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NbC-bearing hypo-eutectic high chromium white cast irons: Production and properties

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Why wear-resistant materials matter?

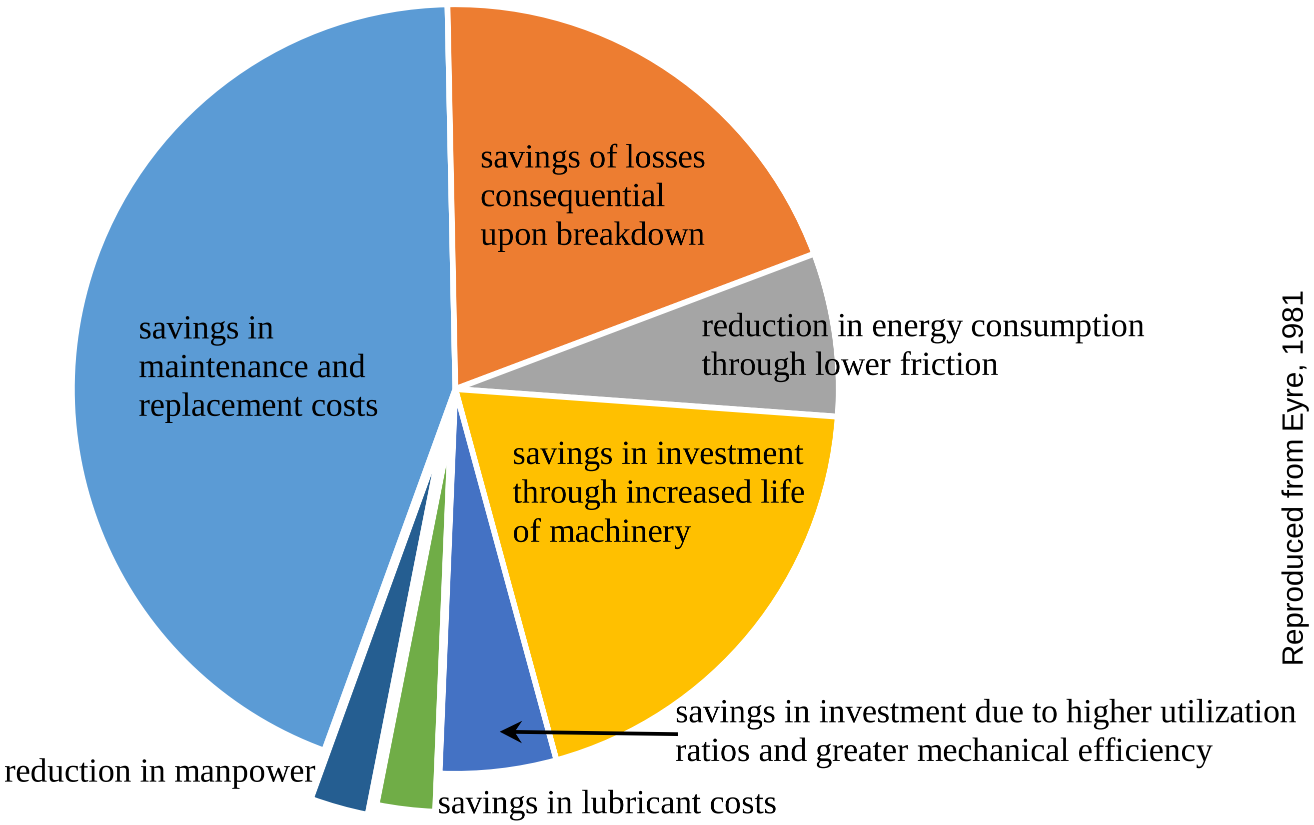
Wear: material degradation process which causes a progressive material removal as a result of relative motion between the contacting surfaces, with or without presence of other substances such as lubricants, wear debris and abrasive particles.

– "The two principal direct operating costs in commercial crushing and grinding are power and metal wear" — also applies to minerals handling and transportation industries.

– Wear loss is considerably higher in wet grinding compared to material handling or dry comminution, due to the contribution of corrosion.

– In addition to material loss, wear causes premature failure of engineering parts.

→ Its financial aspects must account for the expenses involved not only in the replacements, but also inventory, labour costs, and shut-down times — even more costly if unscheduled.



Cost reductions from improvements in tribological systems

Reproduced from Eyre, 1981

Why **abrasion**-resistant materials matter?

– is used beneficially in manufacturing processes such as machining, grinding, polishing, *etc*.

– participates in ~50% of industrial wear problems.

– this imposes an estimated cost of about 2-4% of the gross national product (GNP)

– mining and ore beneficiation industries are the major customers for wear consumables, costing hundreds of millions of dollars per year.

– American government report: $16.25 billion (at 1976 values) could be annually saved by "strategy for energy conservation through tribology" — **this figure is only for energy saving.**

– worldwide mining activities constitute ~6.2% of total global energy consumption (recent study)

– ~16.5% (2 EJ): manufacturing and replacing wear parts and equipment due to abrasive wear failures.

– grinding (32%), haulage (24%), ventilation (9%) and digging (8%) are the largest energy consumers.

– 2.7% of world CO_2 emissions (970 million tonnes)

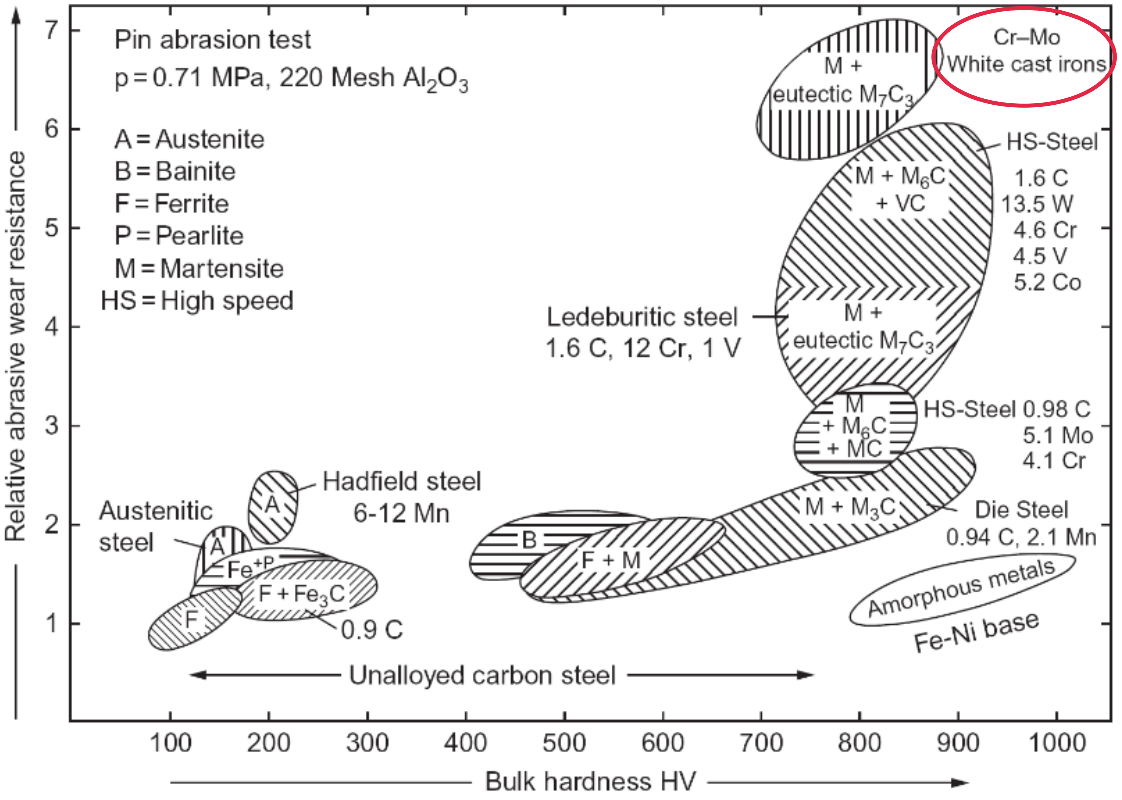
– from 210,000 B€ economic losses in mining, 27% belongs to production of replacement parts and 7% to the lost production.

→ any improvement in the wear life will have huge impact on economy and environment.

Abrasion-resistant materials

Abrasive Wear:

"Wear due to hard particles or hard protuberances forced against and moving along a solid surface" (ASTM G40)



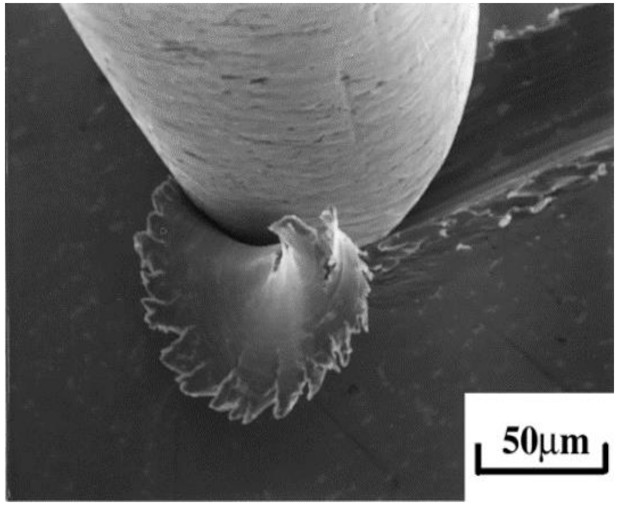
Relative abrasion resistance (RAR) *vs* bulk hardness.

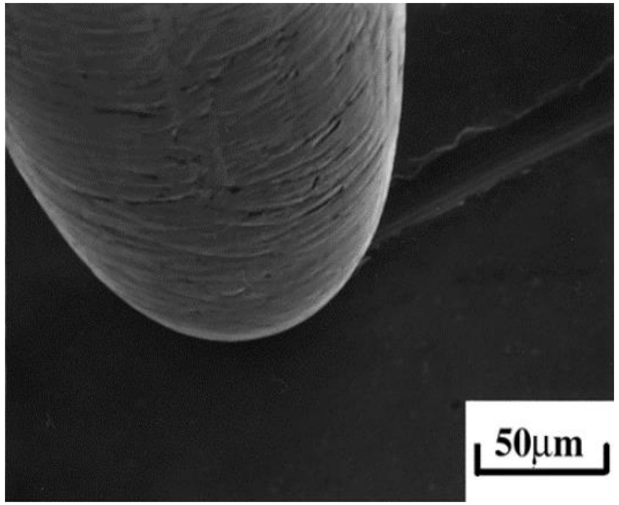
Wear Mechanisms:

the process or set of processes by which wear loss occurs or surface properties/topography changes

Abrasive Wear Mechanisms:

micro-ploughing, micro-cutting, micro-fracture





Metallurgy of White Cast Irons (WCIs)

No-alloy white cast irons

→ contain only C, Si, Mn as well as P and S

Low-alloy white cast irons

→ total alloying elements (Cr, Ni, Mo, Ti, V, Cu and B) less than 5 wt%

High-alloy white cast irons

→ total alloying elements higher than 5 wt%

i) Ni-Cr system (Ni-hard irons, class I in ASTM A532),

ii) Cr-Mo system,

iii) High-Cr system,

iv) W system

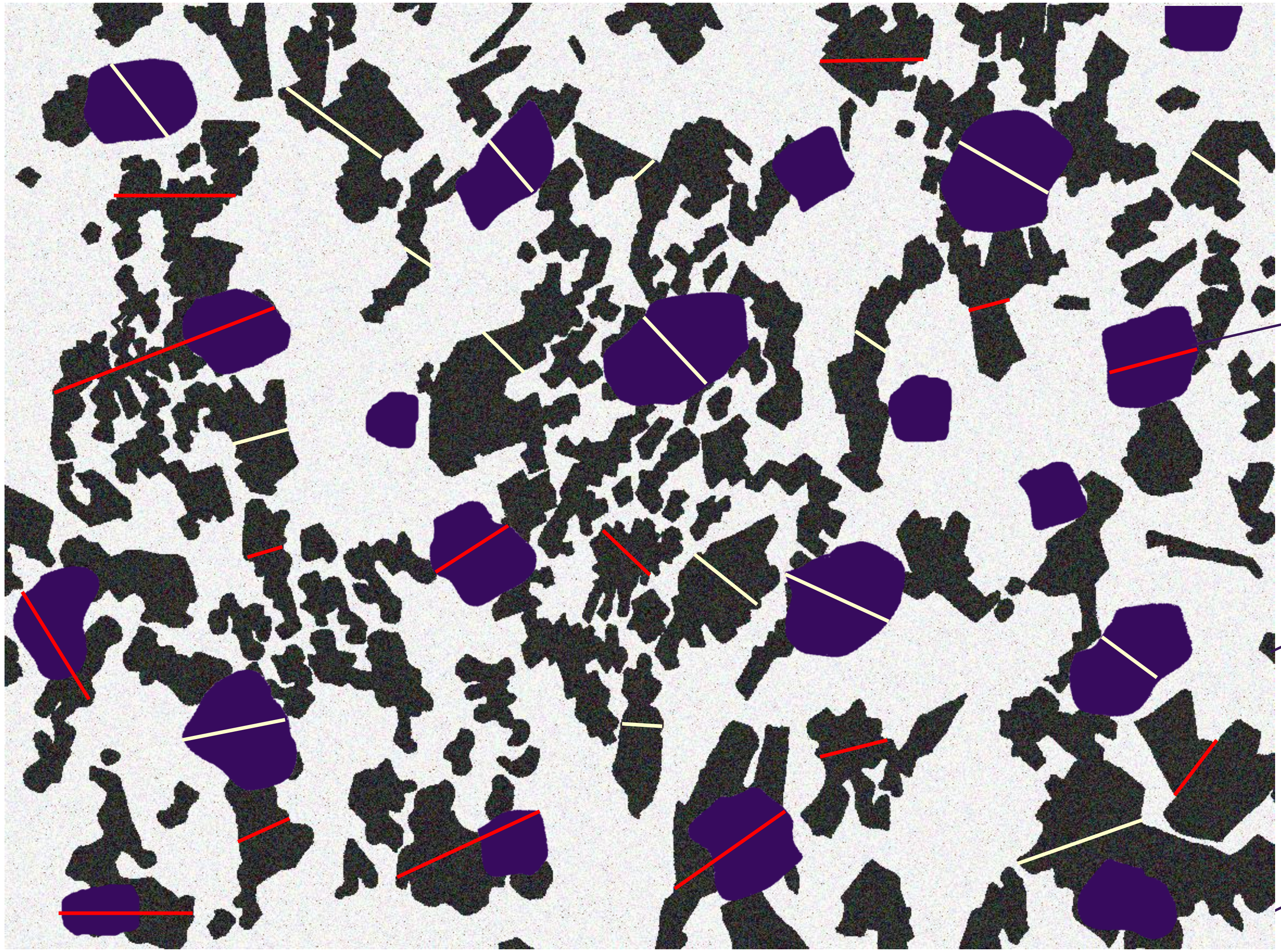
Abrasion-resistant WCIs

high-Cr and high-Cr-Mo WCIs

Class	Type	Designation	Carbon	Manganese	Silicon	Nickel	Chromium	Molybdenum	Copper	Phosphorus	Sulfur
I	A	Ni-Cr-Hc	2.8–3.6	2.0 max	0.8 max	3.3–5.0	1.4–4.0	1.0 max	. . .	0.3 max	0.15 max
I	B	Ni-Cr-Lc	2.4–3.0	2.0 max	0.8 max	3.3–5.0	1.4–4.0	1.0 max	. . .	0.3 max	0.15 max
I	C	Ni-Cr-GB	2.5–3.7	2.0 max	0.8 max	4.0 max	1.0–2.5	1.0 max	. . .	0.3 max	0.15 max
I	D	Ni-HiCr	2.5–3.6	2.0 max	2.0 max	4.5-7.0	7.0–11.0	1.5 max	. . .	0.10 max	0.15 max
II	A	12 % Cr	2.0–3.3	2.0 max	1.5 max	2.5 max	11.0–14.0	3.0 max	1.2 max	0.10 max	0.06 max
II	B	15 % Cr-Mo	2.0–3.3	2.0 max	1.5 max	2.5 max	14.0–18.0	3.0 max	1.2 max	0.10 max	0.06 max
II	D	20 % Cr-Mo	2.0–3.3	2.0 max	1.0–2.2	2.5 max	18.0–23.0	3.0 max	1.2 max	0.10 max	0.06 max
III	A	25 % Cr	2.0–3.3	2.0 max	1.5 max	2.5 max	23.0–30.0	3.0 max	1.2 max	0.10 max	0.06 max

ASTM A532, 2015

Single- and dual-reinforced high-Cr WCIs

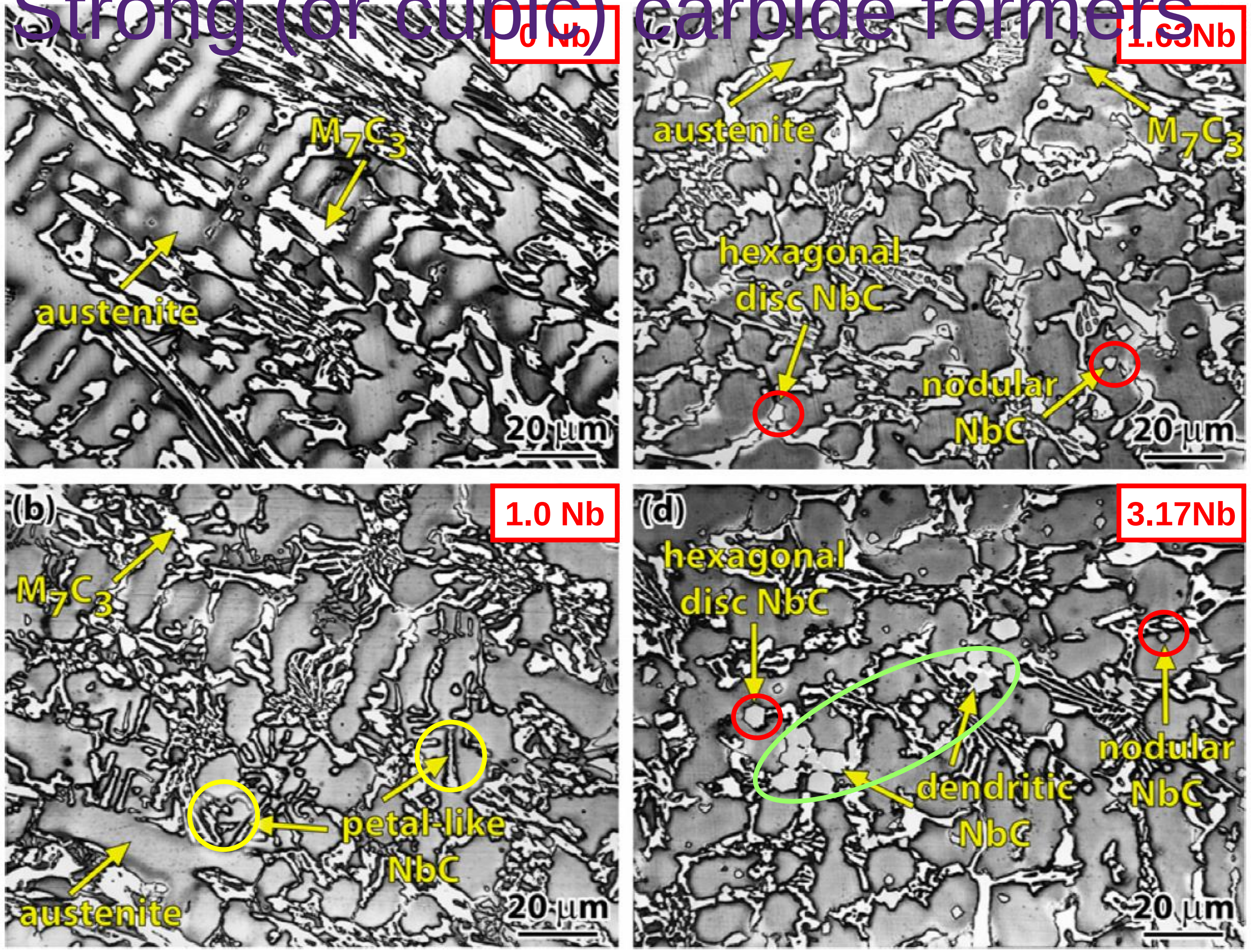


SCF (or CCF) introduced dual-reinforced WCI

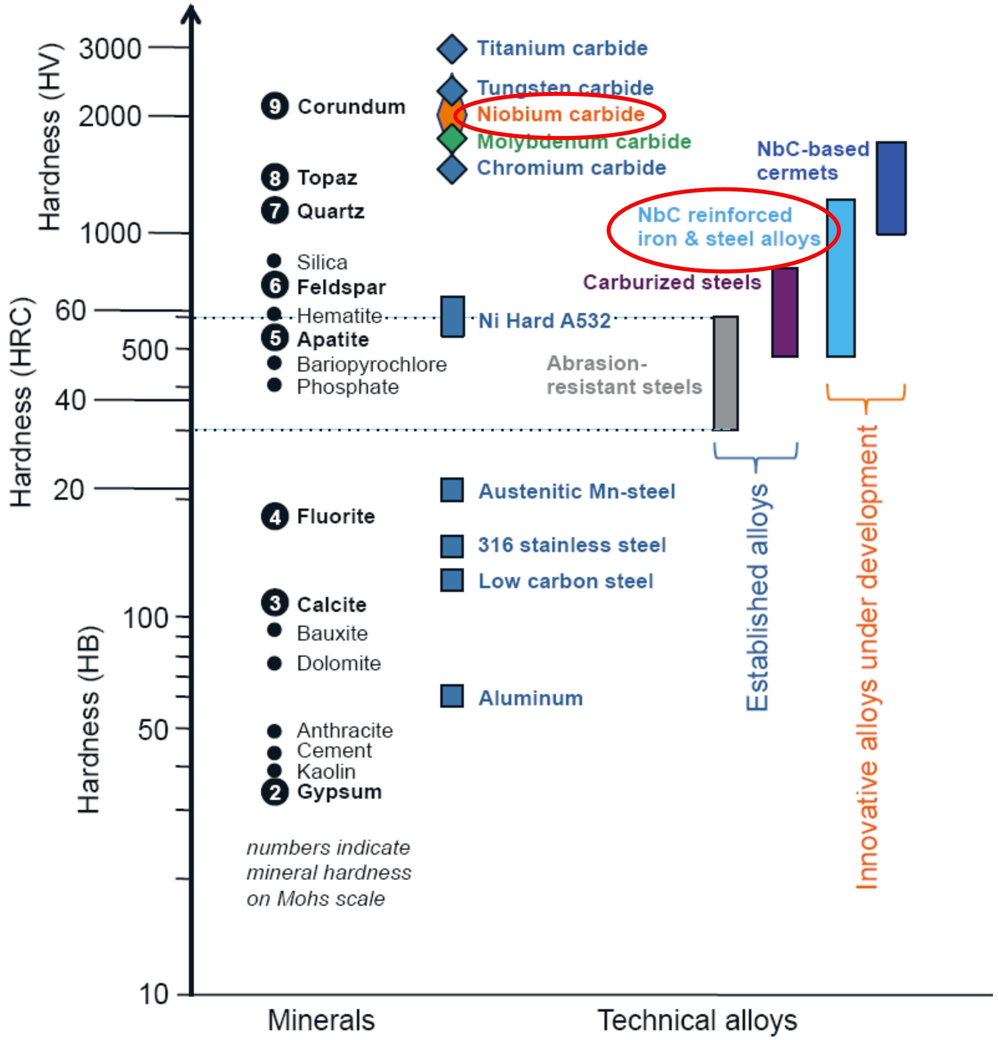
Cr-rich carbides introduced high-Cr (-Mo) WCI

Abrasion-resistant steel (martensitic/austenitic)

Strong (or cubic) carbide formers



Filipovic, 2013



Mohrbacher, 2011

only a narrow range of Nb levels (0.54 to 3.17 wt%), and two base alloys

Abrasive wear testing: Lab *vs* Field

Fact: lab tests do not comply with full scale observations

- → pin abrasion test (PAT) by Albright and Dunn
- → ‘wear gradients’ concept by Blickensderfer
- → poor modelling correlation ($R^2 \geq 60\%$) by Spero *et al.*
- → Jaw Crusher *vs.* Planar Array Field Wear Test by Tylczak *et al.*

Motivation: deficiencies in the predictive ability of ‘standard’ tests

- → Cycling Impact Abrasion Test (CIAT)
- → Impeller-tumbler
- → Jaw Crusher (JC)
- → Ball Mill Abrasion Test (BMAT)
- → Dry Sand – Steel Wheel Abrasion Test (DS-SWAT)
- → Inner Circumference Abrasion Test (ICAT)
- → crushing pin-on-disc

Aim: to simulate industrial condition more realistically

Summary and knowledge gaps

- Wear is an unavoidable industrial problem, leading to huge amount of expenses.
- Abrasive wear is the major wear issue in mining and mineral processing industries (>50%).
- Chromium carbide volume fraction (Cr-CVF) improves the wear resistance but not in high-stress conditions.
- Wear severity and hence carbide micro-fracture are the critical parameters, determining performance of WCIs.
- The type of abrasive mineral can change the severity of the wear.
- **Nb** can improve wear resistance of high-Cr WCIs (dual-reinforcement effect).
- Lab-scale wear tests do not comply with field trial observations (questionable predictive ability).
- Only limited research on Nb addition to WCIs (max 3.5 wt%) and hence the effect of Nb-CVF.
- Very little about methods of physically adding the Nb to the host alloy.

Dual-reinforced alloy development: Series 1D

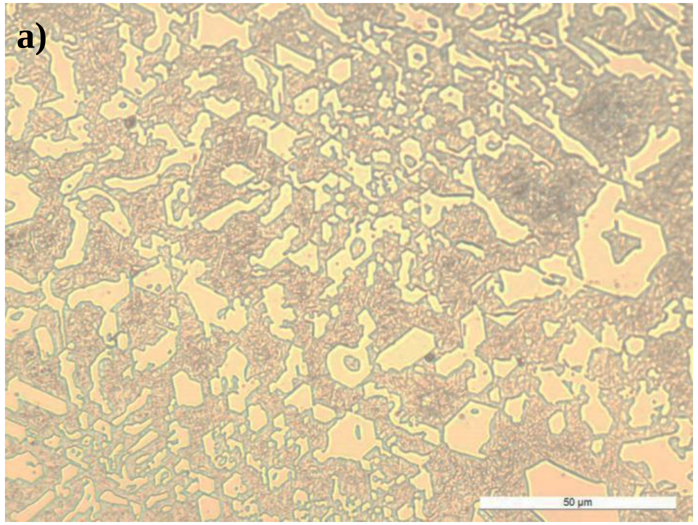
Chemical compositions

Aim: high-Nb WCI with maximum abrasion resistance + sufficient fracture toughness

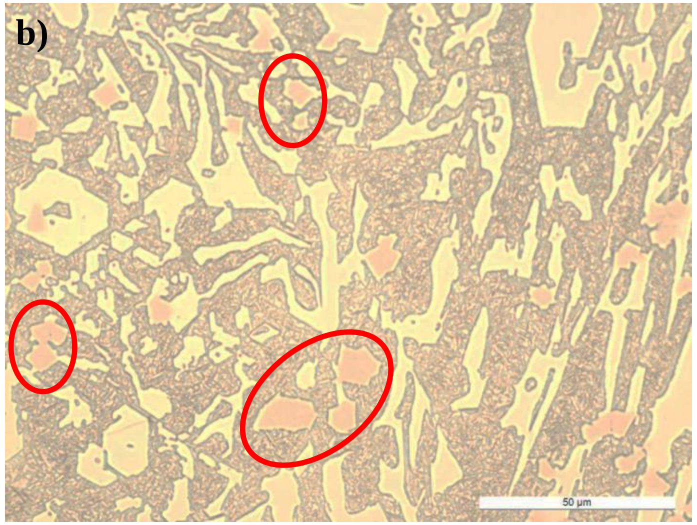
Series 1D: fully eutectic host alloy with Cr-CVF = 37% / Cr/C = 7.1 / Nb-CVF = 0 to 18%

	Planned Alloys – Series 1D											As-cast Alloys – Series 1D											
	Microstructural Features			Chemical Composition								Microstructural Features			Chemical Composition								
CB Code	CrE/C	Cr-CVF	Nb-CVF	C	Cr	Mo	Cu	Mn	Si	Ni	Nb	CrE/C	Cr-CVF	Nb-CVF	C	Cr	Mo	Cu	Mn	Si	Ni	Nb	Al
CB100D	7.1	36.8	**0.0**	3.20	23.00	1.00	0.00	0.90	0.40	0.70	0.00	5.9	42.6	**0.0**	3.71	22.01	0.97	0.00	1.07	0.39	0.94	0.00	0.07
CB101D	7.1	36.9	**1.4**	3.32	22.68	0.99	0.00	0.89	0.39	0.69	1.28	6.8	38.1	**1.3**	3.42	22.59	0.86	0.00	1.21	0.47	0.69	1.15	0.03
CB102D	7.1	36.9	**3.0**	3.46	22.31	0.97	0.00	0.87	0.39	0.68	2.73	6.2	40.6	**2.7**	3.77	21.48	0.90	0.00	0.92	0.37	0.75	2.46	0.07
CB103D	7.1	36.9	**5.0**	3.63	21.85	0.95	0.00	0.86	0.38	0.67	4.56	6.1	40.3	**4.7**	3.92	20.77	0.86	0.00	0.85	0.41	0.69	4.29	0.05
CB104D	7.1	36.9	**7.0**	3.80	21.39	0.93	0.00	0.84	0.37	0.65	6.38	6.9	36.9	**6.8**	3.81	20.90	0.89	0.00	0.82	0.42	0.61	6.23	0.14
CB106D♣	7.1	37.0	**11.6**	4.20	20.33	0.88	0.00	0.80	0.35	0.62	10.57	6.1	42.0	**8.0**	4.29	20.46	0.90	0.00	1.04	0.62	0.68	7.25	0.43
CB105D	7.1	37.0	**9.0**	3.97	20.93	0.91	0.00	0.82	0.36	0.64	8.20	6.9	38.2	**9.0**	4.07	20.87	0.89	0.00	0.95	0.50	0.59	8.23	0.18
CB106P♣	7.1	37.0	**11.6**	4.20	20.33	0.88	0.00	0.80	0.35	0.62	10.57	7.4	36.1	**11.4**	4.10	20.71	0.69	0.00	0.73	0.60	0.50	10.41	0.21
CB107D	7.1	37.1	**14.7**	4.45	19.64	0.85	0.00	0.77	0.34	0.60	13.30	6.5	38.7	**12.8**	4.45	19.38	0.83	0.00	1.06	0.69	0.57	11.68	0.51
CB108D	7.1	37.2	**18.1**	4.74	18.86	0.82	0.00	0.74	0.33	0.57	16.40	6.5	39.4	**17.9**	4.91	18.36	0.75	0.00	0.90	0.61	0.36	16.32	0.80

Series 1D: Microstructure & Hardness



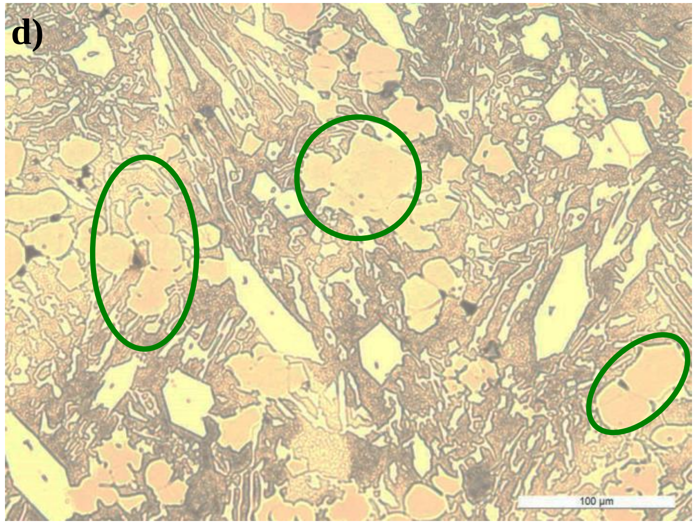
CB100D (0.0 vol% NbC, 42.6 vol% M_7C_3)



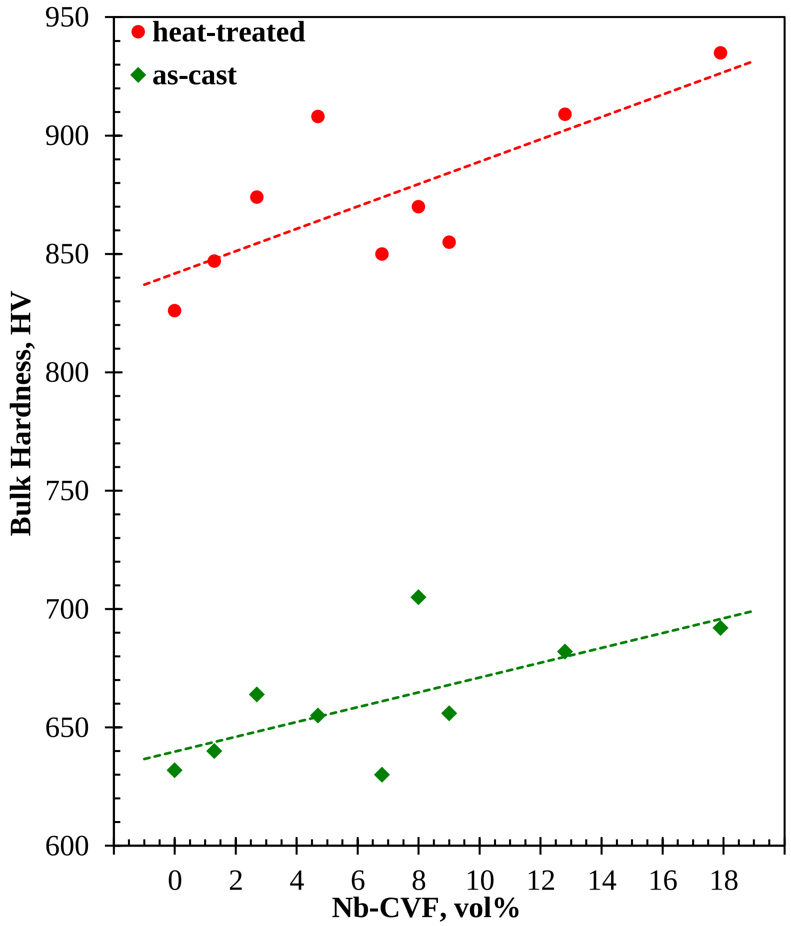
CB103D (4.7 vol% NbC, 40.3 vol% M_7C_3)

No M_7C_3 refinement

CB107D (12.8 vol% NbC, 38.7 vol% M_7C_3)



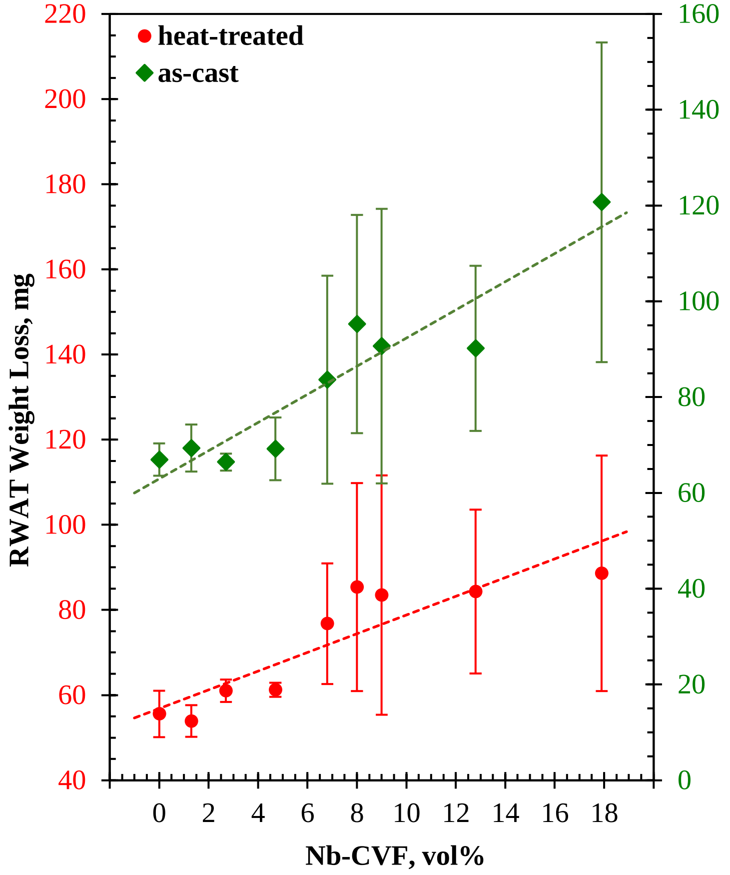
CB108D (17.9 vol% NbC, 39.4 vol% M_7C_3)

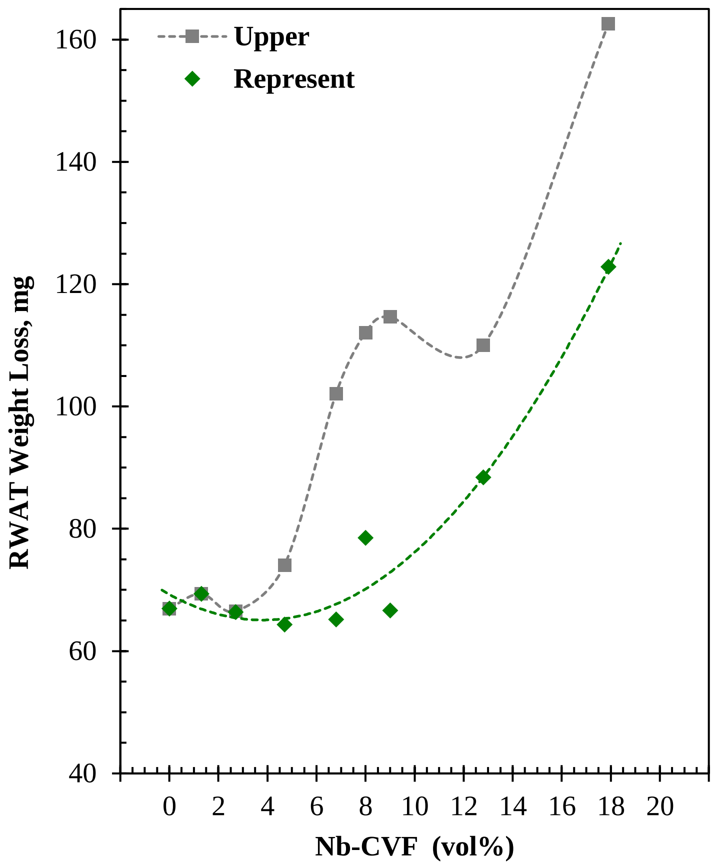


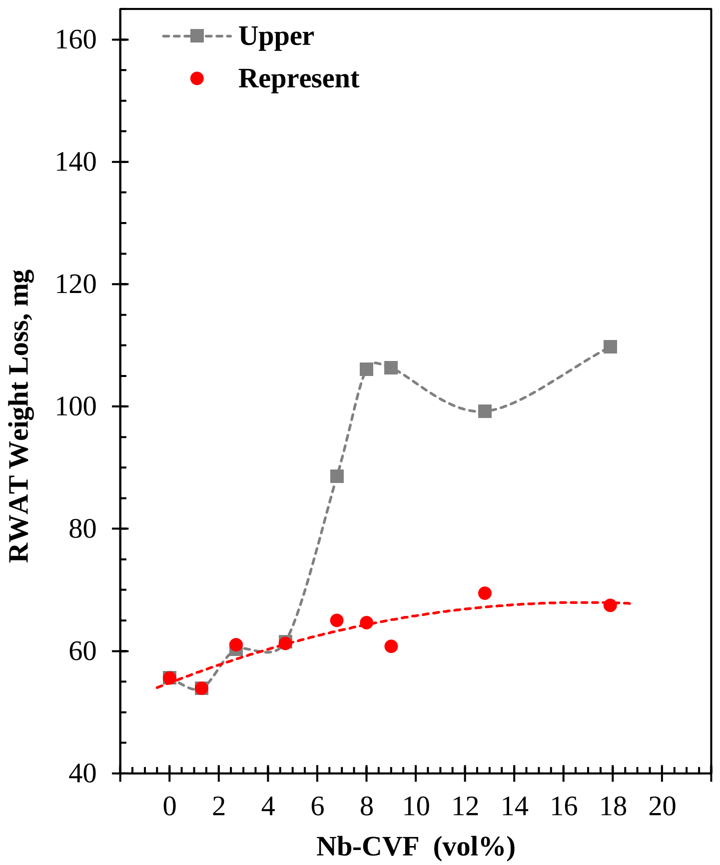
Hardness (HV30):

Nb-CVF ↑ ⇒ Bulk Hardness ↑

Series 1D: Abrasive wear performance





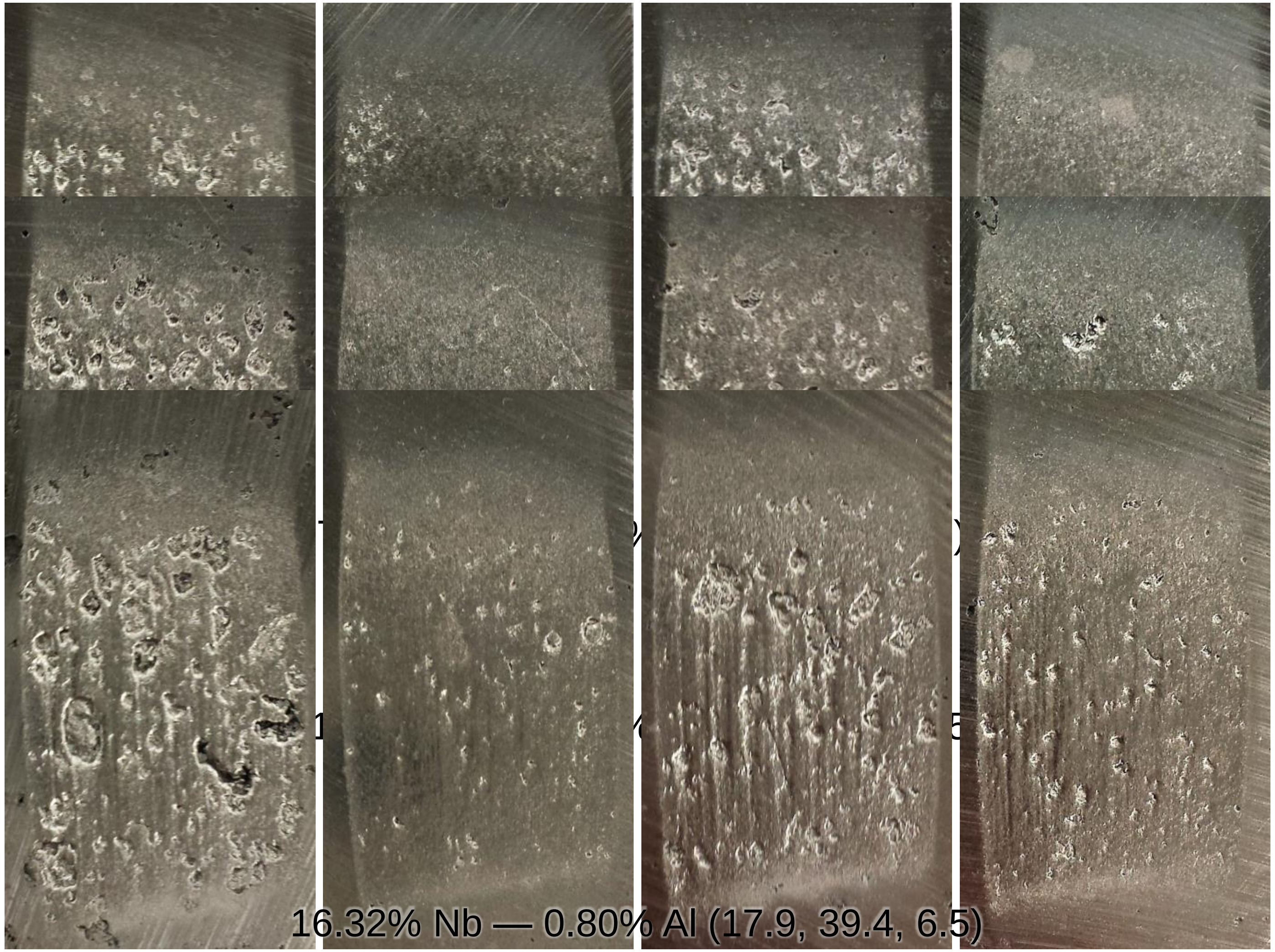


Dry Sand – Rubber Wheel Abrasion Test (DS-RWAT)

Nb-CVF ↑ ⇒ RWAT weight loss ↑ ⇒ LSA wear resistance ↓

Series 1D: Abrasive wear performance

Wear scars after DS-RWAT

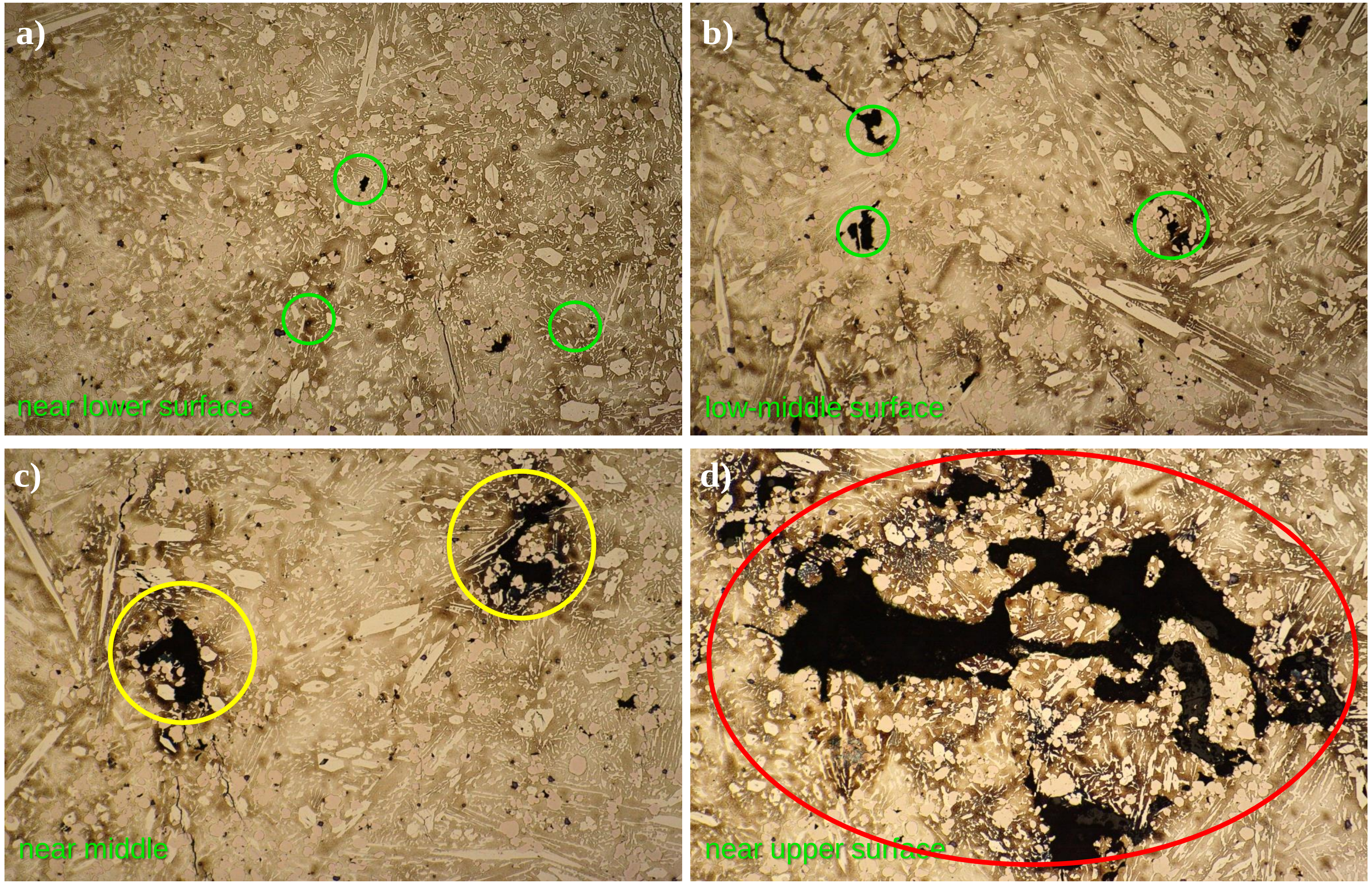


CB108D, Spc 1, Upper face | CB108D, Spc 1, lower face | CB108D, Spc 2, Upper face | CB108D, Spc 2, lower face

Series 1D: Abrasive wear performance

Microstructure of CB107D

gradient of porosity

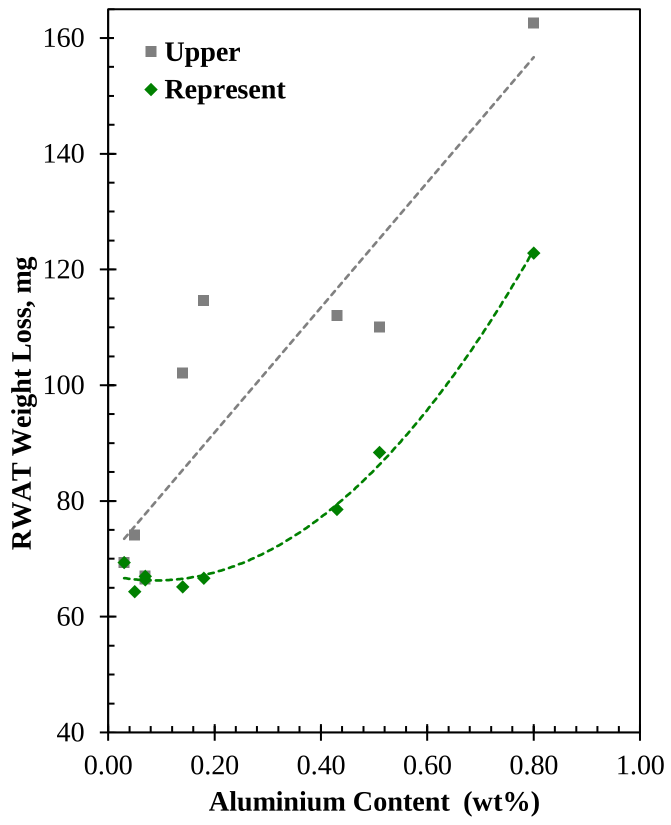


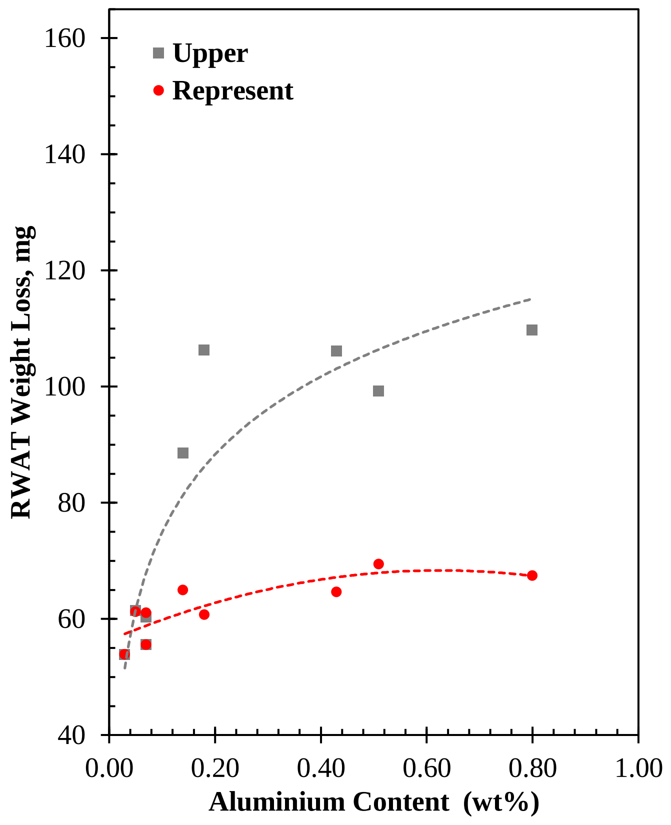
Series 1D: Abrasive wear performance

Al hypothesis — Nb feedstock

Hypothesis: Casting defects are a result of the high Al content of the FeNbC.

Proposal: Attempt to remove this tramp Al in the next alloy series (Series 3D).





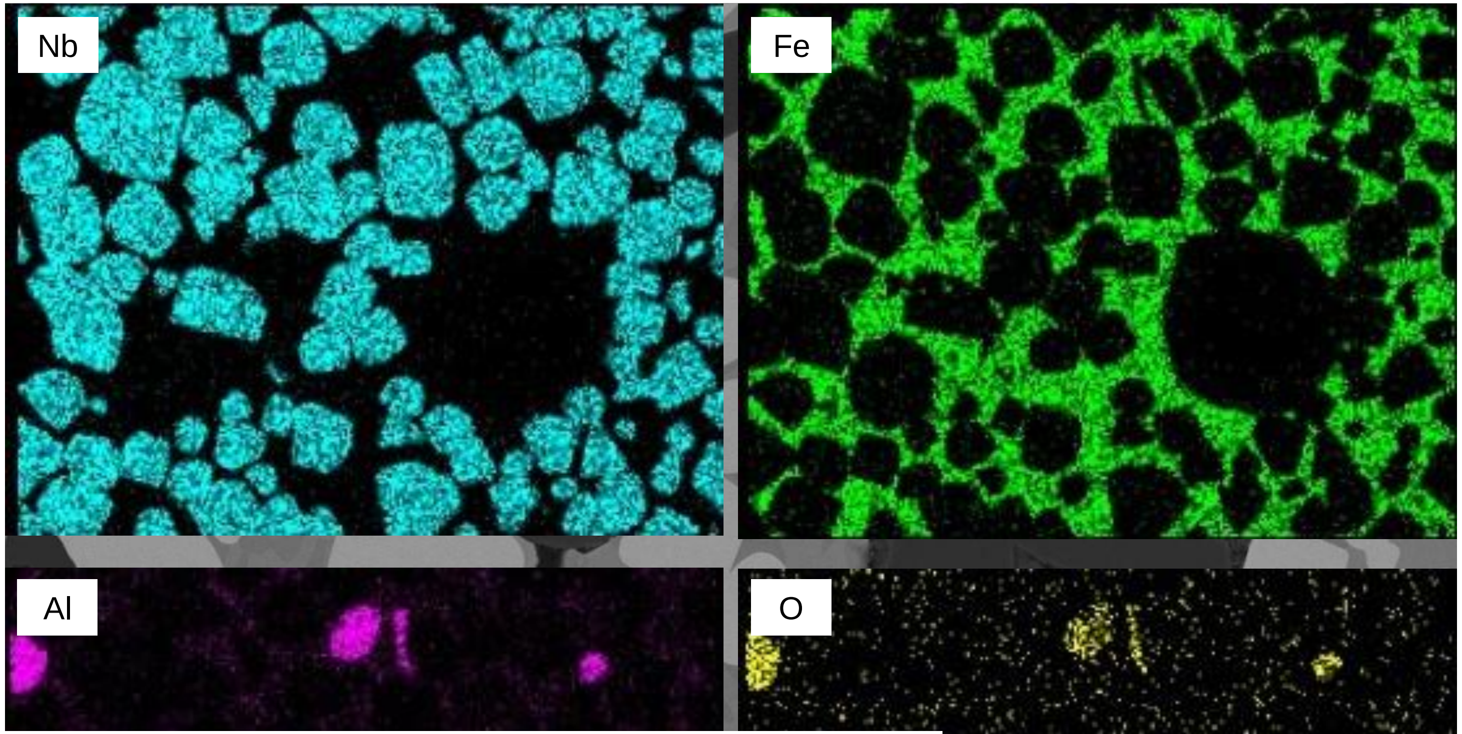
Chemical composition of the FeNbC master alloy.

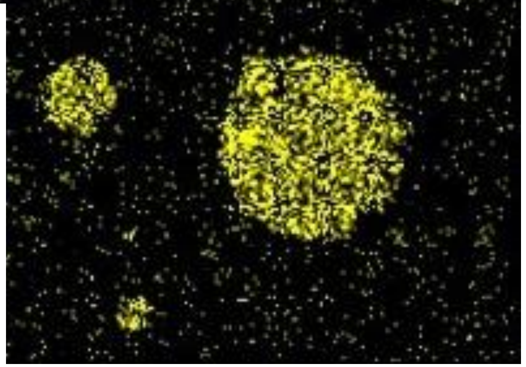
Element	Fe	Nb	C	Al	S	Si	Ta
wt%	39.8	47.4	7.09	3.64	0.038	<0.50	<0.10

Series 1D: Abrasive wear performance

Al hypothesis — Nb feedstock

Closer Look!





Proportion of available Al from FeNbC transferred to castings.

	FeNbC	CB100D	CB101D	CB102D	CB103D	CB104D	CB105D	CB106D	CB107D	CB108D	CB106P
Nb (wt%)	**47.4**	0.00	1.28	2.46	4.29	6.23	8.23	7.25	11.68	16.32	10.41
Al (wt%)	**3.64**	0.07	0.03	0.07	0.05	0.14	0.18	0.43	0.51	0.80	0.21
Transfer Yield			26%	32%	13%	25%	25%	67%	49%	55%	23%

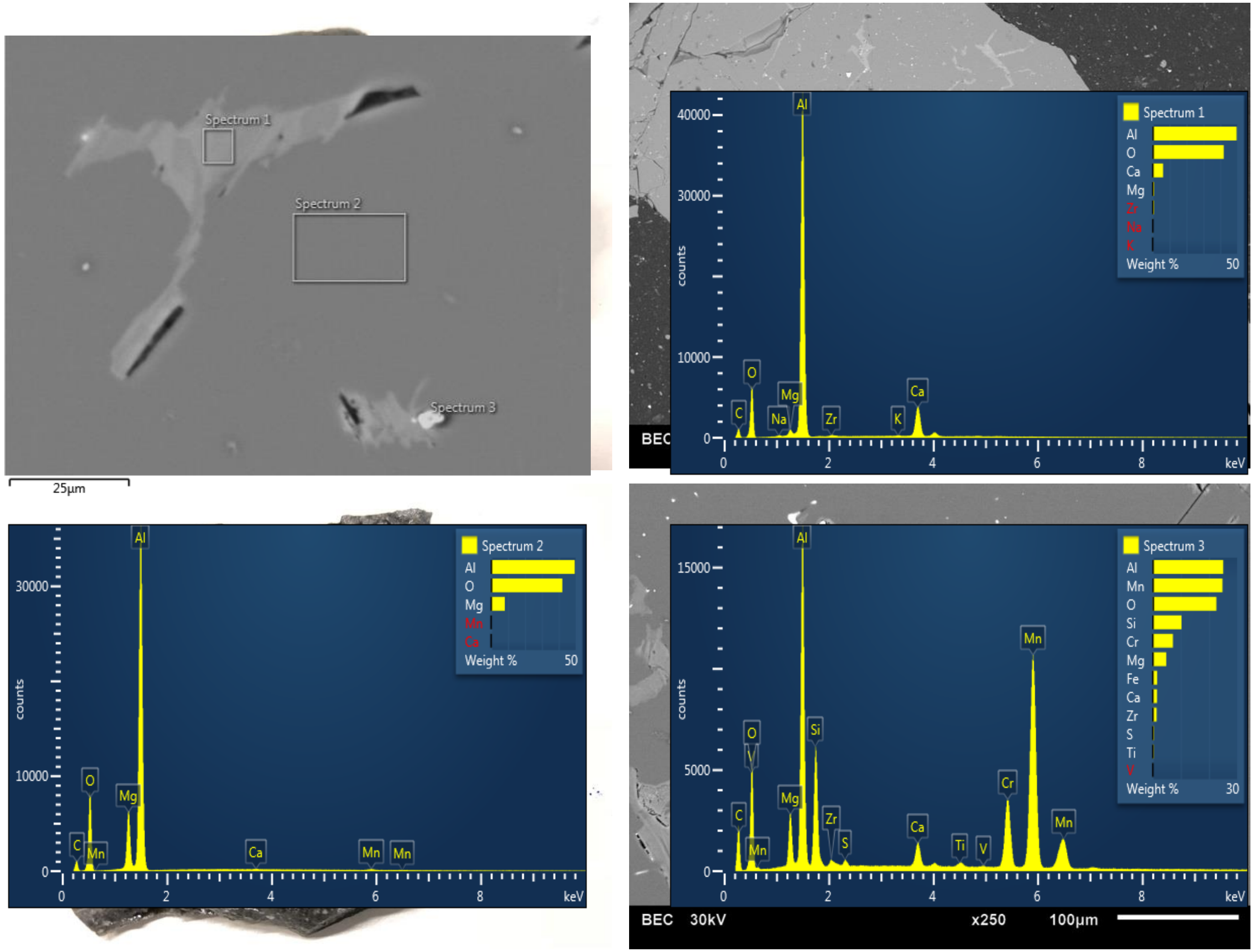
Series 1D: Abrasive wear performance

Al hypothesis — Crust sample analysis

NOTES:

i) it might be assumed that Al of the FeNbC is the source of this crust but the amount of FeNbC (with 4% Al) is not sufficient to provide the amount of crust collected.

ii) The absence of Nb from the crust is obvious.



Series 3D: Experimental trials

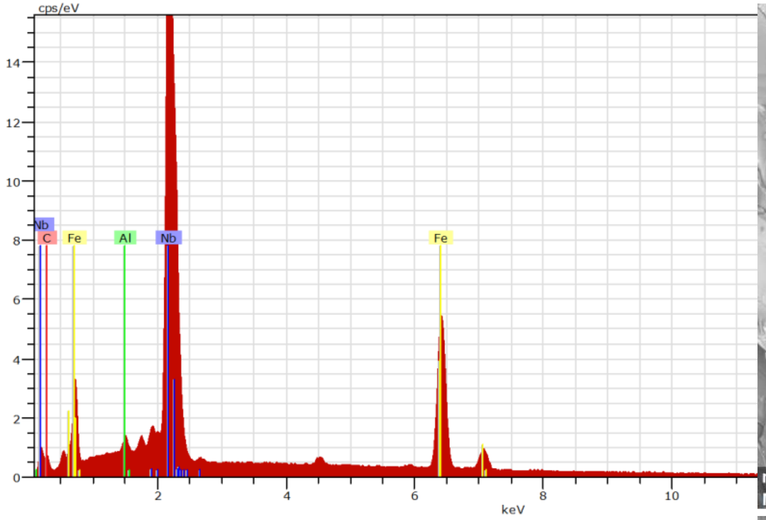
FeNb vs FeNbC — an alternative feedstock

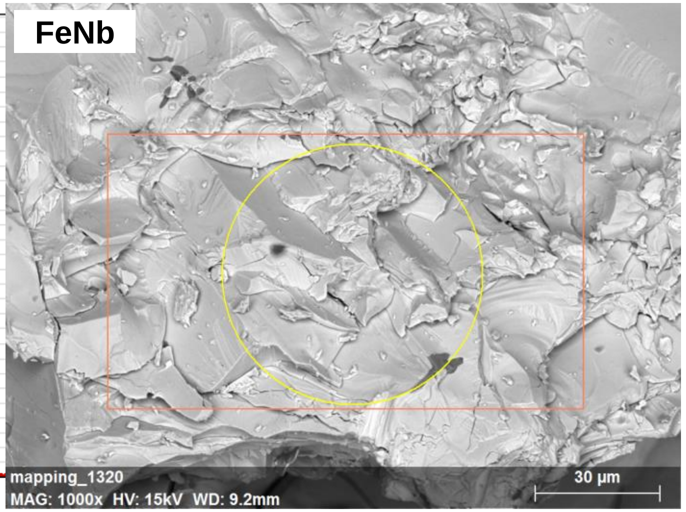
Attempted to understand the effect of Al, by deliberately manipulating its levels:

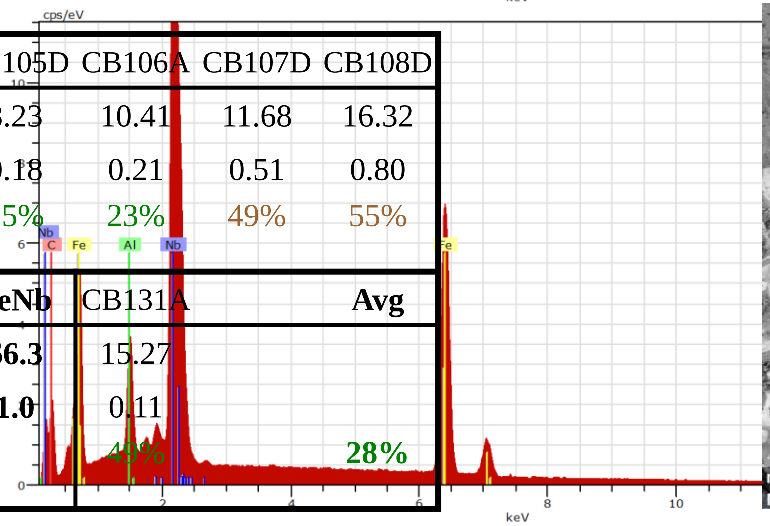
a) Addition of Al (CB123Al)

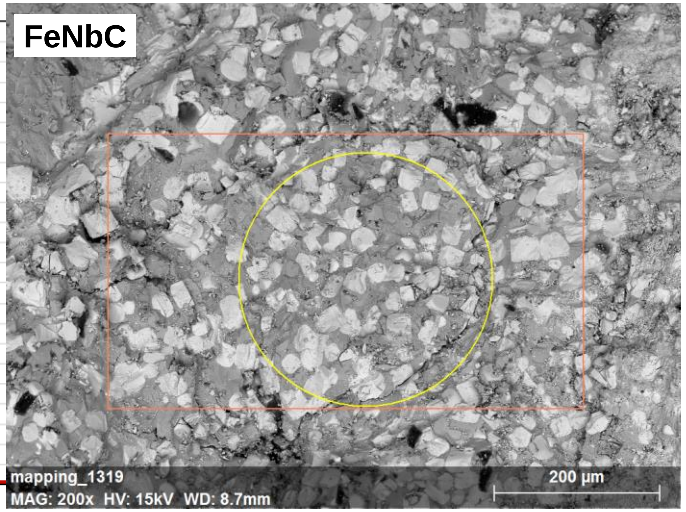
b) Oxidization of Al (CB128A)

c) Changing the Nb-feedstock (CB131A)









	Fe-NbC	CB101	CB102	CB103D	CB104D	CB106D	CB105D	CB106A	CB107D	CB108D
Nb (wt%)	**47.3**	1.28	2.46	4.29	6.23	7.25	8.23	10.41	11.68	16.32
Al (wt%)	**4.2**	0.03	0.07	0.05	0.14	0.43	0.18	0.21	0.51	0.80
Proportional Transfer		26%	32%	13%	25%	67%	25%	23%	49%	55%
	Fe-NbC	CB124	CB125	CB126D	CB128D	CB128A	**FeNb**	CB131A		**Avg**
Nb (wt%)	**47.3**	1.20	2.72	4.58	8.30	9.42	**66.3**	15.27		
Al (wt%)	**4.2**	0.00	0.01	0.05	0.17	0.08	**1.0**	0.11		
Proportional Transfer		1%	5%	13%	23%	10%		49%		**28%**

Dual-reinforced alloy development: Series 3D

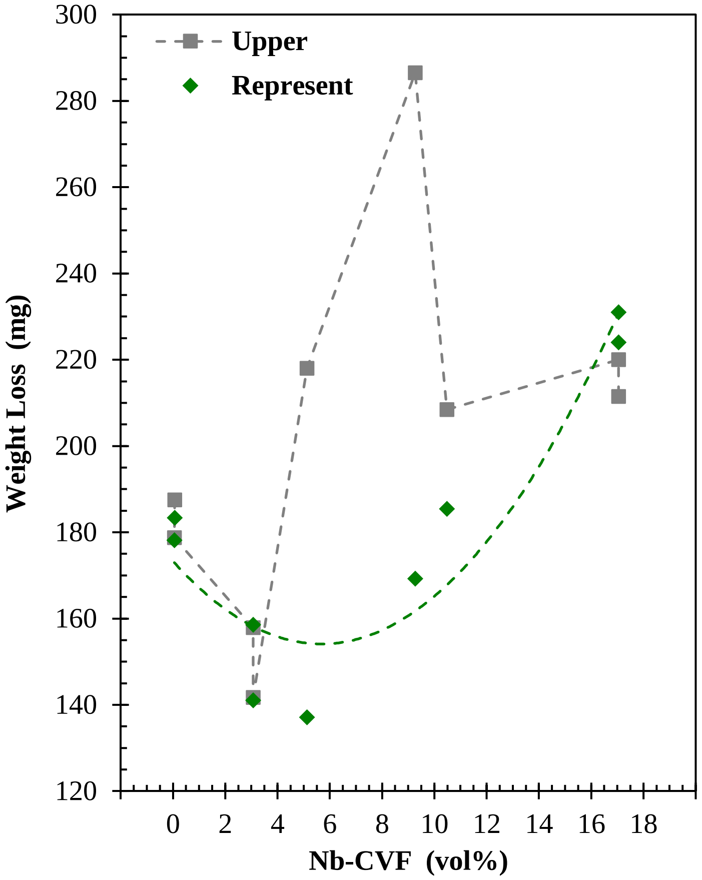
Chemical compositions

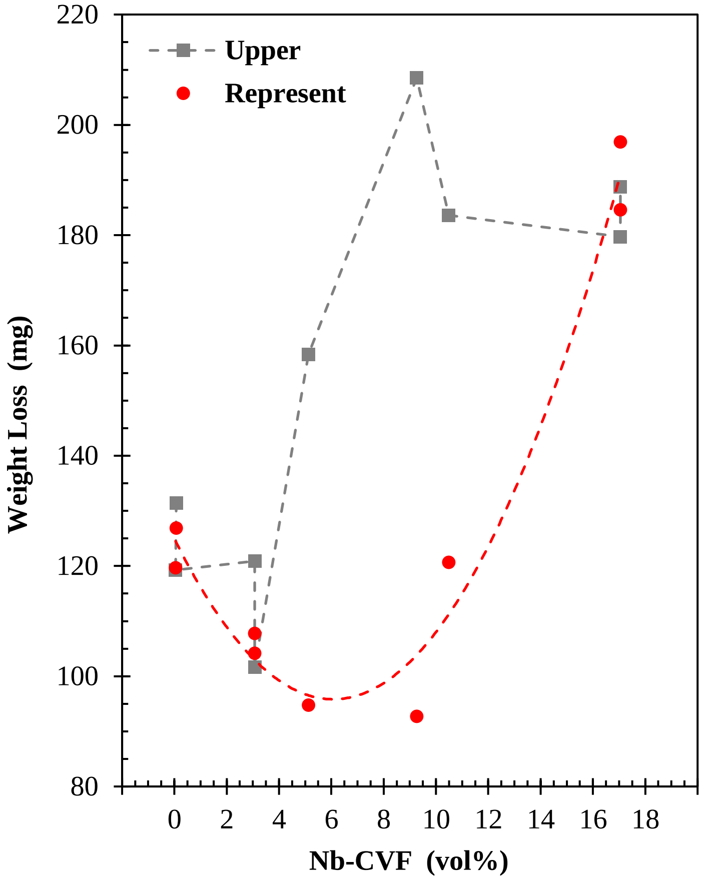
Aim: high-Nb WCI with maximum abrasion resistance + sufficient fracture toughness

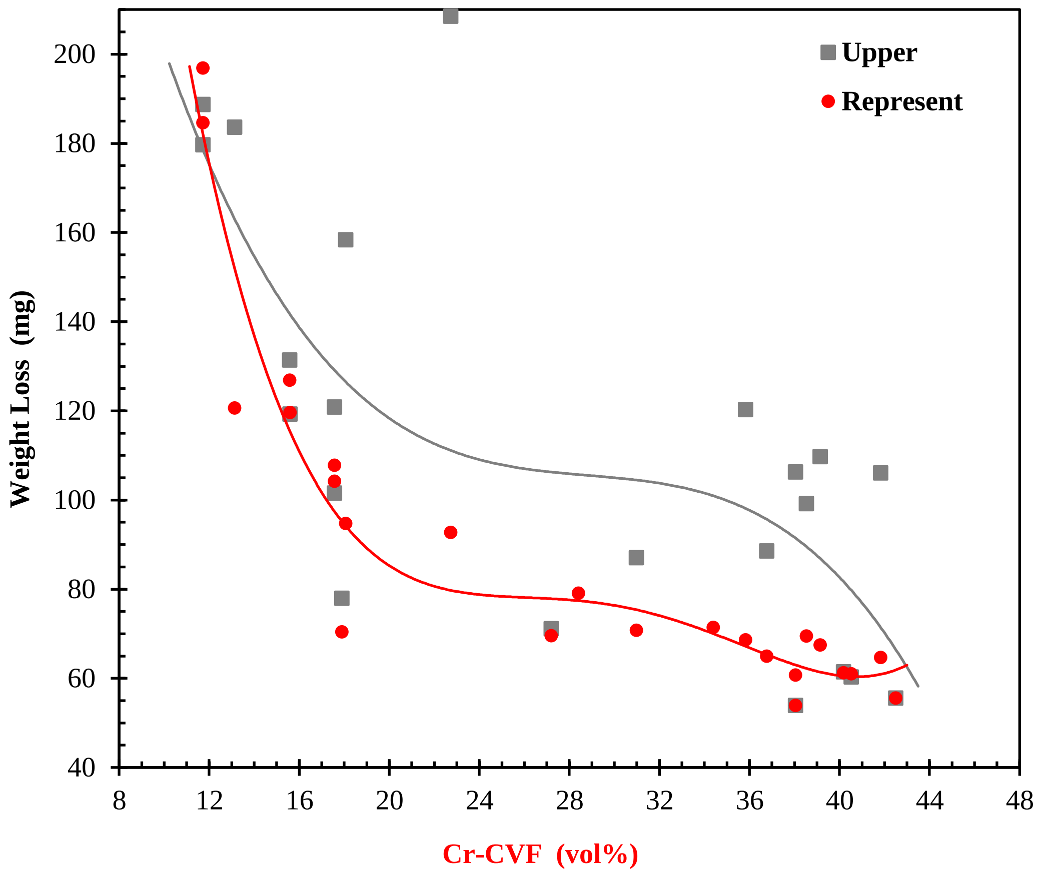
Series 3D: hypo-eutectic host alloy with Cr-CVF = 20% / Cr/C = 9.5 / Nb-CVF = 0 to 18%

	Planned Alloys – Series 3D											As-cast Alloys – Series 3D											
	Microstructural Features			Chemical Composition								Microstructural Features			Chemical Composition								
CB Code	**CrE/C**	**Cr-CVF**	**Nb-CVF**	**C**	**Cr**	**Mo**	**Cu**	**Mn**	**Si**	**Ni**	**Nb**	**CrE/C**	**Cr-CVF**	**Nb-CVF**	**C**	**Cr**	**Mo**	**Cu**	**Mn**	**Si**	**Ni**	**Nb**	**Al**
CB123	9.5	19.8	**0.0**	1.99	19.00	1.05	0.00	0.95	0.50	0.70	0.00	10.4	15.6	**0.1**	1.71	17.94	0.87	0.02	0.74	0.31	0.75	0.00	0.00
CB123Al												10.2	15.6	**0.1**	1.72	17.74	0.86	0.02	0.73	0.31	0.76	0.00	0.98
CB124	9.5	19.8	**1.4**	2.13	18.73	1.04	0.00	0.94	0.49	0.69	1.28	9.5	17.6	**3.1**	2.03	17.46	0.95	0.04	0.85	0.43	0.77	1.20	0.00
CB125	9.5	19.8	**3.0**	2.29	18.43	1.02	0.00	0.92	0.49	0.68	2.73	9.5	17.6	**3.1**	2.17	17.35	0.87	0.05	0.73	0.44	0.59	2.72	0.01
CB126D	9.5	19.8	**5.0**	2.48	18.05	1.00	0.00	0.90	0.48	0.67	4.56	9.1	18.1	**5.1**	2.42	16.70	1.00	0.04	0.83	0.62	0.59	4.58	0.05
CB127	9.5	19.8	**8.0**	2.78	17.48	0.97	0.00	0.87	0.46	0.64	7.29												
CB128D	9.5	19.9	**9.0**	2.87	17.29	0.96	0.00	0.86	0.46	0.64	8.20	6.8	22.7	**9.3**	3.23	14.69	0.96	0.05	0.89	0.52	0.46	8.30	0.17
CB128A												12.3	13.1	**10.5**	2.56	16.39	0.92	0.10	0.99	0.45	0.43	9.42	0.08
CB129	9.5	19.9	**11.5**	3.12	16.82	0.93	0.00	0.84	0.44	0.62	10.48												
CB130	9.5	19.9	**13.8**	3.33	16.40	0.91	0.00	0.82	0.43	0.60	12.48												
CB131A	9.5	20.0	**18.1**	3.75	15.58	0.86	0.00	0.78	0.41	0.57	16.40	12.6	11.7	**17.1**	3.17	14.63	0.81	0.08	0.80	0.57	0.33	15.27	0.11

Series 3D: Abrasive wear performance







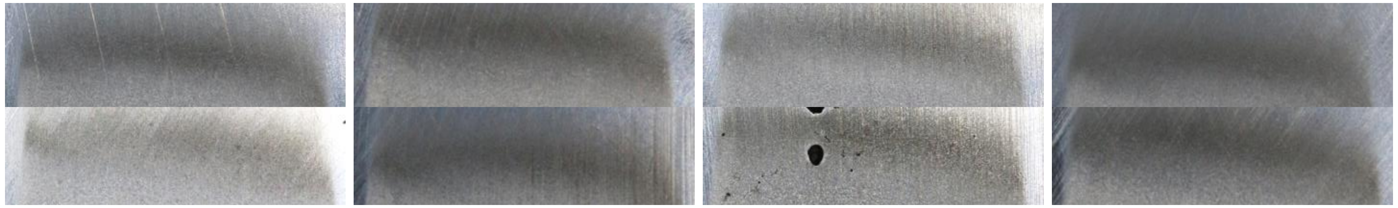
Series 3D: Some success in reducing tramp Al **but** NO success in reducing vertical segregation

All Series 1D & 3D alloys
(various levels of Nb-CVF BUT…)

Series 3D: Abrasive wear performance

Wear scars after DS-RWAT

U/L Differential for all alloys

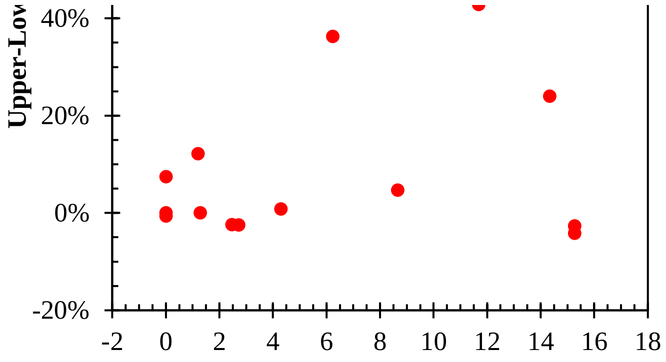


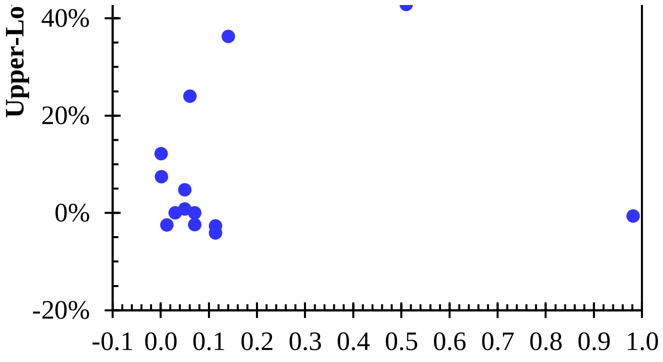
Wrong Hypothesis:

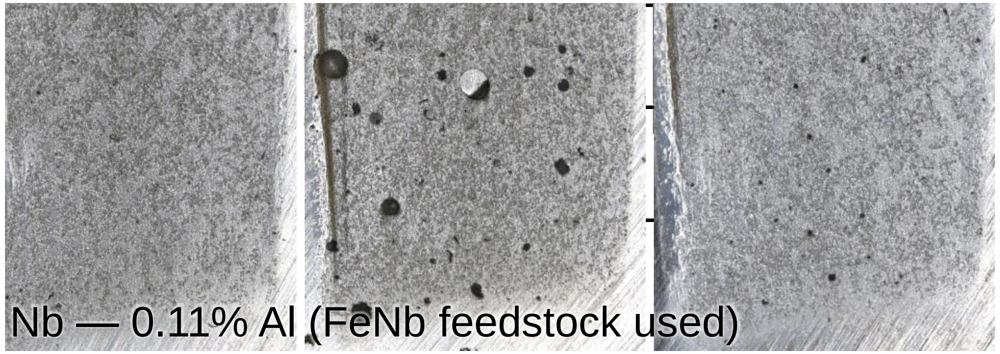
Al is **NOT** the sole cause of the poor performance of high-Nb WCIs.

Question:

Is NbC really beneficial in abrasive wear applications?







131A1, Spc 1, lower face   CB131A1, Spc 2, Upper face   CB131A1, Spc 2, lower face

Mechanistic studies

Questions:

Q1A. Are NbCs proud of the matrix? →

Q1B. Are NbCs proud of the M7C3? →

Q2. Do NbCs show signs of micro-fractur

Q3. Do NbCs suffer micro-fracture? What

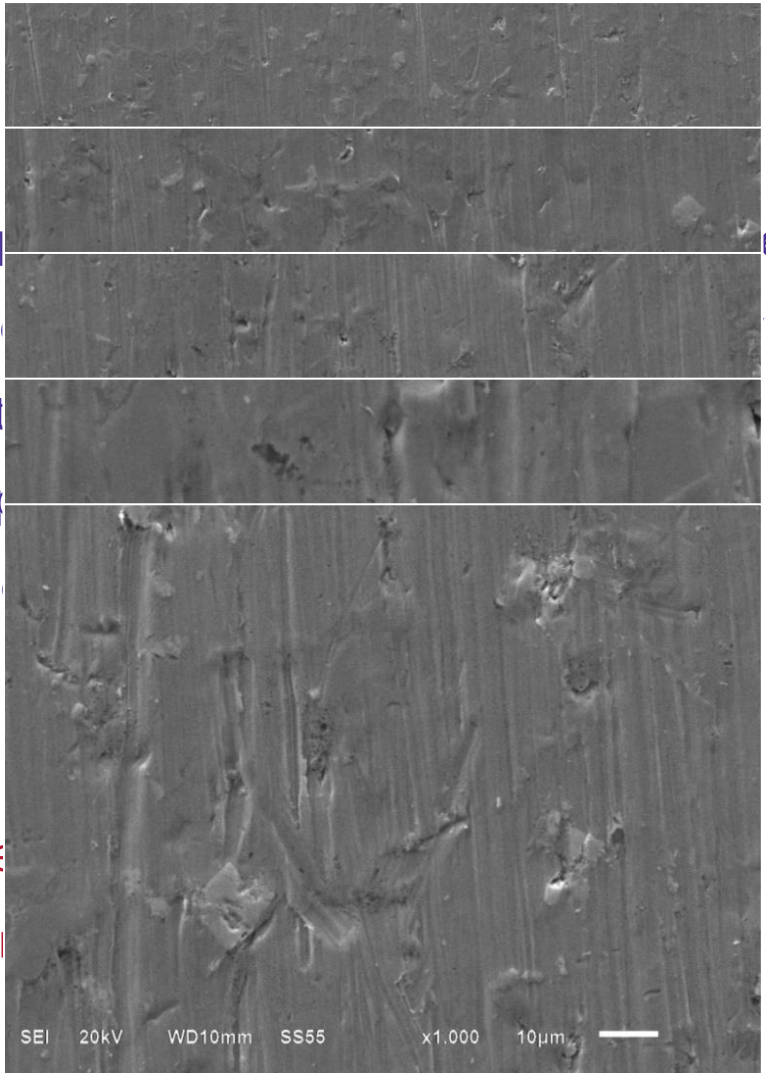
Q4. Do NbCs & M7C3 show different prop

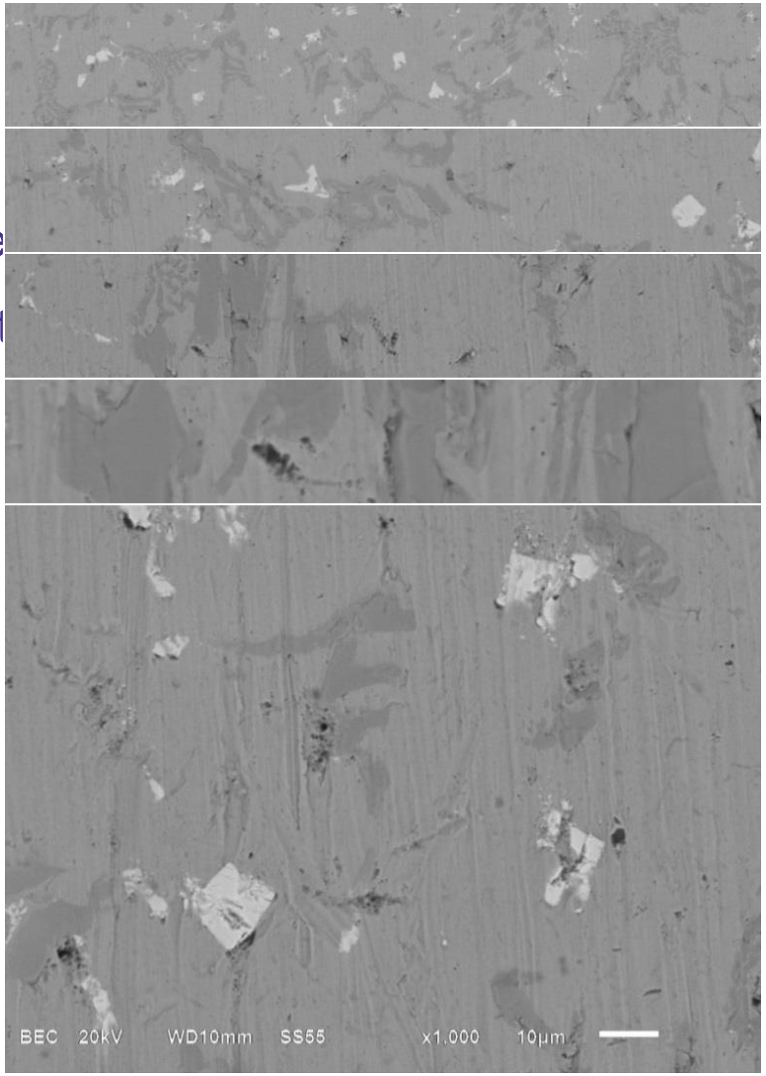
→ The difference is related to th

Outcomes:

YES. NbC particles show a protective effe

So many conclusions should not be draw

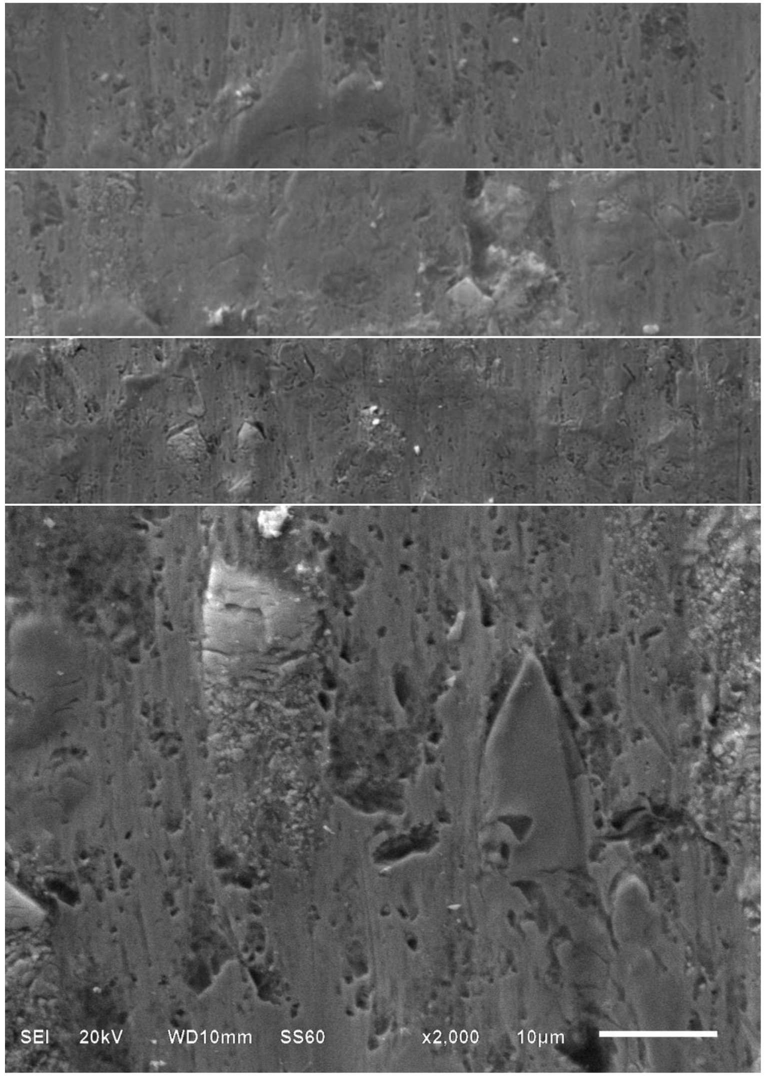


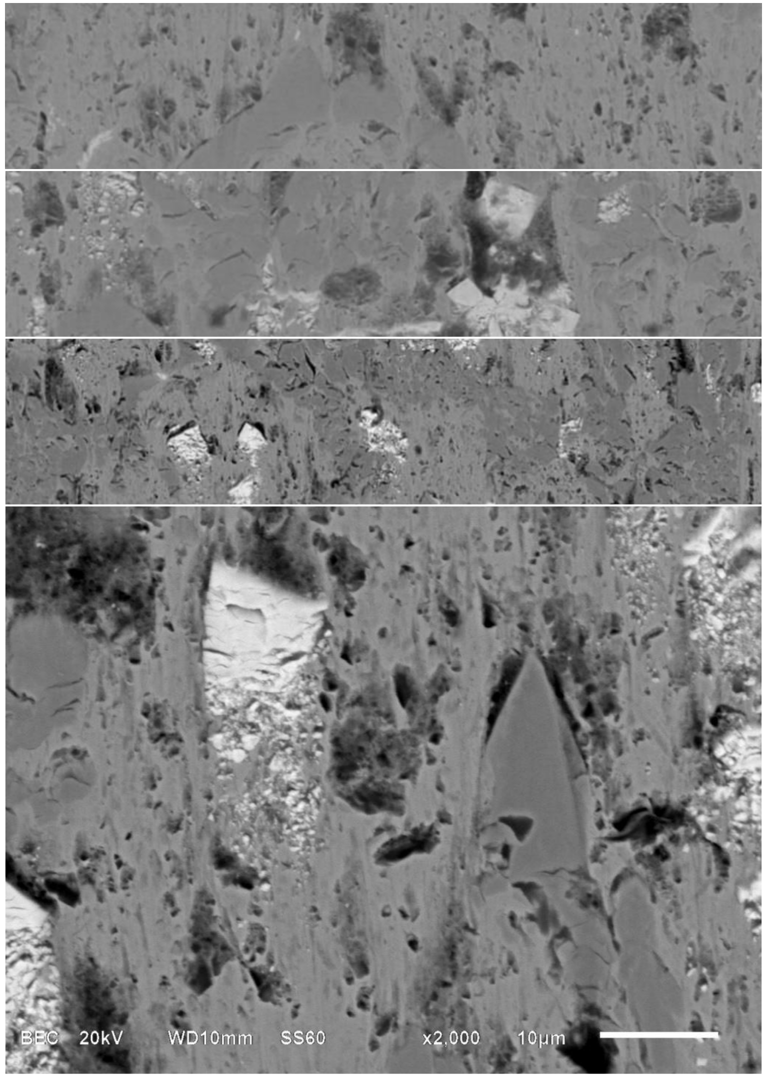


Mechanistic studies

CB126D (5%NbC, 18%M_7C_3, 0.05%Al)

Face L – Med Duration



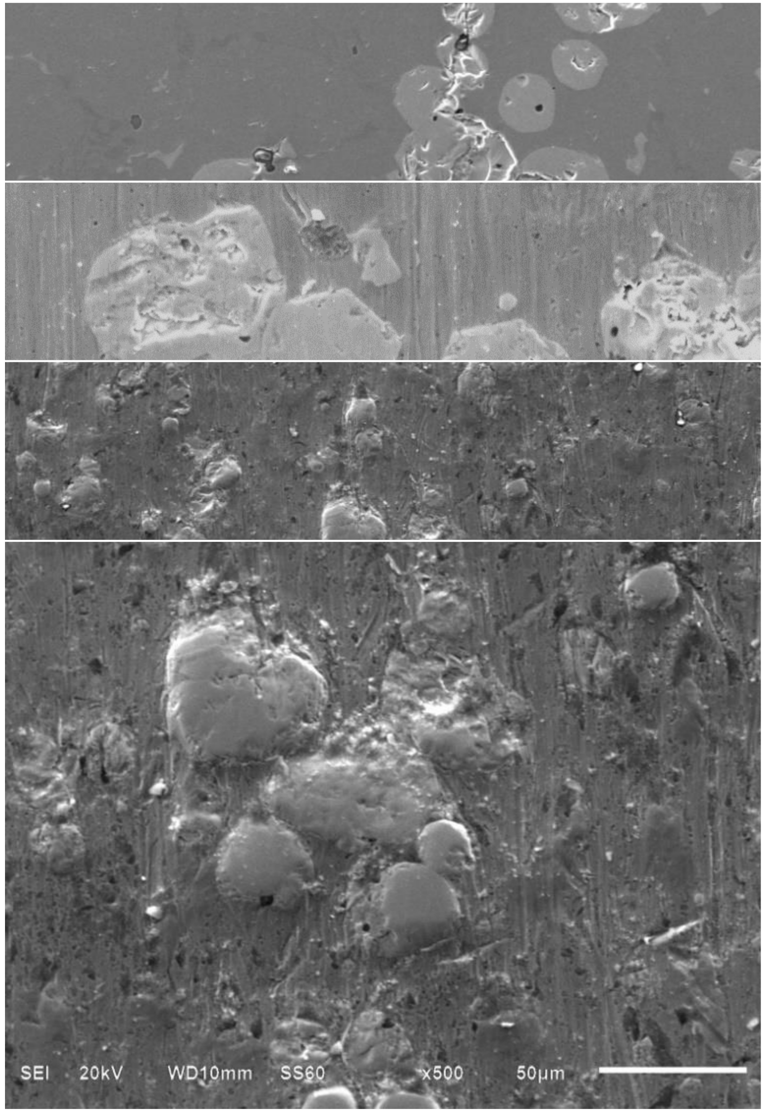


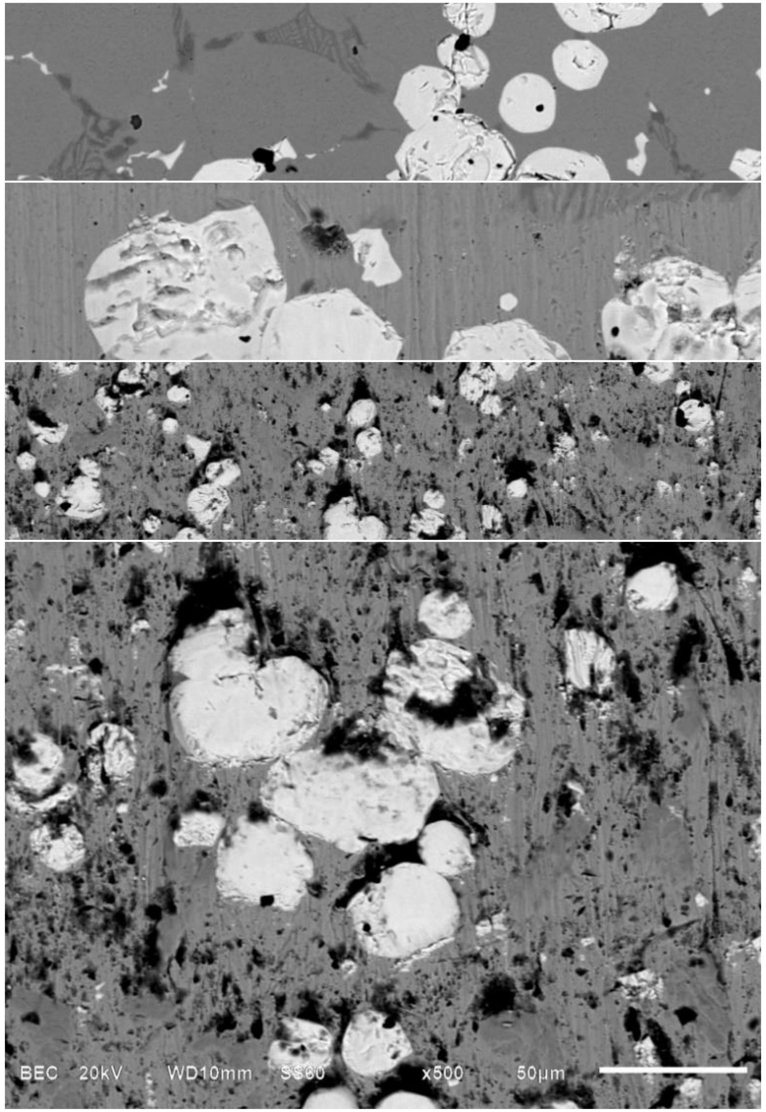
Mechanistic studies

CB131A (No U/L differential)

(17%NbC, 12%M7C3, 0.11%Al, Cr/C = 12.6)

Face L – Polished vs VSDA





In-house casting

Decision:

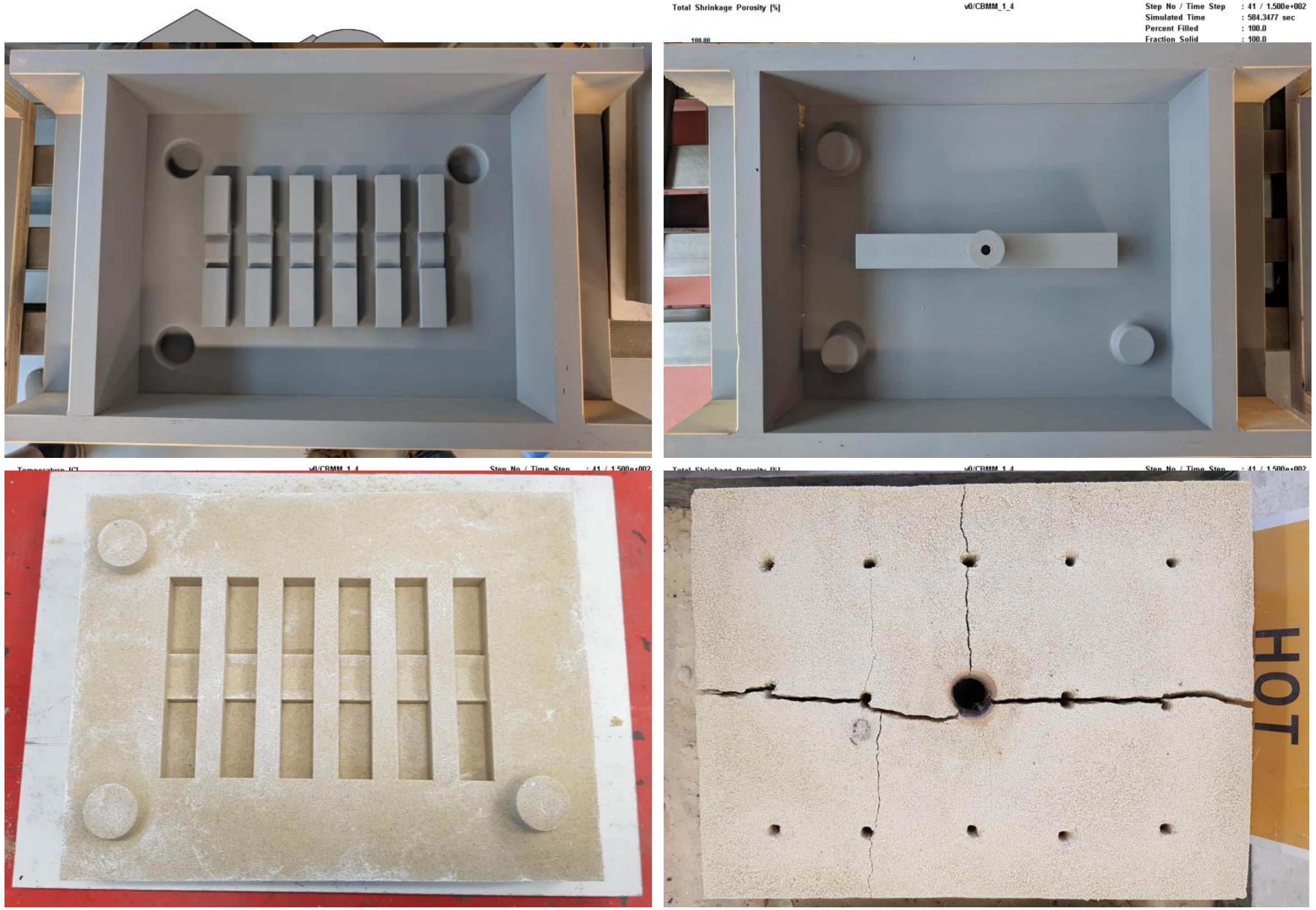
To shift the melting program from external partner foundry to UQ.

Pattern design,

Solidification modelling,

Wooden pattern (cope and drag),

Prepared mould



In-house casting

Crucibles and Coating Materials

Refractory reaction hypothesis:
A WCI melt with 12% Nb added (FeNbC) aggressive thermo-chemical reactions with aluminosilicate crucible.

Zircoat: NO visible reaction occurred (even when the required superheat for full dissolution of the FeNbC) and NO significant defects in the casting!

In-house casting

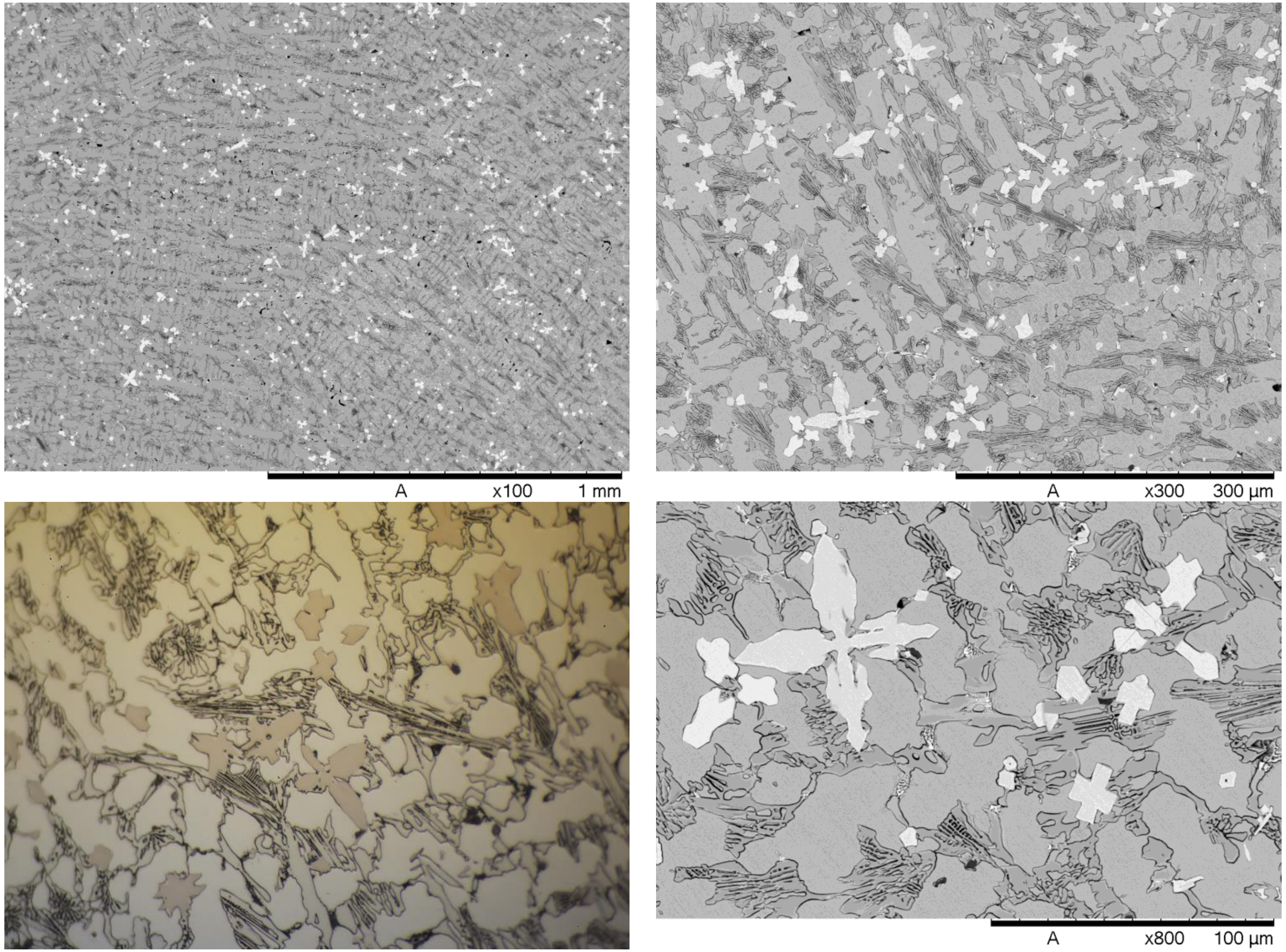
First-phase trials:

1. Bare Crucible + 3.5kg 15.3 WCI
2. Double Zircoat Al_2O_3 Crucible + 3.2kg 15.3 WCI
3. Triple Zircoat Al_2O_3 Crucible + 2.4kg 15.3 WCI + 0.6kg FeNbC
4. Bare Al_2O_3 Crucible + 3.0kg 15.3 WCI + 50%50% NbC
5. Double Zircoat Al_2O_3 Crucible + 2.4kg 15.3 WCI + 0.6kg FeNbC
6. **Double Zircoat Al_2O_3 Crucible + 3.5kg 15.3 WCI + 506g FeNbC SF6 Ar**
7. Double Zircoat Al_2O_3 Crucible + 3.6kg 15.3 WCI + 366g **FeNb** + 80g C SF6 A

In-house casting

SUCCESS!

LML #6 — most of the NbCs are not the usual cuboid particles but instead a petal-like morphology (Chinese Script).



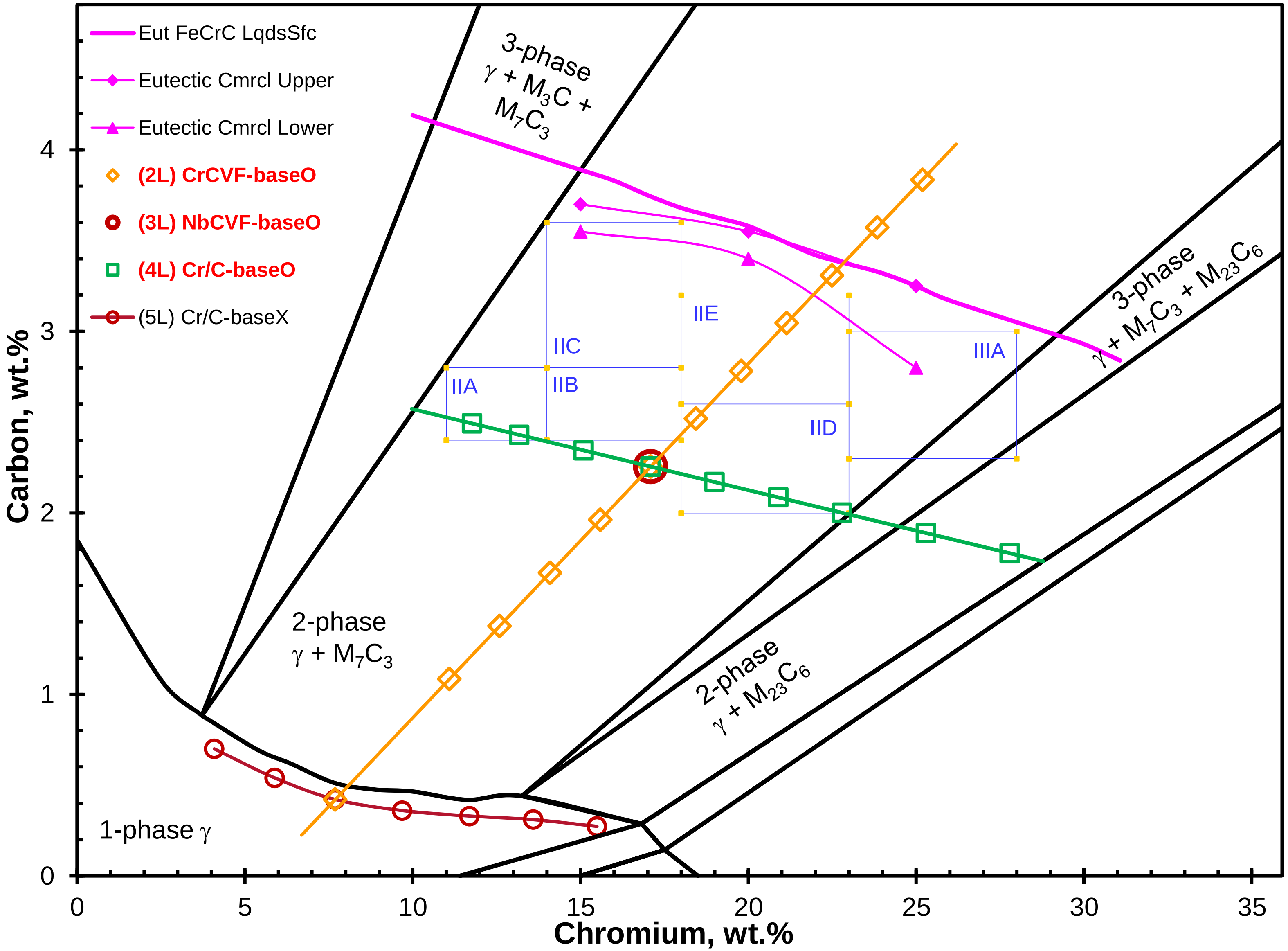
In-house production of systematic alloy series

Experimental Design:

(2L) Cr-CVF Series (7 vol% NbC, Cr/E ~7)

(3L) Nb-CVF Series (22 vol% M_7C_3, Cr/E ~7)

(4L) Cr/C Series (7 vol% NbC, 22 vol% M_7C_3)

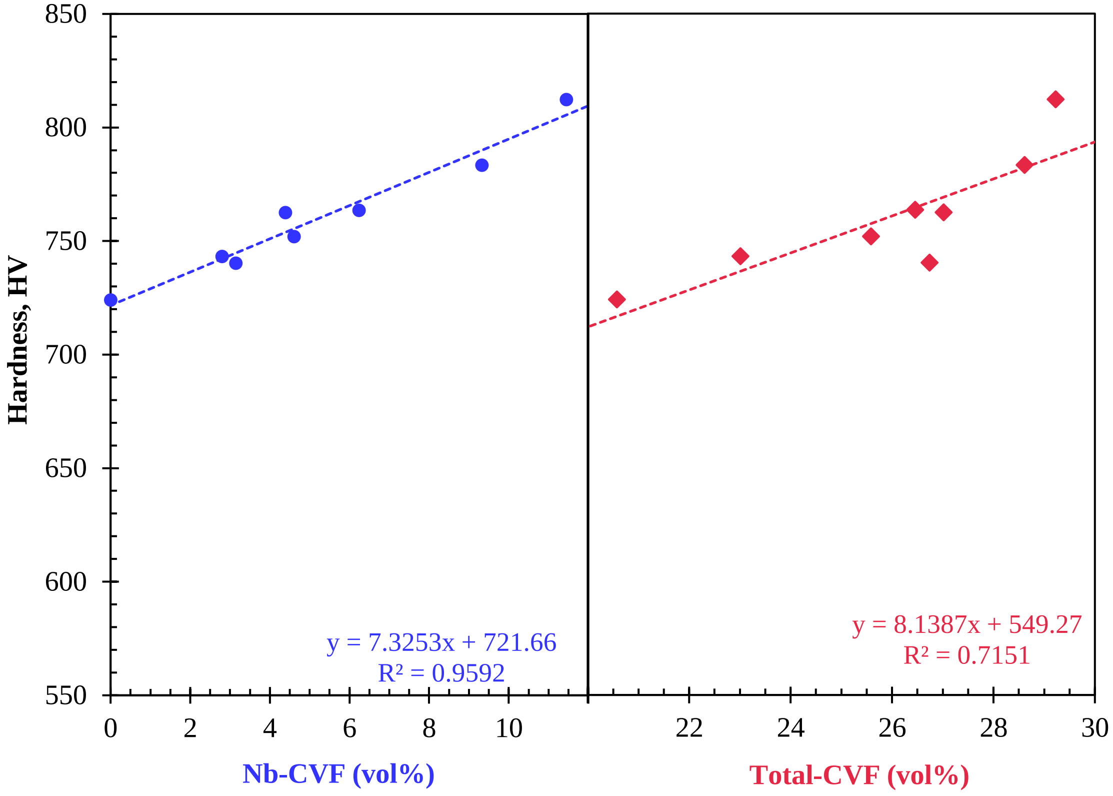


In-house production of systematic alloy series

Chemical Composition of Nb-CVF Series: Bulk / Host / Matrix

Alloy Code	Chemical Compositions																	Alloy Parameters				Matrix		
	Bulk Alloy									Host Alloy								Bulk Cr:C	Host Cr:C	Cr-CVF	Nb-CVF			
	C	Cr	Mo	Cu	Mn	Si	Ni	Nb	Al	C	Cr	Mo	Cu	Mn	Si	Ni						C	Cr	Cr:C
CB132	2.16	17.20	1.19	0.06	0.71	0.67	0.78	0.00	0.00	2.16	17.20	1.19	0.06	0.71	0.67	0.78		8.0	8.0	20.6	0.0	0.490	8.52	17.37
CB134A	2.45	17.10	1.10	0.32	0.75	0.68	0.76	2.62	0.06	2.16	17.63	1.13	0.33	0.77	0.70	0.78		7.0	8.1	20.8	2.8	0.480	8.76	18.25
CB134B	2.74	16.90	1.23	0.11	0.87	0.81	0.84	2.69	0.03	2.46	17.44	1.27	0.11	0.90	0.84	0.87		6.2	7.1	24.4	3.1	0.522	7.76	14.87
CB136C	2.81	16.70	1.11	0.12	1.04	0.91	0.78	3.91	0.19	2.40	17.48	1.16	0.13	1.09	0.95	0.82		5.9	7.3	23.7	4.4	0.514	7.94	15.46
CB136A	2.73	16.10	1.16	0.14	0.66	0.60	0.72	4.20	0.02	2.28	16.92	1.22	0.15	0.69	0.63	0.76		5.9	7.4	22.0	4.6	0.513	7.96	15.50
CB136B	2.85	16.10	1.01	0.16	0.78	0.70	0.70	5.75	0.29	2.24	17.23	1.08	0.17	0.83	0.75	0.75		5.6	7.7	21.6	6.2	0.500	8.28	16.57
CB138B	3.16	14.60	1.01	0.20	0.98	0.83	0.74	8.63	0.39	2.25	16.19	1.12	0.22	1.09	0.92	0.82		4.6	7.2	21.3	9.3	0.528	7.62	14.42
CB139	3.26	15.10	1.14	0.22	0.99	0.84	0.80	10.70	0.38	2.12	17.19	1.30	0.25	1.13	0.96	0.91		4.6	8.1	20.1	11.4	0.485	8.64	17.81

In-house production of systematic alloy series

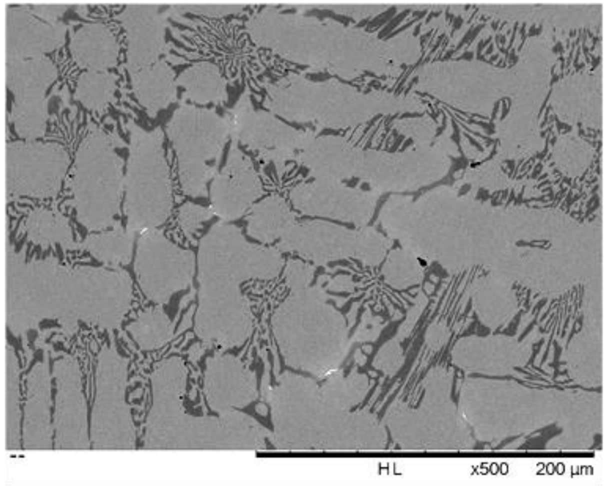


Hardness increases linearly (R^2=0.9592) with increase in NbC content

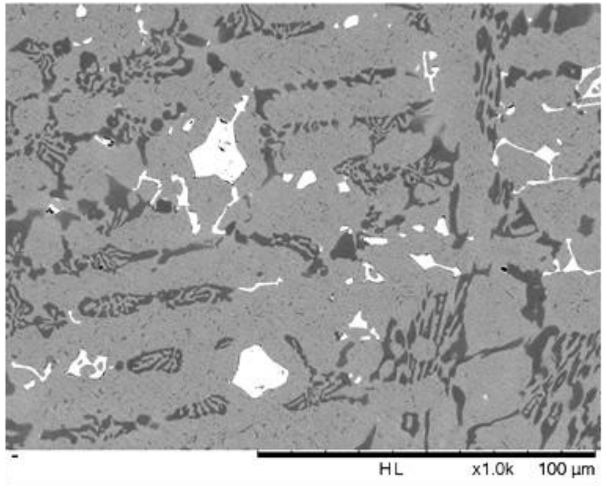
S1: Spheroidal
S2: Scalloped
F1: Blocky
F2: Facetted
F3: Flower-like
C1: Chinese-script, partially formed
C2: Chinese-script, fully formed
B: Bimodal

Alloy	Nb-CVF	NbC Morphology	Nb-feedstock	Nb Loss	Defect Severity
CB132	0.0	None	None	None	0.0
CB134A	2.8	F2, C1> F3	FeNb	4%	0.0
CB134B	3.1	F3> C1> C2	FeNbC	2%	0.0
CB136A	4.6	F2>> C1> L1	FeNb	34%	1.5
CB136B	6.2	F3/S2> F2> C1> L1	FeNbC	10%	2.5
CB136C	4.4	F2> F3> S2, C1> L1	FeNbC	39%	2.0
CB138B	9.3	S2> F2/F1>> C1, B	FeNbC	18%	4.0
CB139	11.4	S2>> F2/F1> C1> L0	FeNbC	19%	5.0

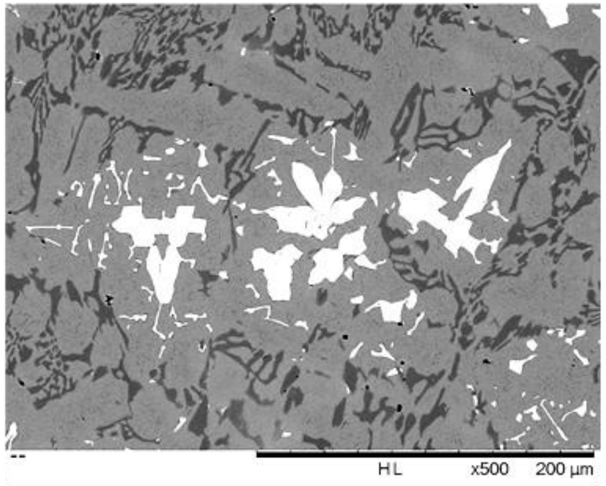
In-house production of systematic alloy series



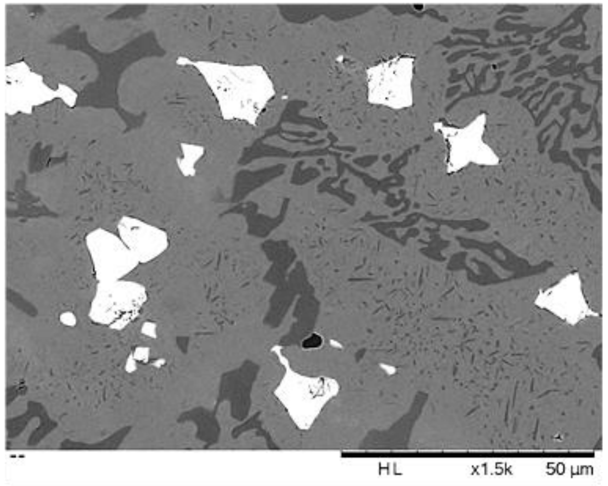
CB132 (0.0%Nb-CVF, 20.6%Cr-CVF, 8.0Cr:C)



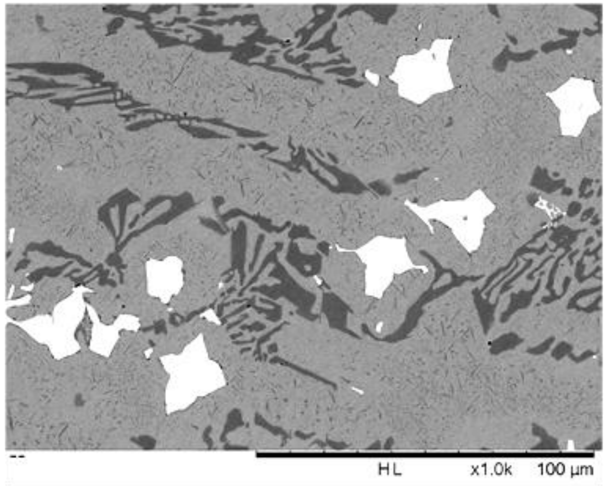
CB134A (2.8%Nb-CVF, 20.8%Cr-CVF, 8.1Cr:C)



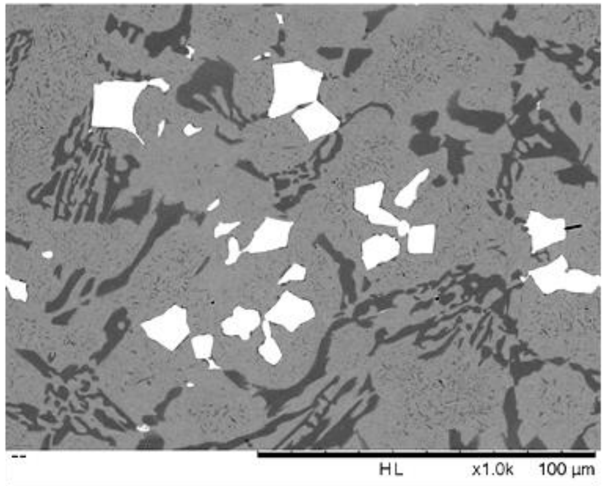
CB134B (3.1%Nb-CVF, 24.4%Cr-CVF, 7.1Cr:C)



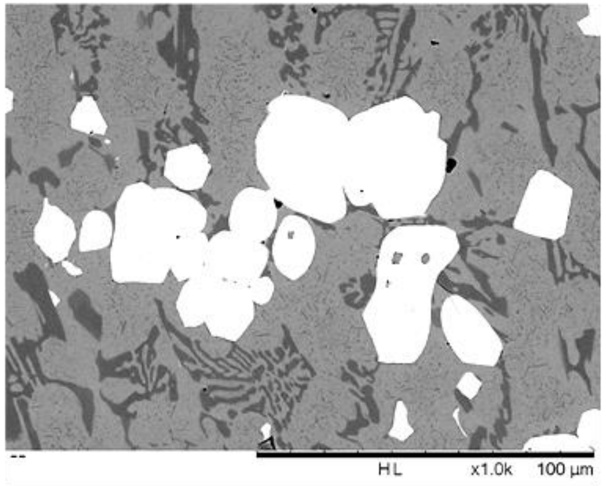
CB136A (4.6%Nb-CVF, 22.0%Cr-CVF, 7.4Cr:C)



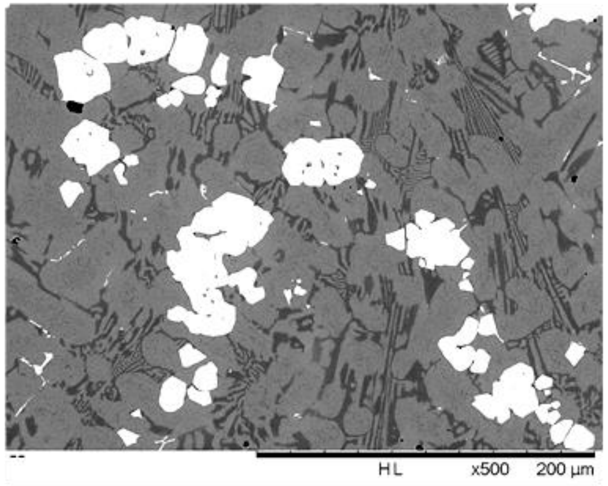
CB136B (6.2%Nb-CVF, 21.6%Cr-CVF, 7.7Cr:C)



CB136C (4.4%Nb-CVF, 23.7%Cr-CVF, 7.3Cr:C)

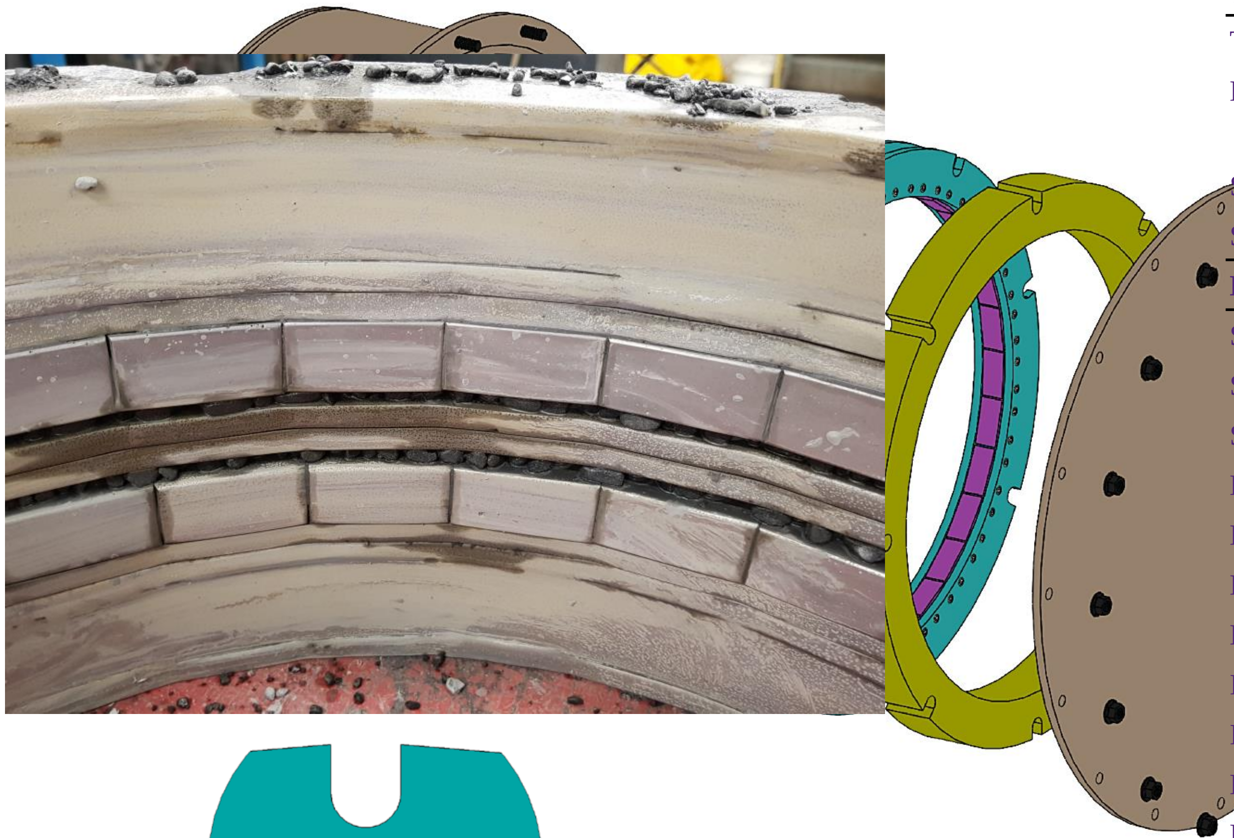


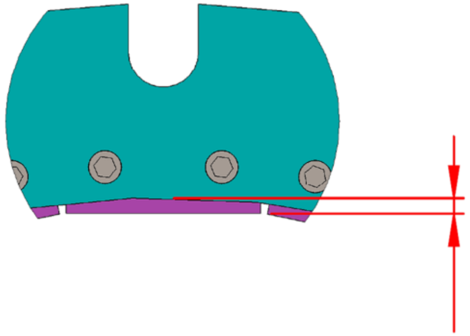
CB138B (9.3%Nb-CVF, 21.3%Cr-CVF, 7.2Cr:C)



CB139 (11.4%Nb-CVF, 20.1%Cr-CVF, 8.1Cr:C)

Ball mill abrasion test — BMAT-C

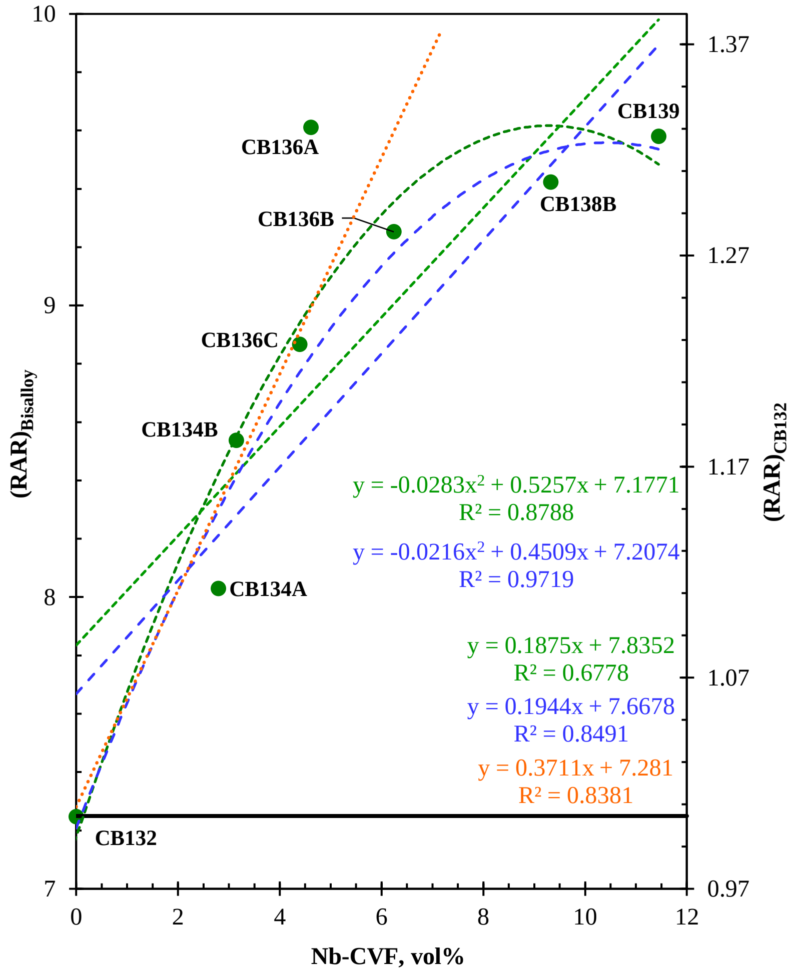


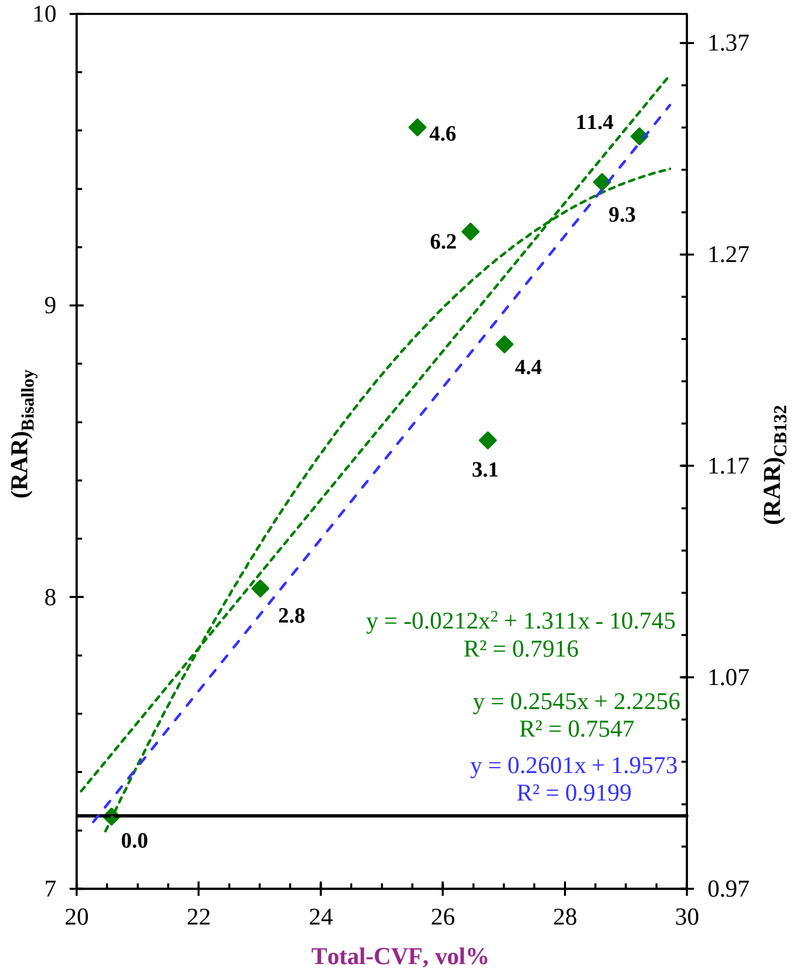


TESTING METHODOLOGY	
Test type	BMAT-C (liner mode)
Batch protocol	pre-weigh; 4 intervals of 20hr long test; post-weigh
Specimen type	slightly rounded edge
Specimen holder	rings A & B
METAL CHARGES & INTERSTICES	
Specimens total mass	11.38kg
Specimen avg. mass	189 g
Specimen equity diam.	17.9 mm
Number of alloys	4+4+1
Makeup charge mass	30.0kg
Makeup type	WCI (Mag B)
Makeup diam.	25mm
Interstices volume	3.0L
Interstices fill plan	350%
BMAT-T pulp volume	10.50L
BMAT-C pulp volume	14.40L
MILL OPERATION	
Critical speed (CS)	62.7rpm
Speed (of CS)	55%
Speed rpm	34.5rpm

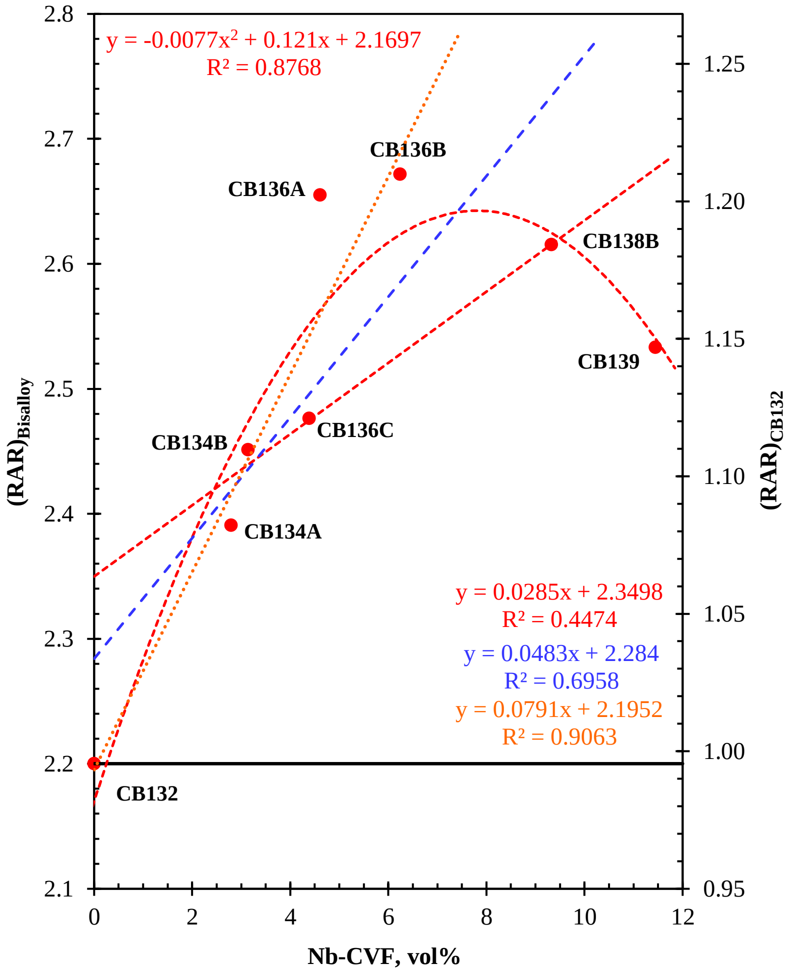
MINERAL SLURRY (PULP)	
Abrasive mineral	Basalt, Quartzite
Particle size	13.2 -9.5mm
Slurry water (wt%)	55wt%
Slurry solids (wt%)	45wt%
Slurry water (vol%)	76vol%
Slurry solids (vol%)	24vol%
Water volume (or mass)	10.95L
Mineral volume	3.45L
Mineral mass	8.96kg
Dry mineral inters fill 1	115%
Dry mineral inters fill 2	84%
MILL FILLING	
Total metal charge	30.0kg
Mill nominal diameter	601mm
Action space diameter	480mm
Mill length	209mm
Mill nominal volume	59.3L
Action space volume	37.8L
Mill filling 1	48%
Mill filling 2	38%
Excess pulp volume	11.4L, 7.5L

Relative abrasion resistance — RAR



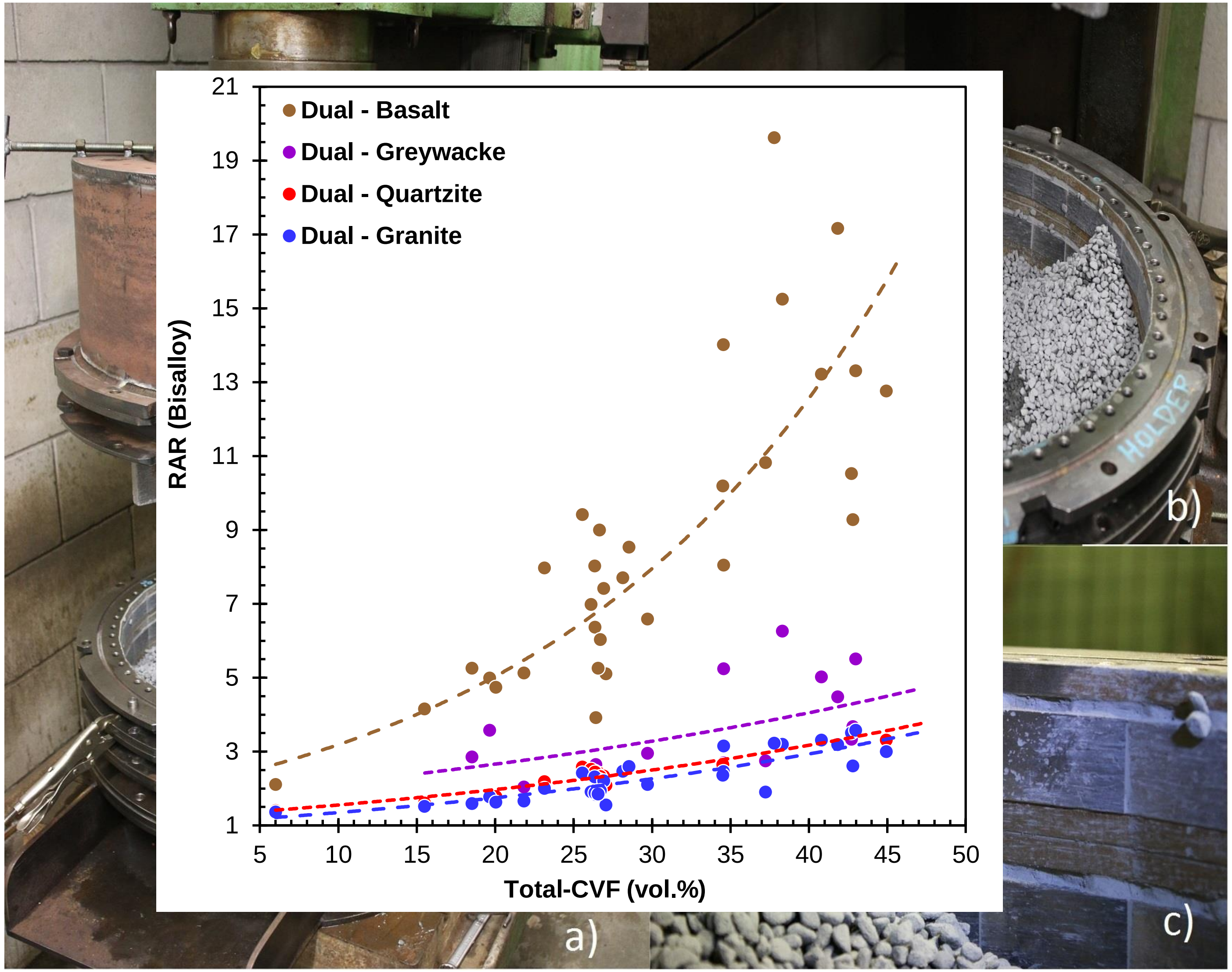


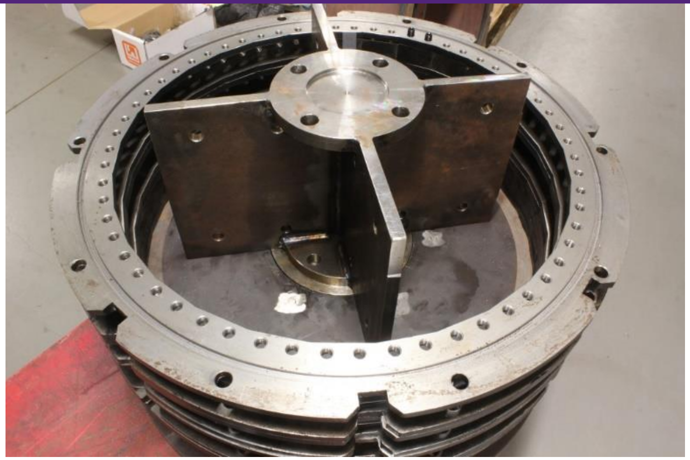
Basalt

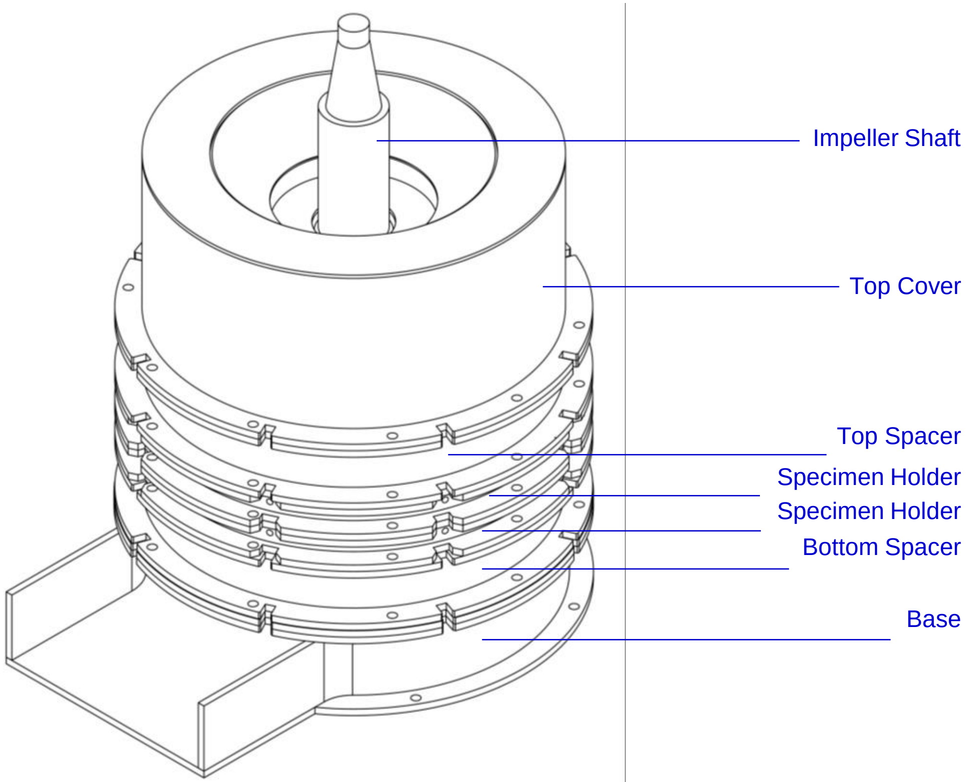


Quartzite

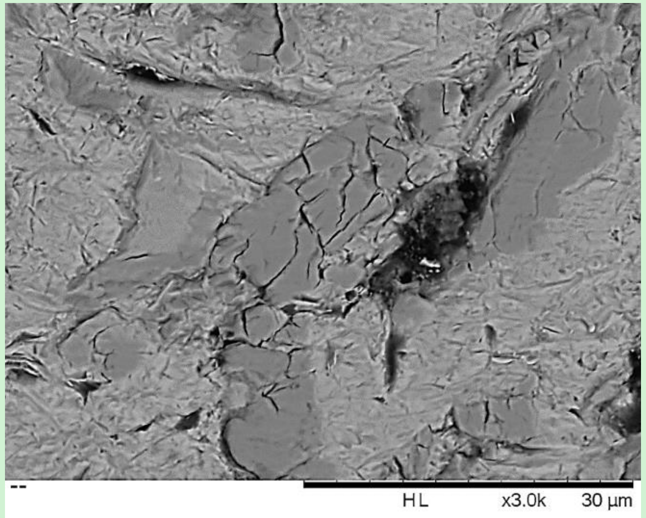
Inner circumference abrasion test — ICAT



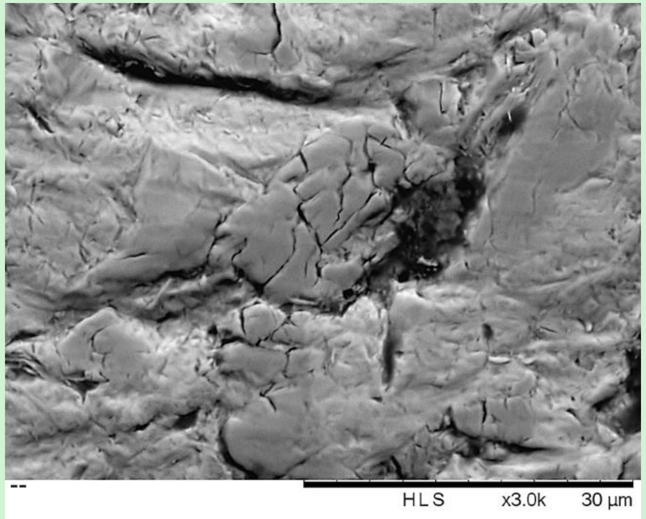


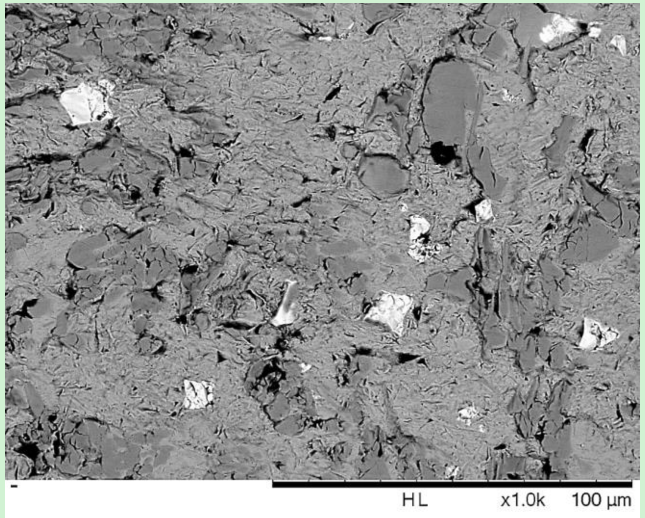


Abrasive wear micro-mechanisms

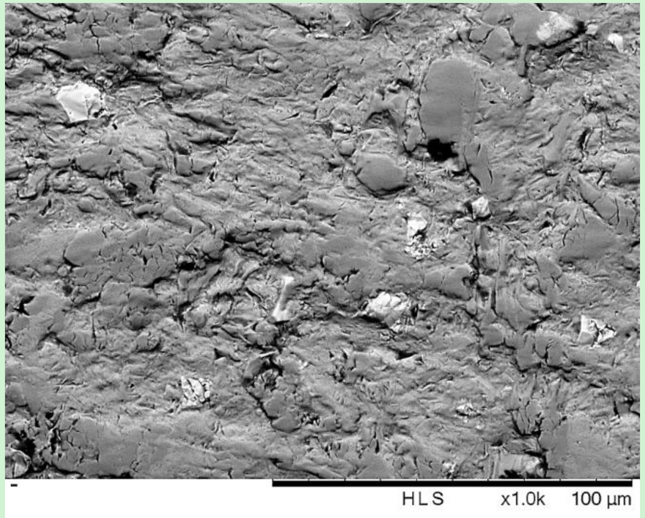


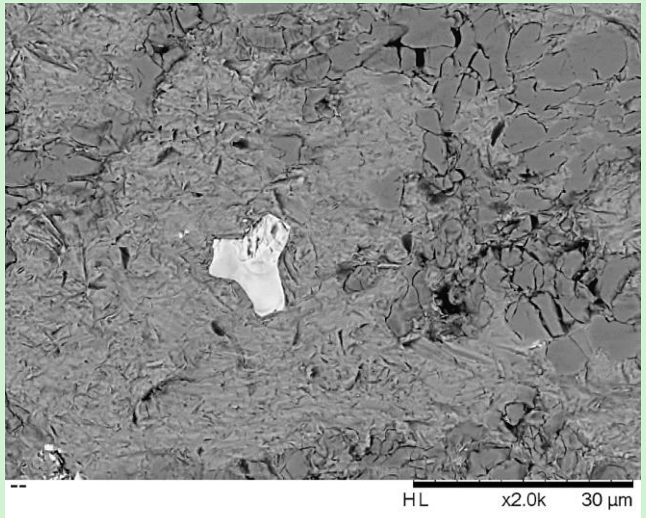
0%Nb-CVF – 21%Cr-CVF



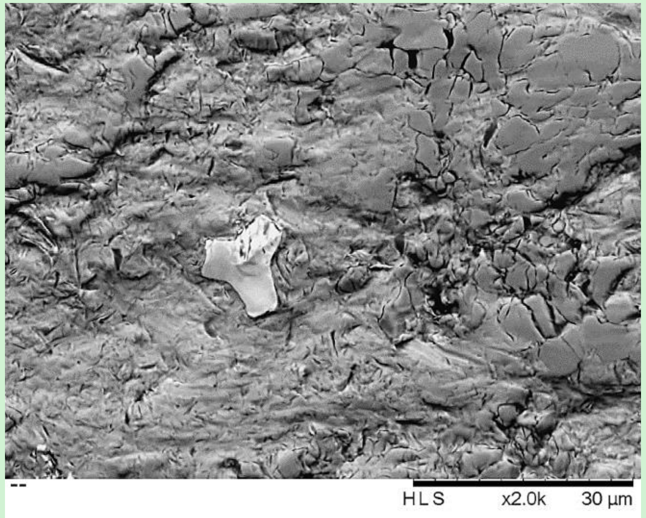


3%Nb-CVF – 21%Cr-CVF

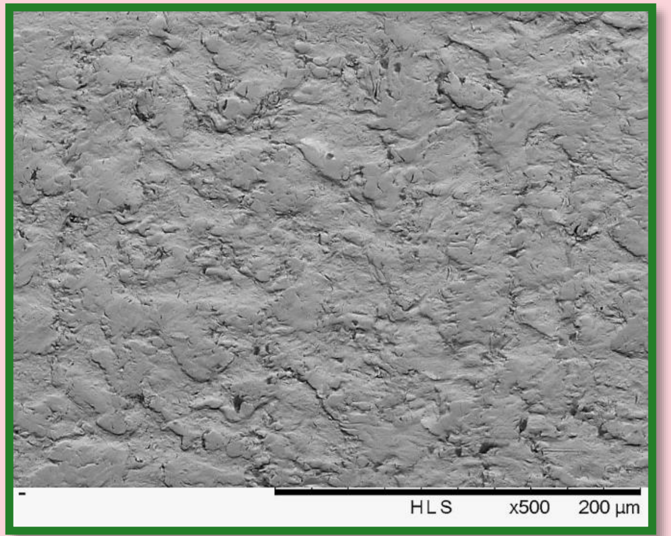


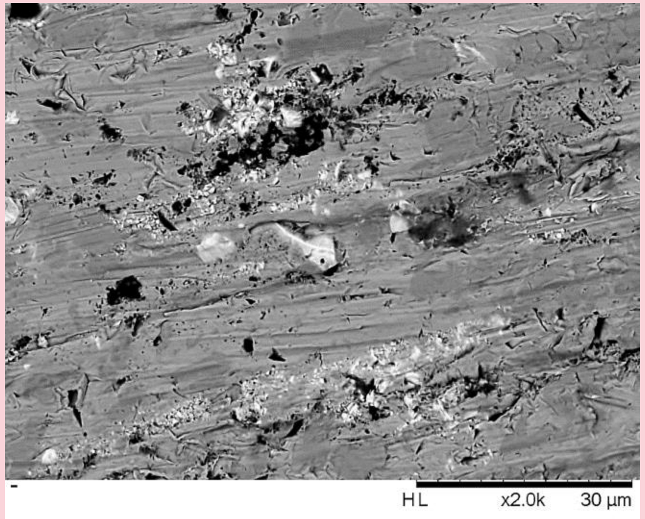


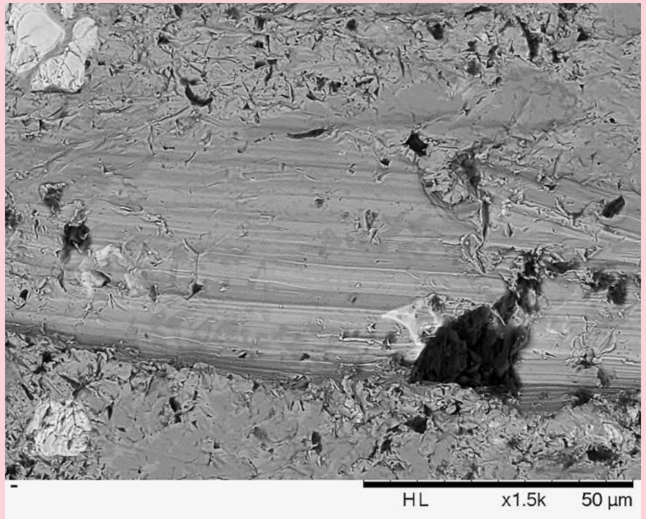
5%Nb-CVF – 23%Cr-CVF



Abrasive wear micro-mechanisms



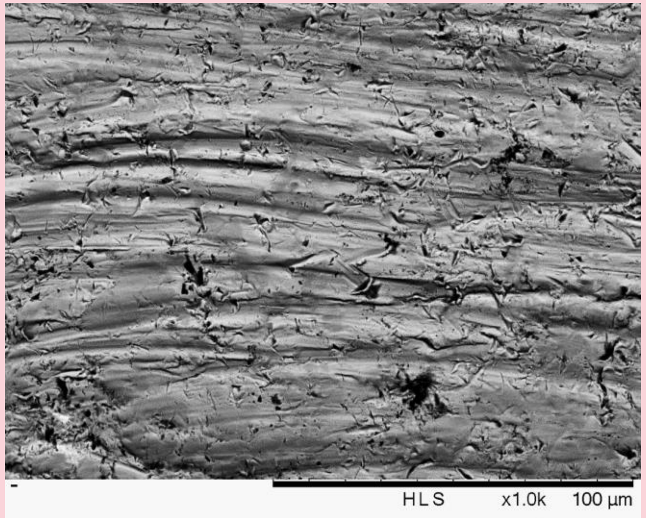


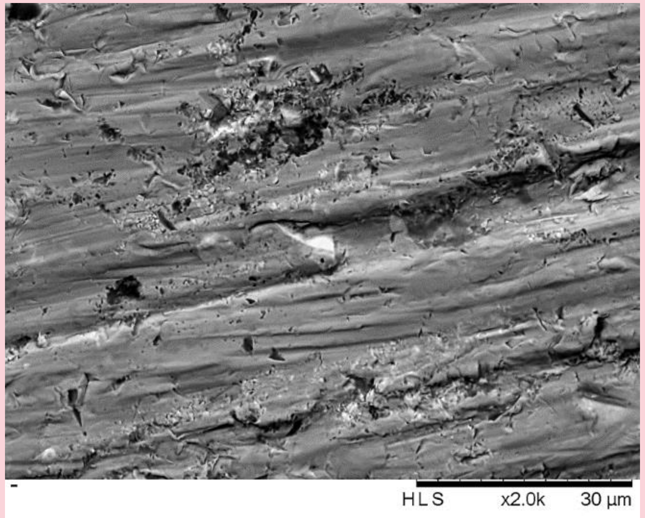


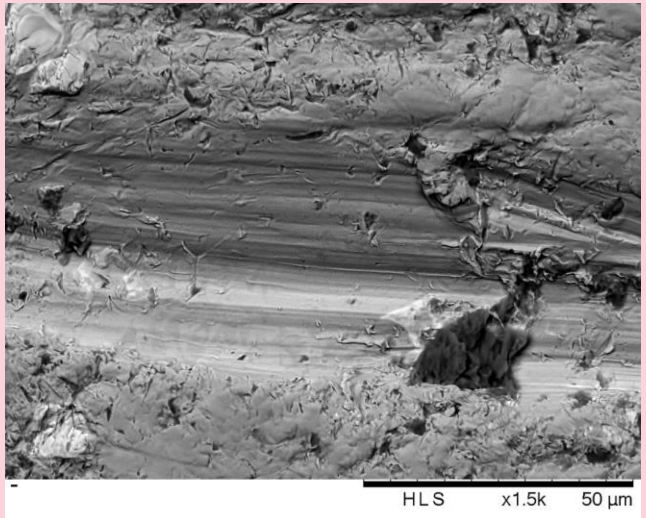
0%Nb-CVF – 21%Cr-CVF

4%Nb-CVF – 23%Cr-CVF

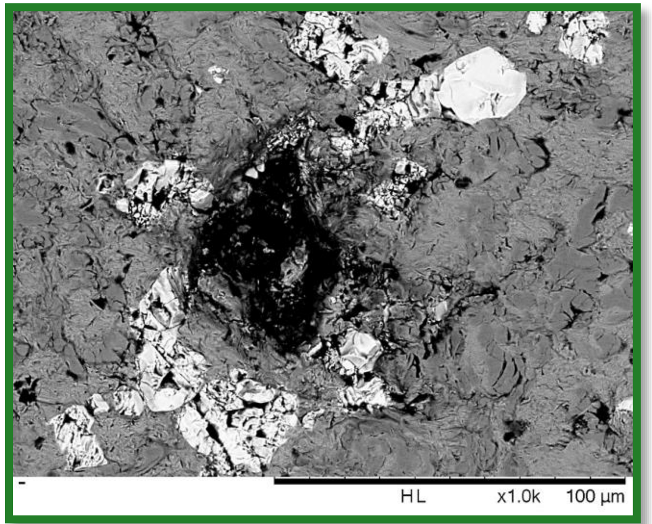
6%Nb-CVF – 22%Cr-CVF



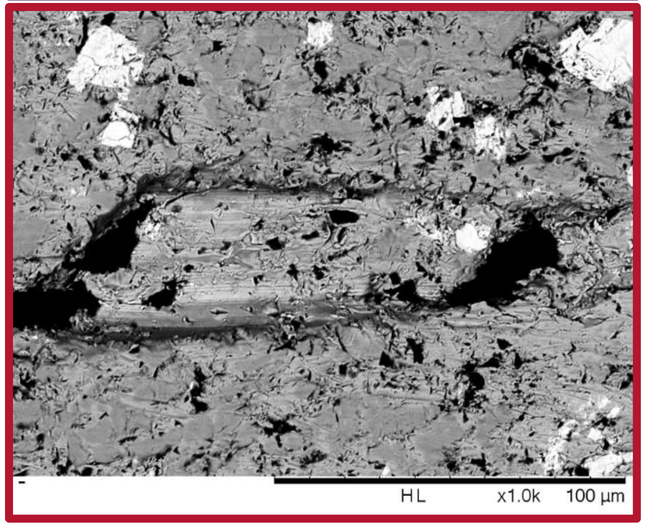


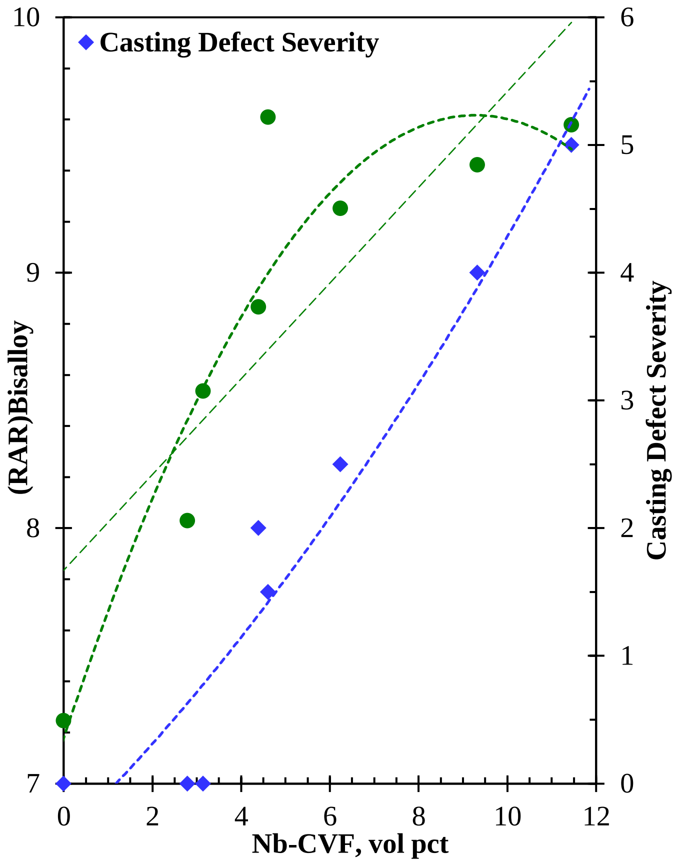


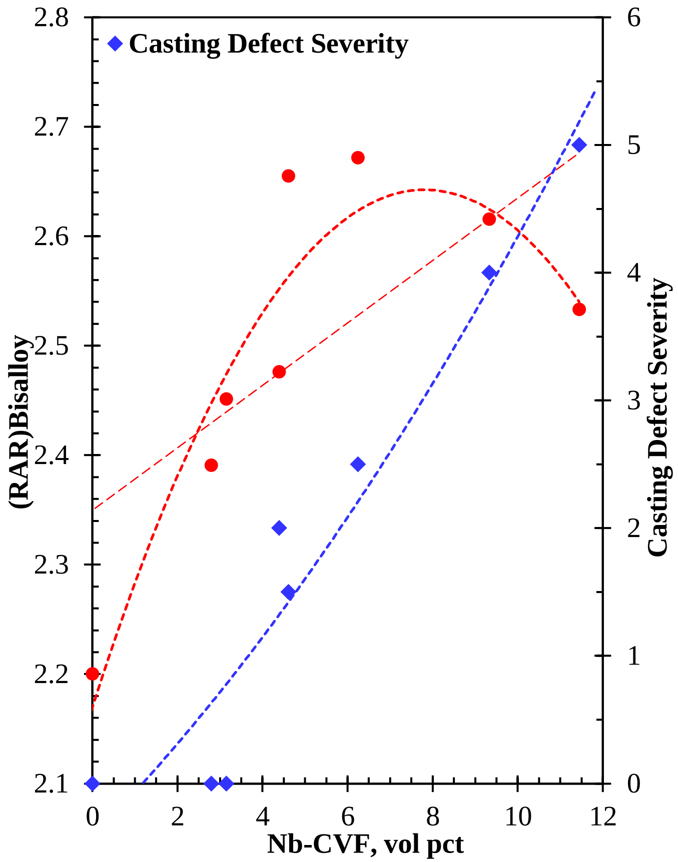
To where from here…



11.5%Nb-CVF – 20.1%Cr-CVF







Casting defects explain the lower-than-expected performance of high-Nb alloys.

Further improvement in abrasion resistance is achievable!

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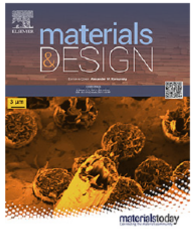

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Effects of niobium macro-additions to high chromium white cast iron on microstructure, hardness and abrasive wear behaviour

Hamid Pourasiabi *, J.D. Gates

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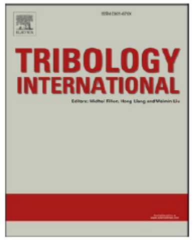

Effects of matrix chromium-to-carbon ratio on high-stress abrasive wear behavior of high chromium white cast irons dual-reinforced by niobium carbides

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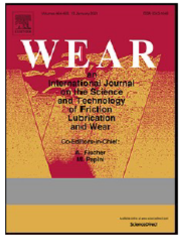

Check for updates

Effects of chromium carbide volume fraction on high-stress abrasion performance of NbC-bearing high chromium white cast irons

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Mechanistic studies

CB128D (9%NbC, 23%M7C3, 0.17%Al)

Face U – Polished region