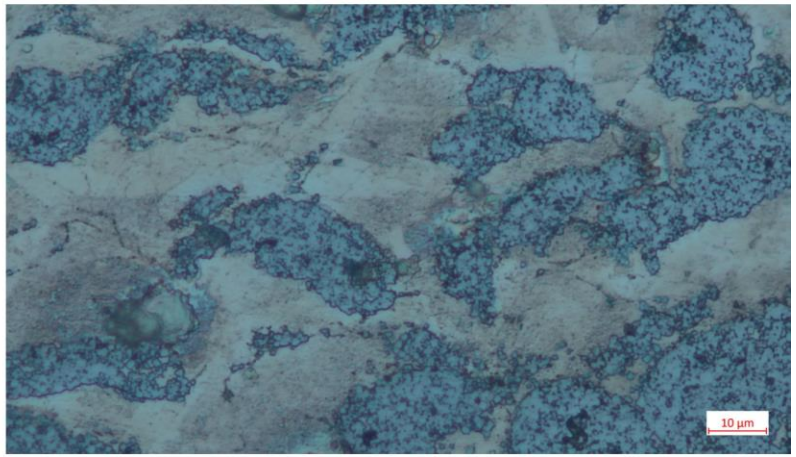
30° 60° 90°

440C



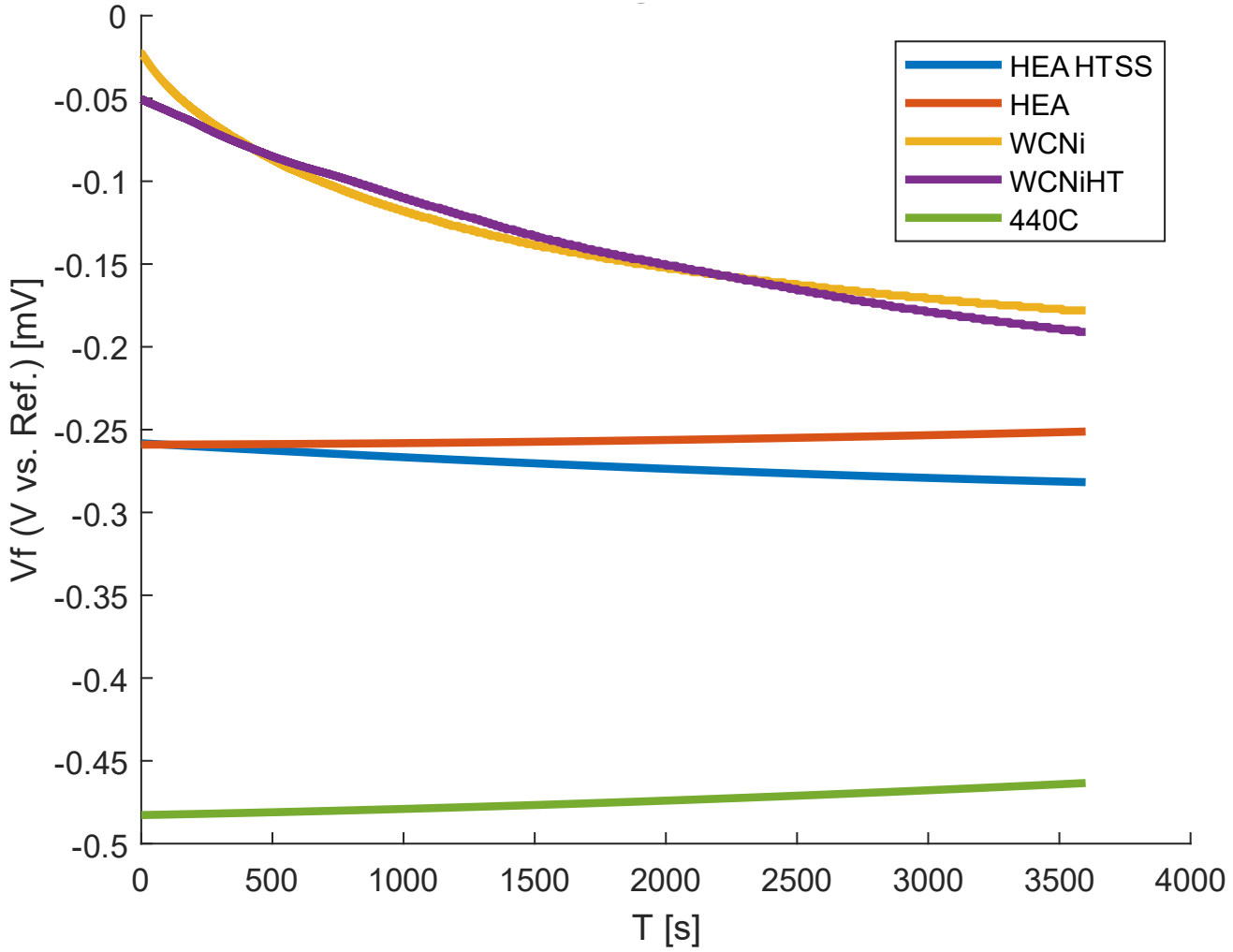
WP6 – Cold Spray

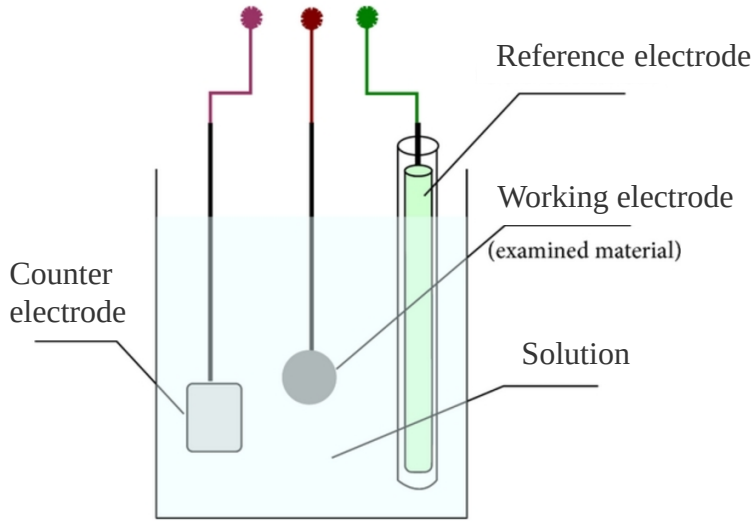
Corrosion test ISO11846 – Method B

	440C	HEA	WC/Ni-Ni
Before			
After			

WP6 – Cold Spray

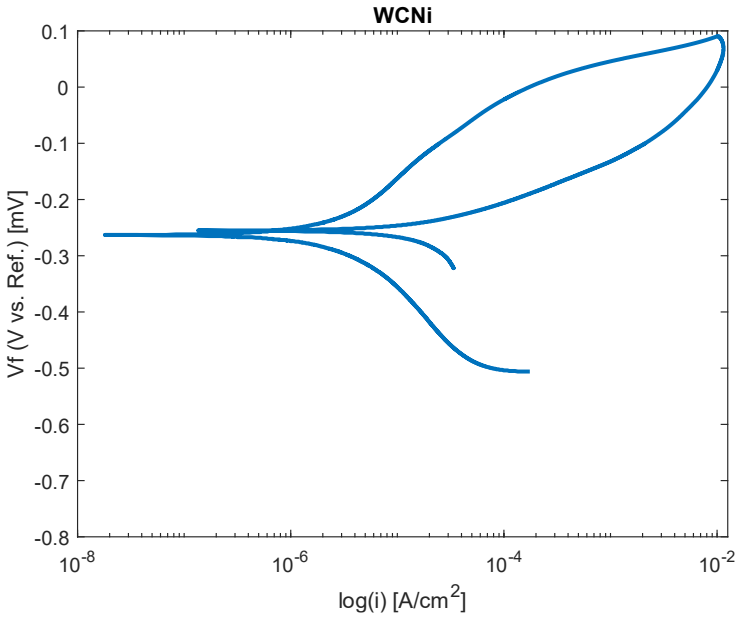
Open circuit potential

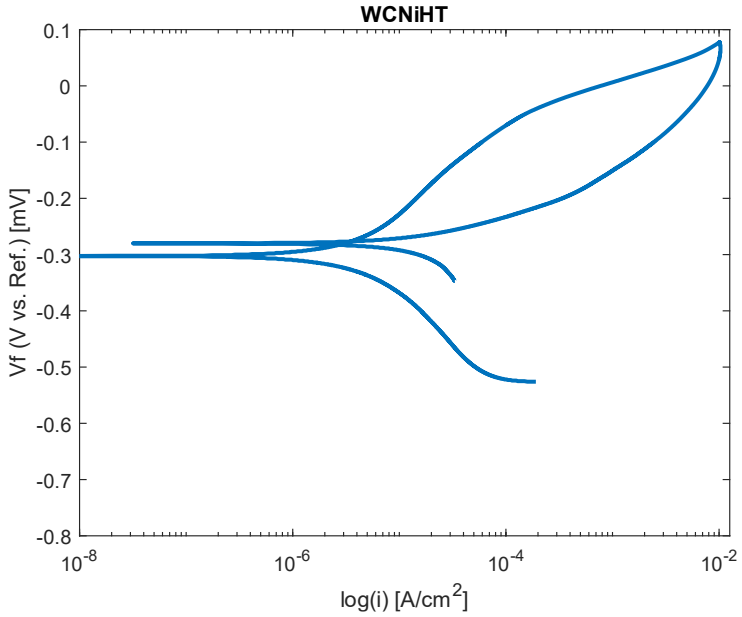


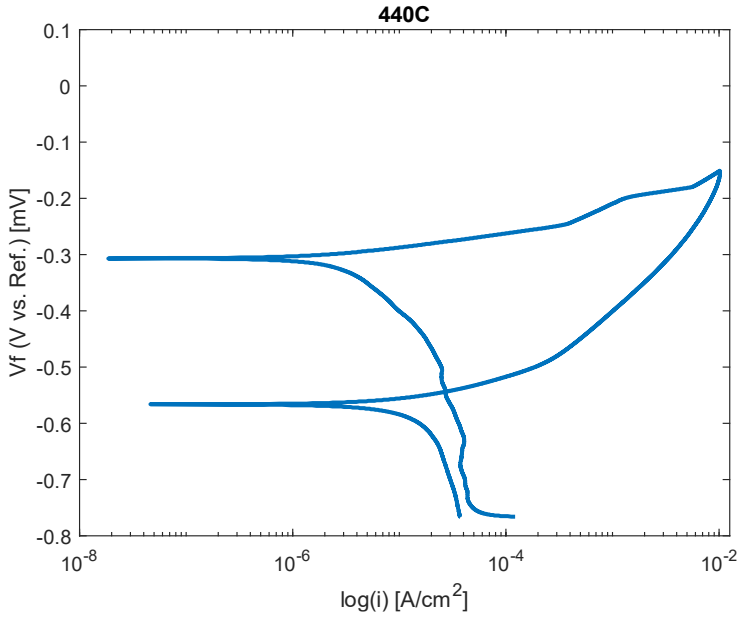


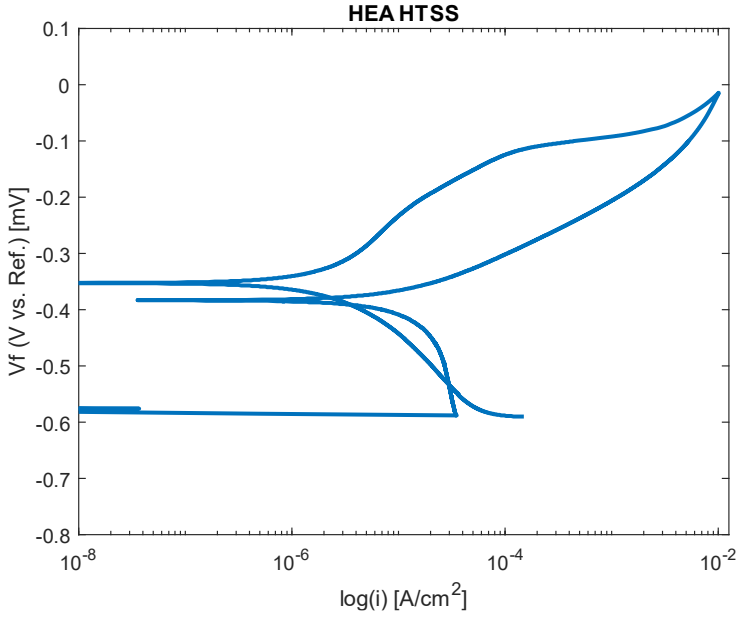
WP6 – Cold Spray

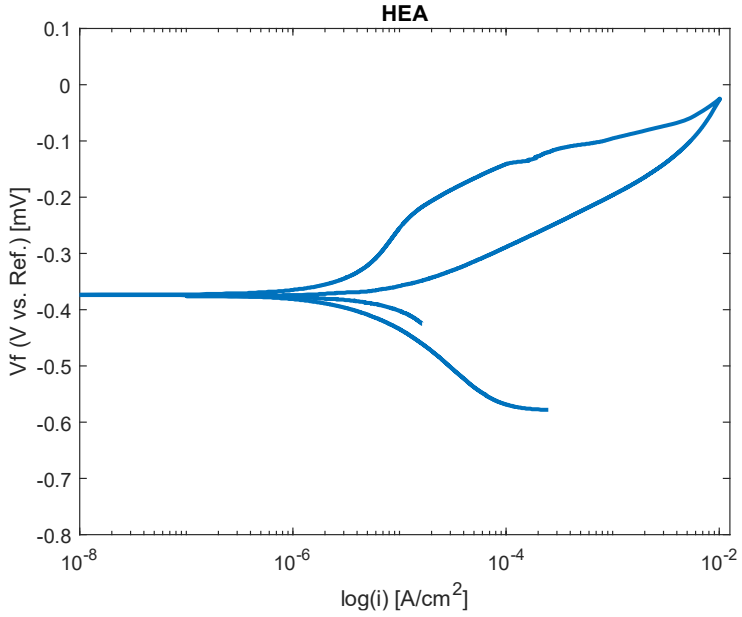
Cyclic potentiodynamic polarization











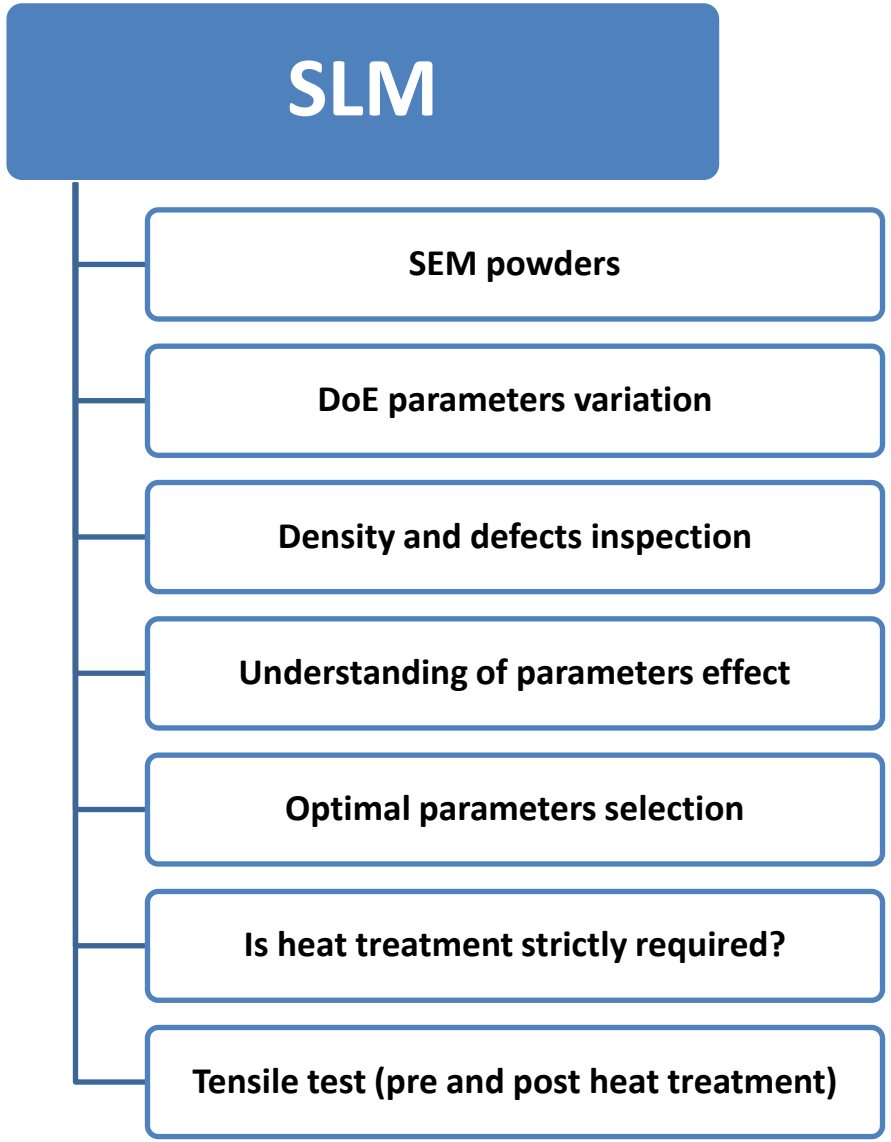
WP6 – Cold Spray

Material	Open circuit potential [mV]	Corrosion current [µA/cm²]	Corrosion potential [mV]	Corrosion rate [mpy]	Corrosion rate [mm/y]
440C (annealed 800°C)	-365	4.47	-307	2.04	0.052
HEA	-256	2.59	-373	1.17	0.030
HEA on HTSS	-278	1.95	-352	0.88	0.022
WC/Ni-Ni	-178	2.31	-263	0.78	0.020
HT WC/Ni-Ni	-191	3.11	-303	1.05	0.027

In literature, 440C with martensite alpha phase showed corrosion potential -485 mV and corrosion current 15.0 µA/cm² much higher than the one recorded here.

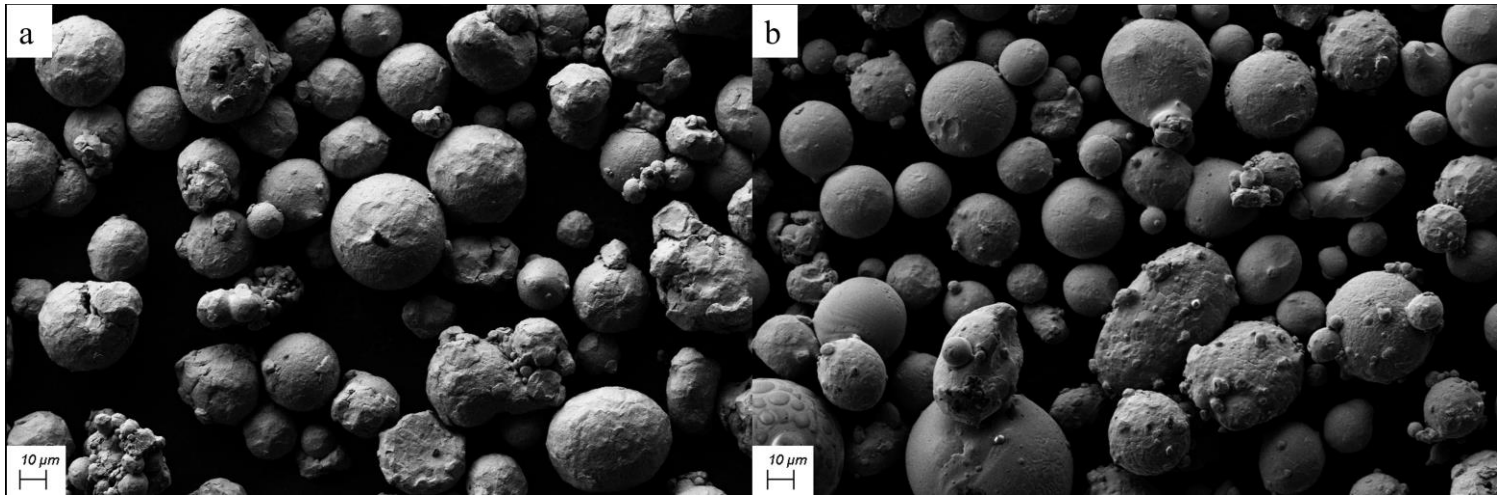
→ The 440C currently in use might be even worse then the tested one!

WP6 – Selective Laser Melting



WP6 – Selective Laser Melting

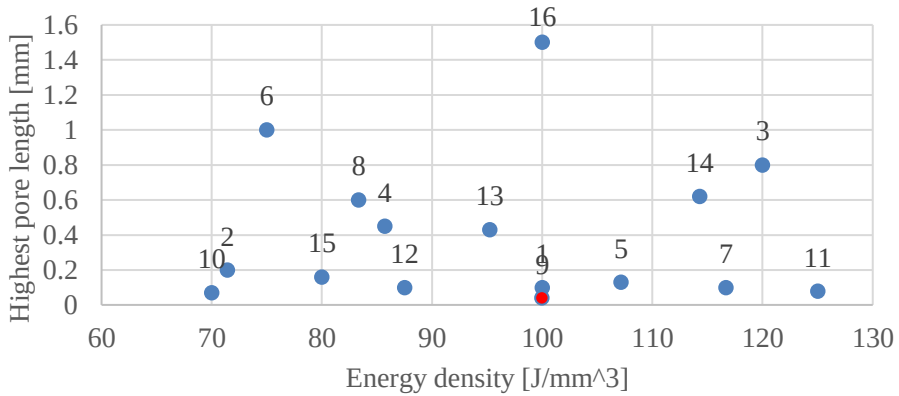
SLM

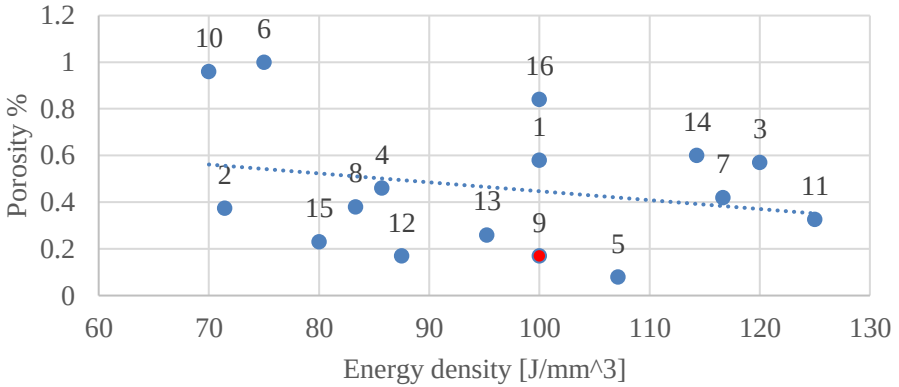


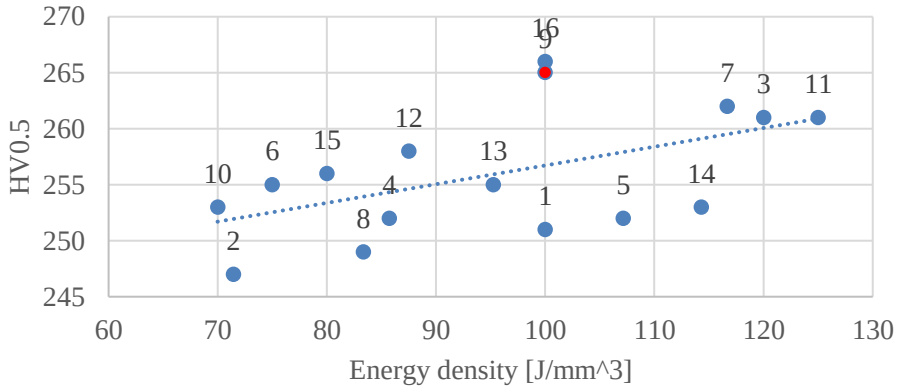
a) Maraging 18Ni300 steel
b) Stainless steel 316.

SLM – Stainless steel 316

Sample	Power [W]	Scanning Speed [mm/s]	Hatch [mm]	Energy Density [J/mm^3]]	Highest pore length [mm]	Porosity %	HV0.5
1	180	1200	0.05	100	0.1	0.58	251
2	180	1200	0.07	71	0.2	0.375	247
3	180	1000	0.05	120	0.8	0.57	261
4	180	1000	0.07	86	0.45	0.461	252
5	180	800	0.07	107	0.13	0.08	252
6	180	800	0.1	75	1	1	276
7	210	1200	0.05	117	0.1	0.42	262
8	210	1200	0.07	83	0.6	0.38	249
9	210	1000	0.07	100	0.04	0.17	265
10	210	1000	0.1	70	0.07	0.96	253
11	210	800	0.07	125	0.08	0.327	261
12	210	800	0.1	88	0.1	0.17	258
13	240	1200	0.07	95	0.43	0.26	255
14	240	1000	0.07	114	0.62	0.6	253
15	240	1000	0.1	80	0.16	0.23	256
16	240	800	0.1	100	1.5	0.84	266



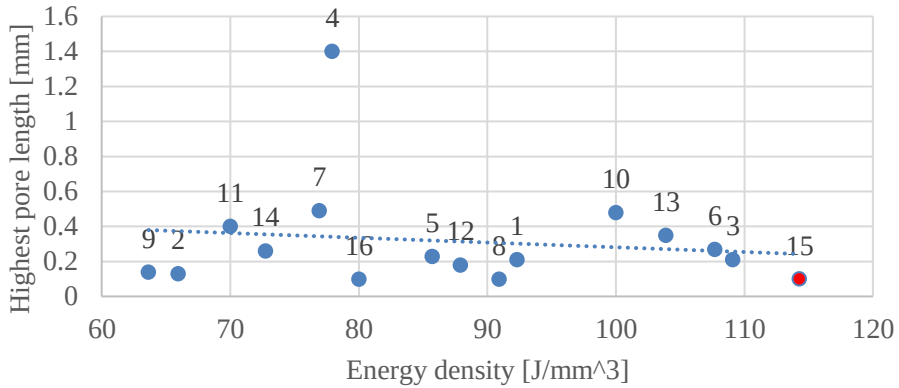


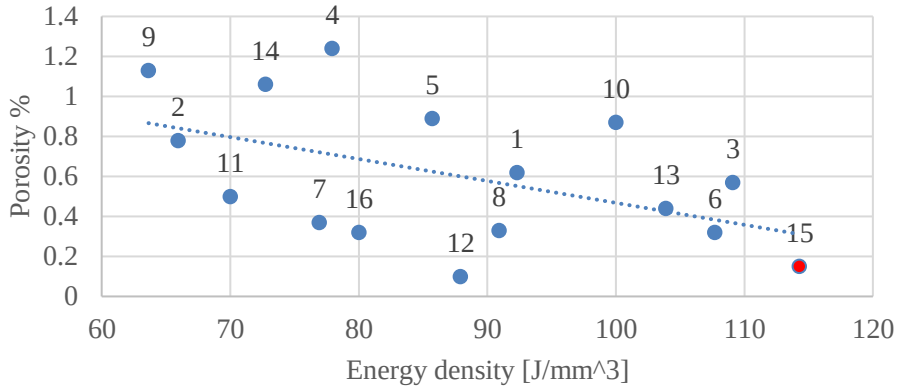


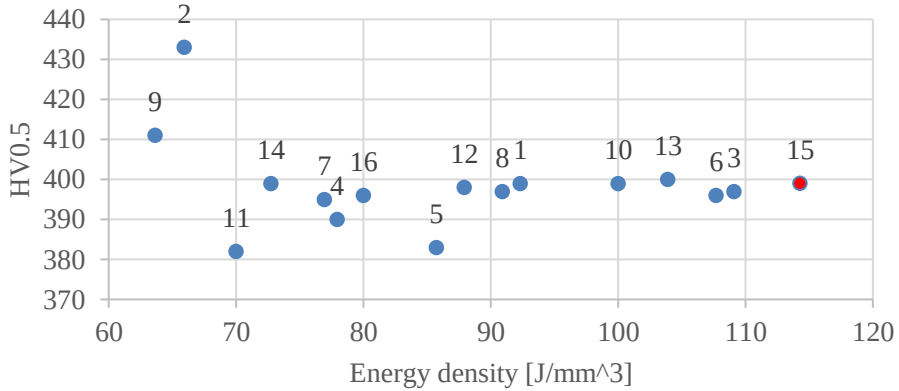
Parameters of sample 9 selected for tensile samples preparation

SLM – Maraging steel 18Ni300

Sample	Power [W]	Scanning Speed [mm/s]	Hatch [mm]	Energy Density [J/mm^3]]	Highest pore length [mm]	Porosity %	HV0.5
1	180	1300	0.05	92	0.21	0.62	399
2	180	1300	0.07	66	0.13	0.78	433
3	180	1100	0.05	109	0.21	0.57	397
4	180	1100	0.07	78	1.4	1.24	390
5	180	1000	0.07	86	0.23	0.89	383
6	210	1300	0.05	108	0.27	0.32	396
7	210	1300	0.07	77	0.49	0.37	395
8	210	1100	0.07	91	0.1	0.33	397
9	210	1100	0.1	64	0.14	1.13	411
10	210	1000	0.07	100	0.48	0.87	399
11	210	1000	0.1	70	0.4	0.5	382
12	240	1300	0.07	88	0.18	0.1	398
13	240	1100	0.07	104	0.35	0.44	400
14	240	1100	0.1	73	0.26	1.06	399
15	240	1000	0.07	114	0.1	0.15	399
16	240	1000	0.1	80	0.1	0.32	396







Parameters of sample 15 selected for tensile samples preparation

WP6 – Selective Laser Melting

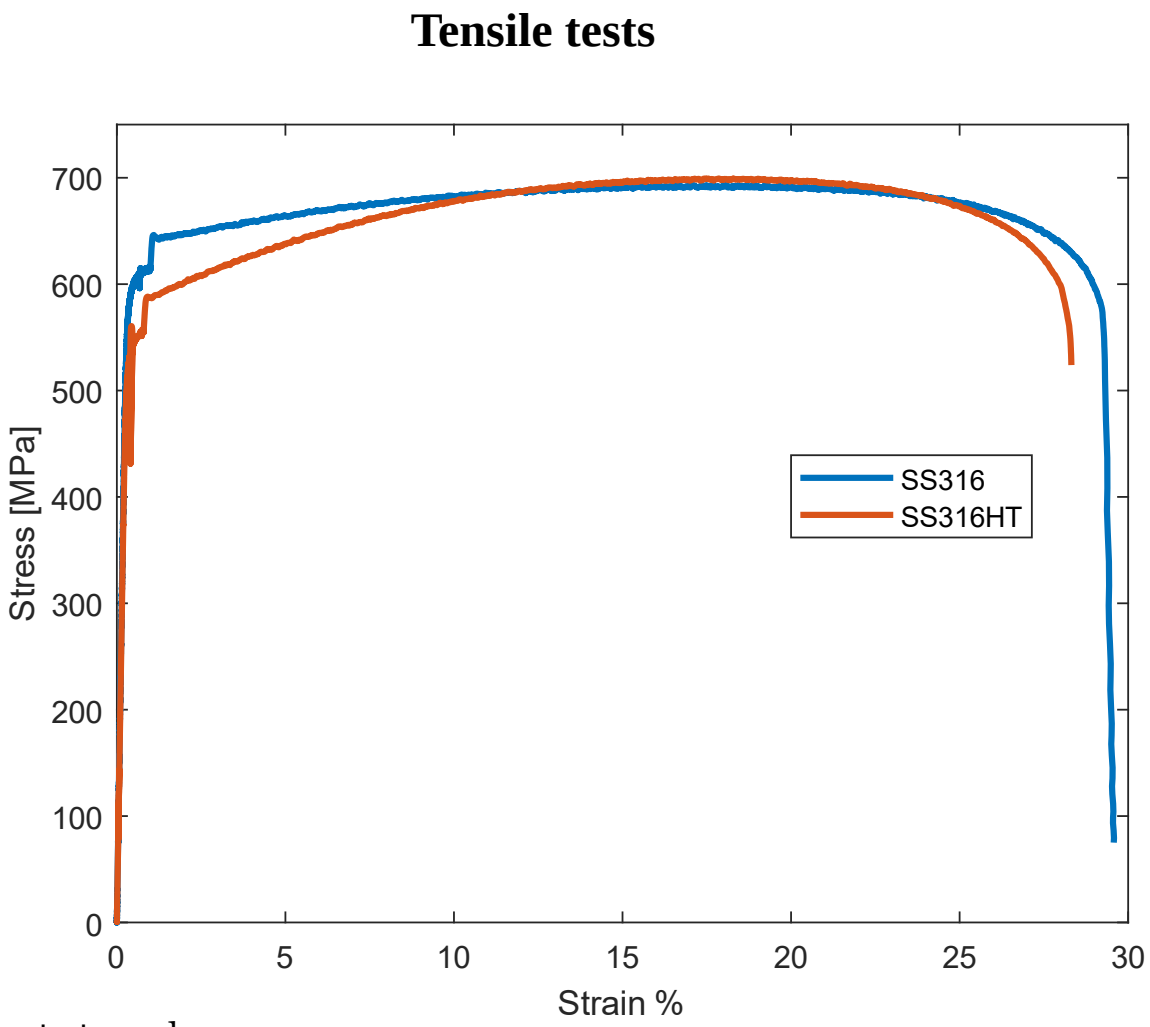
Heat treatments

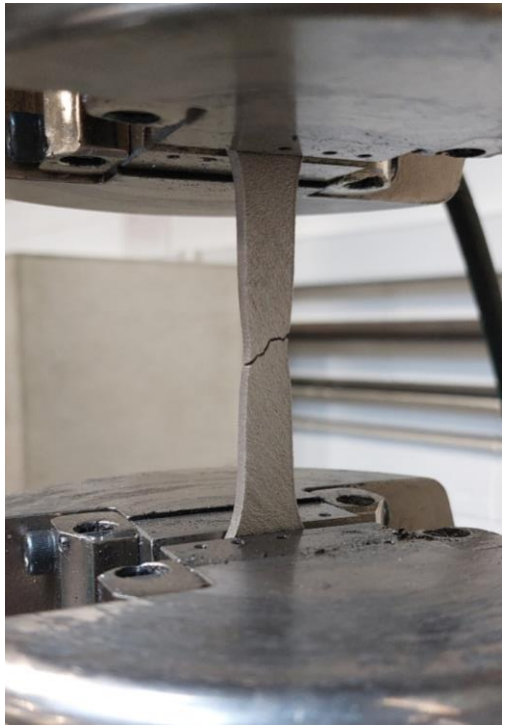
SS316
600 °C – 2 hours dwell time – slow cooling → Ductility improved, hardness slightly reduced from 265 to 255HV0.5

18Ni300
815°C – 30 minutes dwell time – water quenching
480°C – 6 hours aging – slow cooling → Precipitation hardening, hardness significantly increased from 400 to 565HV0.5

WP6 – Selective Laser Melting

	SS316	SS316HT
Young modulus E [Gpa]	206	196
Proof strength 0.2% [Mpa]	600	540
Rm [Mpa]	693	699
Strain at break %	29.6	28.3



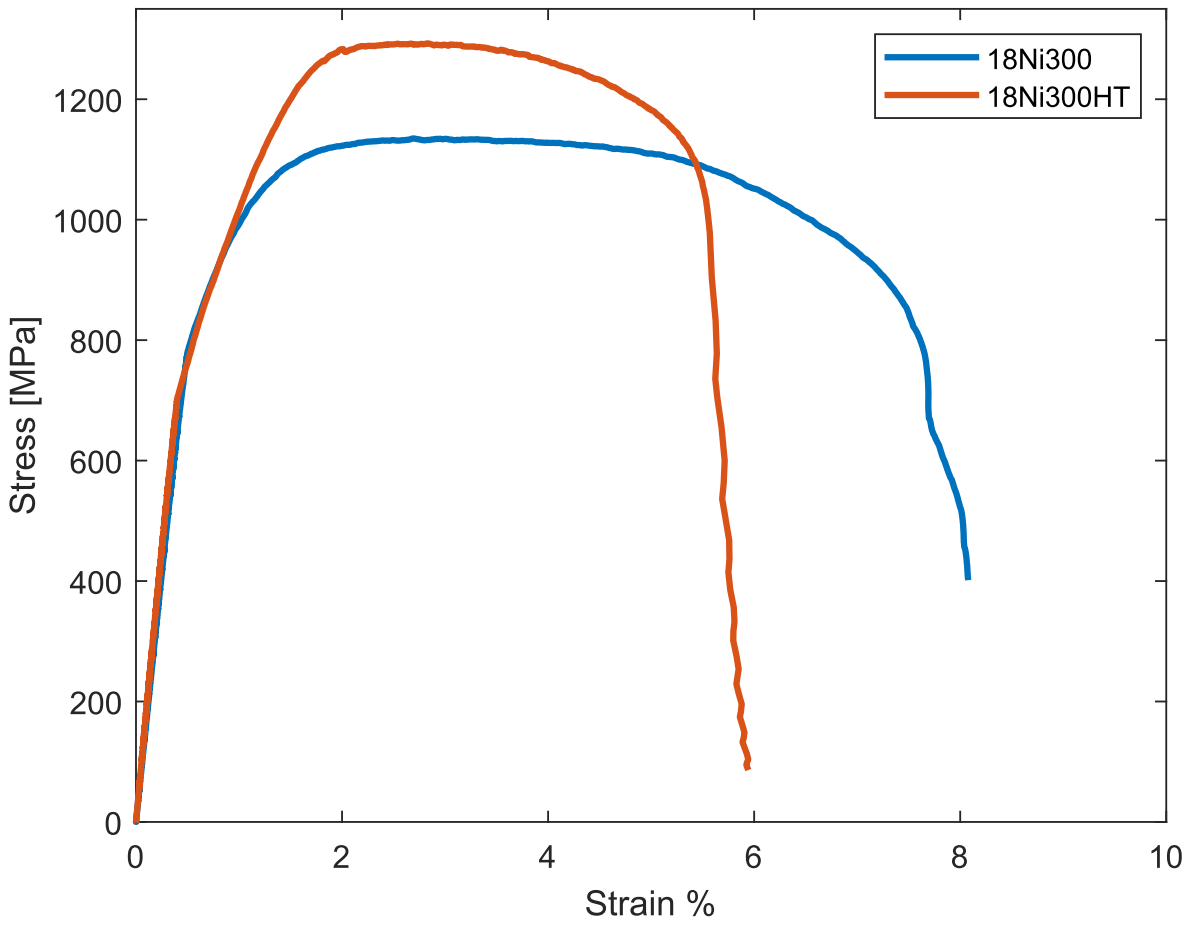


Section: 4x13mm
1% strain limit for strain control at 0.002 s^-1 test speed
After yield 3mm/min displacement control
Gauge length 25 mm

WP6 – Selective Laser Melting

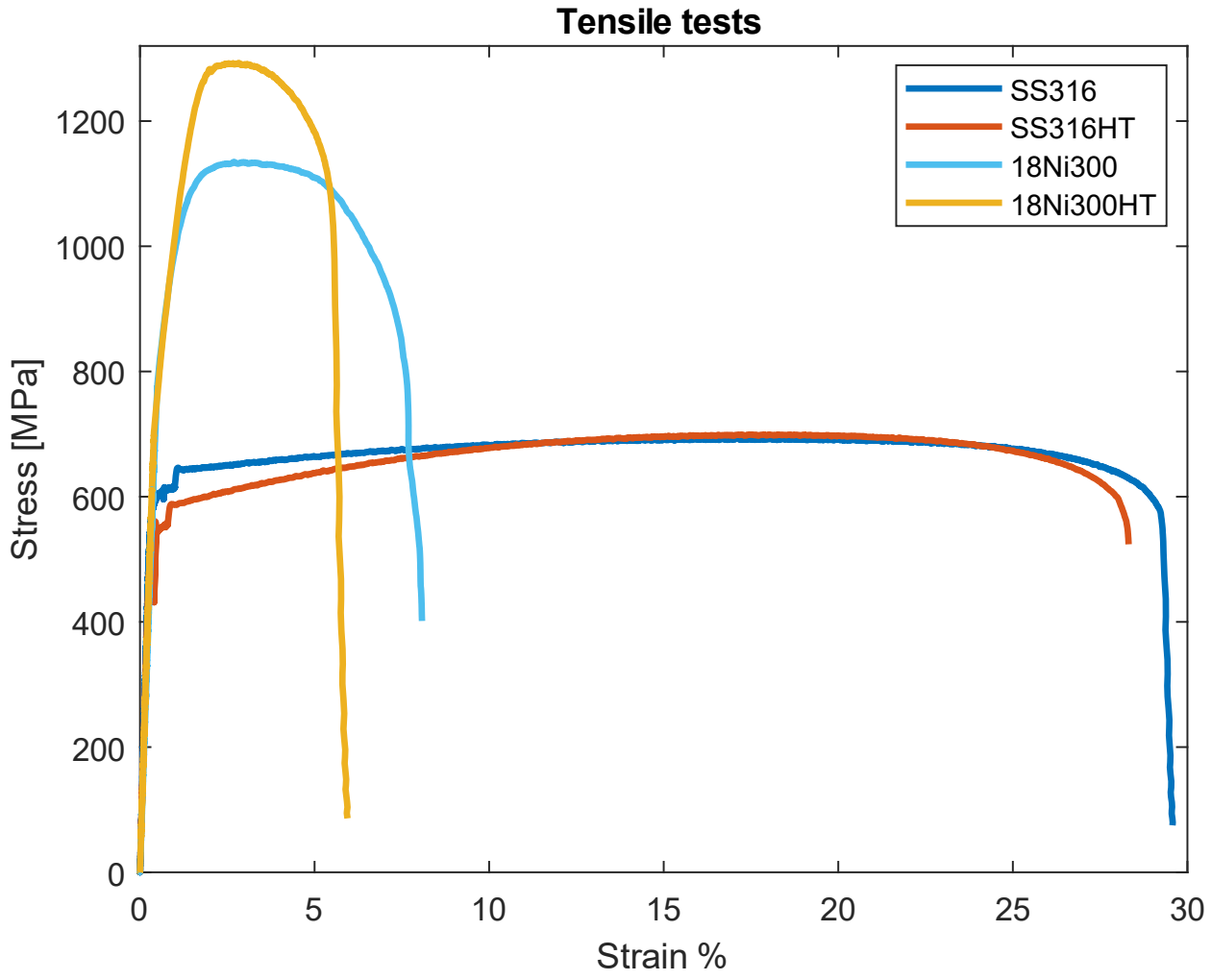
Tensile tests

	18Ni300	18Ni300 HT
Young modulus E [Gpa]	165	184
Proof strength 0.2% [Mpa]	1135	863
Rm [Mpa]	900	1293
Strain at break %	8	6



Section: 2.7x13mm
0.5% strain limit for strain control 0.002 s^-1
After yield 3mm/min displacement control
Gauge length 25 mm

WP6 – Selective Laser Melting



WP7 – Cold Spray

Cold spray

Properties		Tested materials				
		AN440C	WC/Ni-Ni	WC/Ni-Ni HT	HEA on SS316	HEA on HTSS316
Microstructure	Porosity	\	1.50	0.70	1.80	1.00
	Microhardness HV0.5	353	370	252	420	430
Adhesion	Coating adhesion chisel test	\	OK	OK	Low adhesion of SS316 coating to 2205 Duplex SS	SS316 adhesion to substrate is higher than HEA adhesion to SS316
	Coating adhesion coarse mill test	\	OK	OK	OK	OK
Erosion	Expected volume loss in 6 months at 0.03 g/s Al2O3 federate, 30° impact angle for 40 hr per week [cm^3/6 months]	26	37	36	30	40
Corrosion	Corrosion current [µA/cm^2]	4.47	2.31	3.11	2.59	1.95
	Corrosion potential [mV]	-307	-263	-303	-373	-352
	Corrosion rate [mm/y]	0.052	0.027	0.020	0.030	0.022

WP7 – Selective Laser Melting

SLM

Properties		Tested materials			
		SS316	SS316HT	18Ni300	18Ni300HT
DOE	Optimal energy density [J/mm^3]	100		114	
	Porosity %	0.08	0.06	0.1	0.07
	Microhardness HV0.5	265	255	400	565
	Highest pore length [mm]	0.04	\	0.1	\
Tensile test	Young modulus E [Gpa]	206	196	165	184
	Proof strength 0.2% [Mpa]	600	540	1135	863
	Rm [Mpa]	693	699	900	1293
	Strain at break %	29.6	28.3	8	6

Deliverables

- TECHNICAL NOTES √
- TDP TECHNICAL DATA PACKAGE (The final versions of all approved technical documents)
- ESR EXECUTIVE SUMMARY REPORT (shall not exceed 5 pages of text and 10 pages in total) **– in progress**
- FR FINAL REPORT (Shall provide a complete description of all the work done during the study and shall be self-standing) **– in progress**
- CCD CONTRACT CLOSURE DOCUMENTATION
- TAS TECHNOLOGY ACHIEVEMENT SUMMARY (http://www.esa.int/Our_Activities/Space_Engineering_Technology/Shaping_the_Future/Download_Area)

Trinity College Dublin
Coláiste na Tríonóide, Baile Átha Cliath
The University of Dublin

Thank You!