Tribochemical study of $Ni_{62}Nb_{33}Zr_5$ metallic glass depending on the Cr content of steel counterparts

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CONTEXT

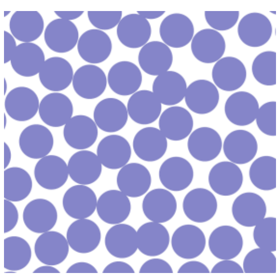
Amorphous Metallic Alloy → Bulk Metallic Glass

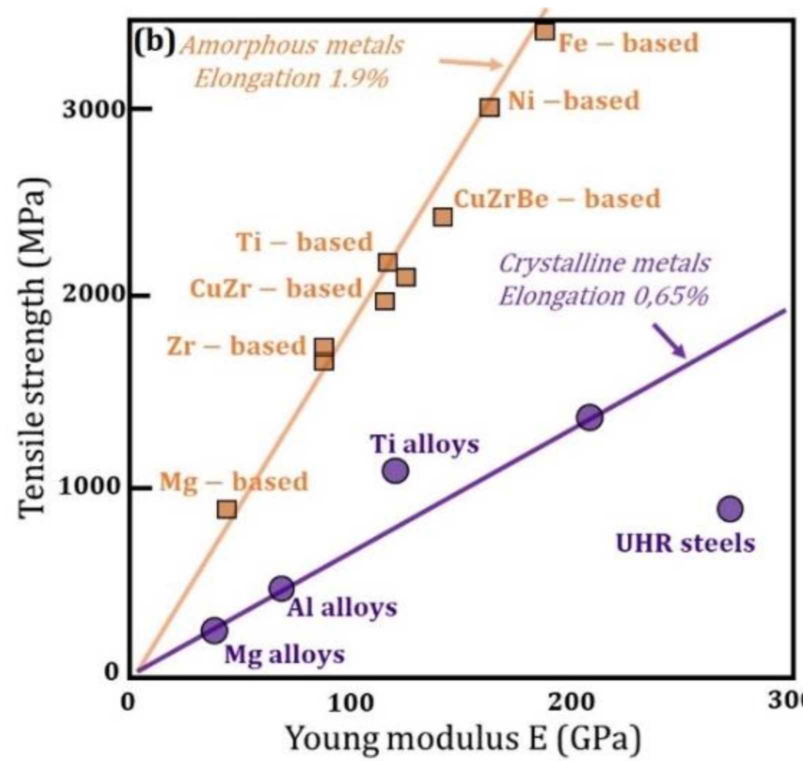
Direct **solidification**

well-defined **pure metals mixture**

through **extremely fast cooling**

amorphous





CONTEXT

Amorphous Metallic Alloy → Bulk Metallic Glass

- Erratic tribological behaviours …

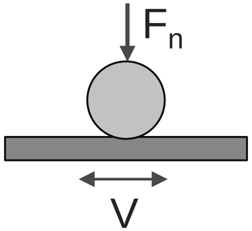
Usually relatively high friction (0.3 to 0.7)

High and low wear independently of the friction coefficient and hardness … even for a single composition

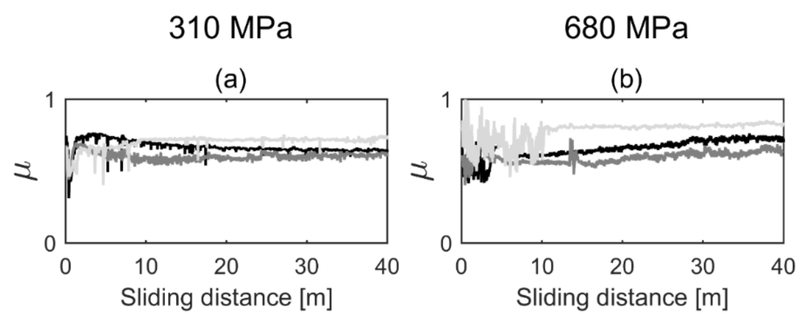
Particular crack propagation impeding and accentuating wear

… Really ? … No ! As long as contact conditions are well controlled

Pure sliding, 100Cr6 steel ball against BMG Plate



Zr



Cornuault et al, 2019, Trib. Int.

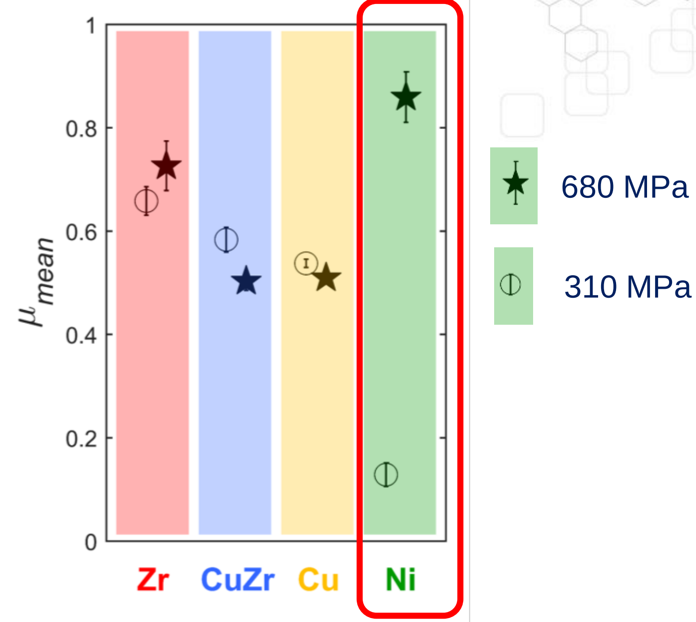
Zr52.5Ti5Cu17.9Ni14.6Al10

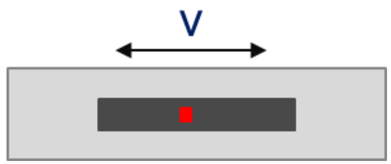
CONTEXT – Our previous study

$Zr_{52.5}Ti_5Cu_{17.9}Ni_{14.6}Al_{10}$ – *mechanically driven wear*

$Cu_{60}Zr_{33}Ti_7$ & $Cu_{47}Zr_{46}Al_7$ – *mechanically and/or chemically driven µ and wear (C, Zr migration, change in accommodation)*

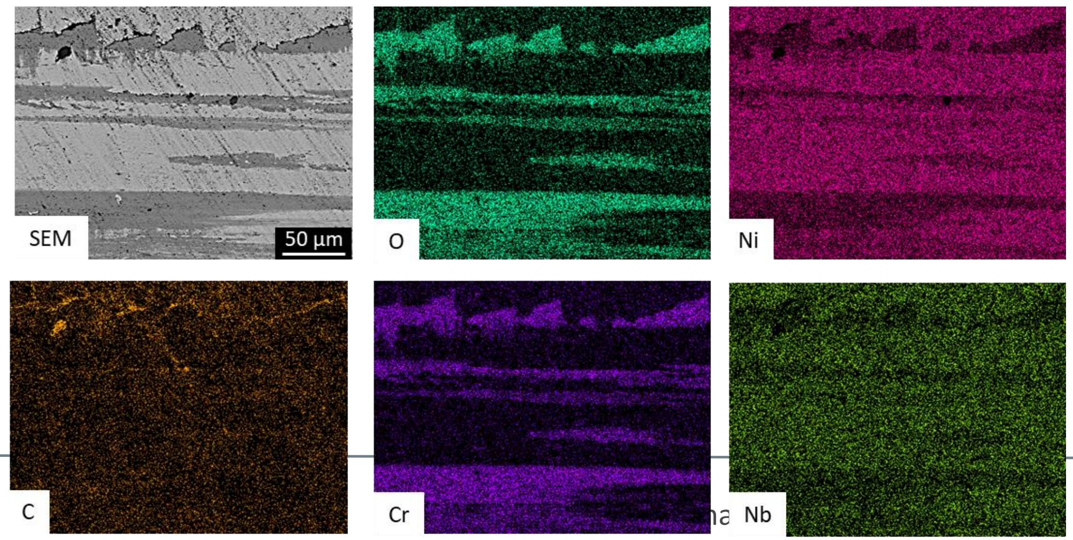
$Ni_{62}Nb_{33}Zr_5$ – mainly *chemically driven µ and wear (Cr migration, C detected, Nb migration like Zr)*





At high loads lots of Cr in the friction track

The steel slider had 1.5% Cr…



OBJECTIVES

Study the effect of Cr content in the steel slider on the tribological behaviours of the $Ni_{62}Nb_{33}Zr_5$ BMG in pure sliding conditions

Why? *to further explore the possibility to control friction of the BMG by finely tuning the composition of the counterparts*

MATERIALS

3 Steel compositions (Ball)

Steel	Fe	C	Cr	Mo	Mn	Si	Ni	Cu
X105CrMo17	*Balance*	0.95-1.20	16.00-18.00	0.75 max	1.00 max	1.00 max	-	-
100Cr6	*Balance*	0.95-1.05	1.40-1.65	-	0.25-0.45	0.15-0.35	0.30 max	0.20 max
C90	*Balance*	0.9	-	0.6	1	0.6	-	-

1 Amorphous Alloys (Plate)

Sample denomination	Composition [at%]	Young's modulus [GPa]	Yield strength [MPa]	Hardness [HV]
Ni	$Ni_{62}Nb_{33}Zr_5$	135	2750	798

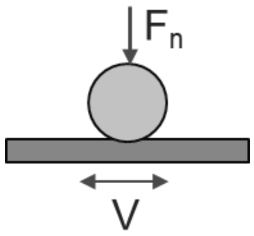
Mechanical properties

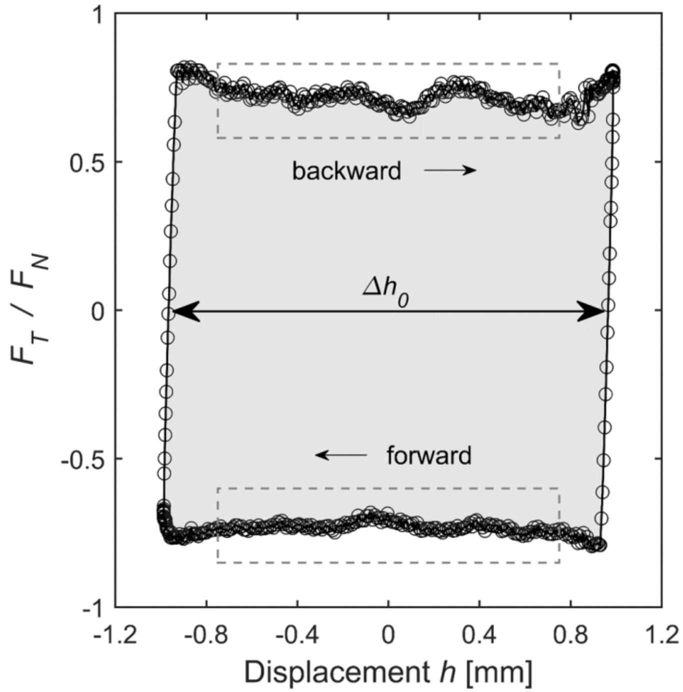
Steel	E (GPa)	Y (MPa)	H (HV
X105CrMo17	210	~1850	750
100Cr6	210	~1700	800
C90	210	~	800

METHODS

Reciprocating linear ball-on-plate friction tests

- **Plate:** $Ni_{62}Nb_{33}Zr_5$
- **Ball:** 3 Steels - Ø 6 mm
- Contact pressure **P = 680 MPa**
- Displacement stroke **Δh = ± 1 mm**
- Motion frequency **f = 1 Hz**
- Sliding speed **V = 4 mm/s**
- Sliding distance **Sd = 40 m** (10,000 cycles)

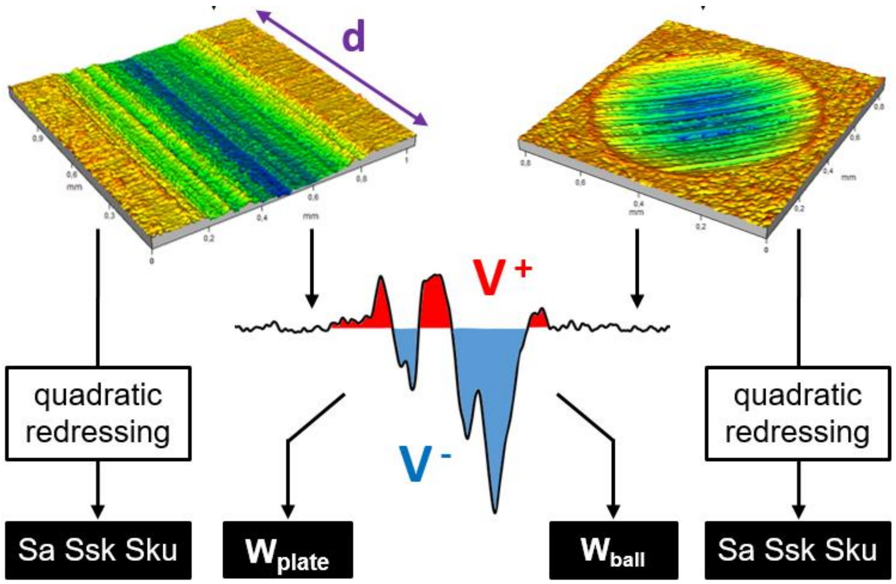




- Friction coefficient calculated as : $$\mu = \frac{1}{2\,\Delta h_0} \int \left| \frac{F_T}{F_N} \right| dh$$

METHODS

« Wear » and roughness analysis using variable focus microscope



$$W_{plate} = \frac{V_p^- - V_p^+}{2\, d\, N_{cycles}}$$

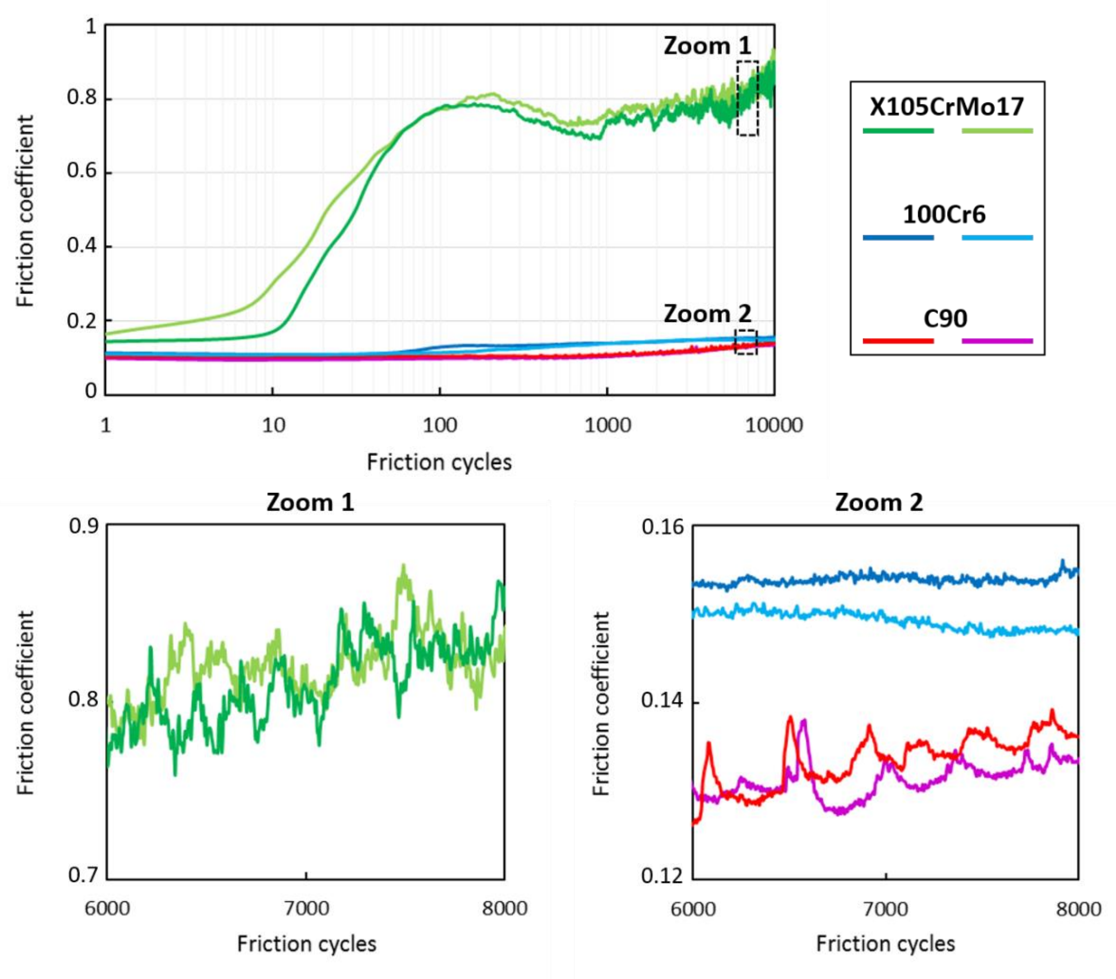
$$W_{ball} = \frac{V_b^- - V_b^+}{4\, N_{cycles}}$$

$$W_{tot} = W_{plate} + W_{ball}$$

Morphologies and compositions of the tracks analyzed with SEM/EDX, Raman spectroscopy, XPS, and NanoSIMS

Results

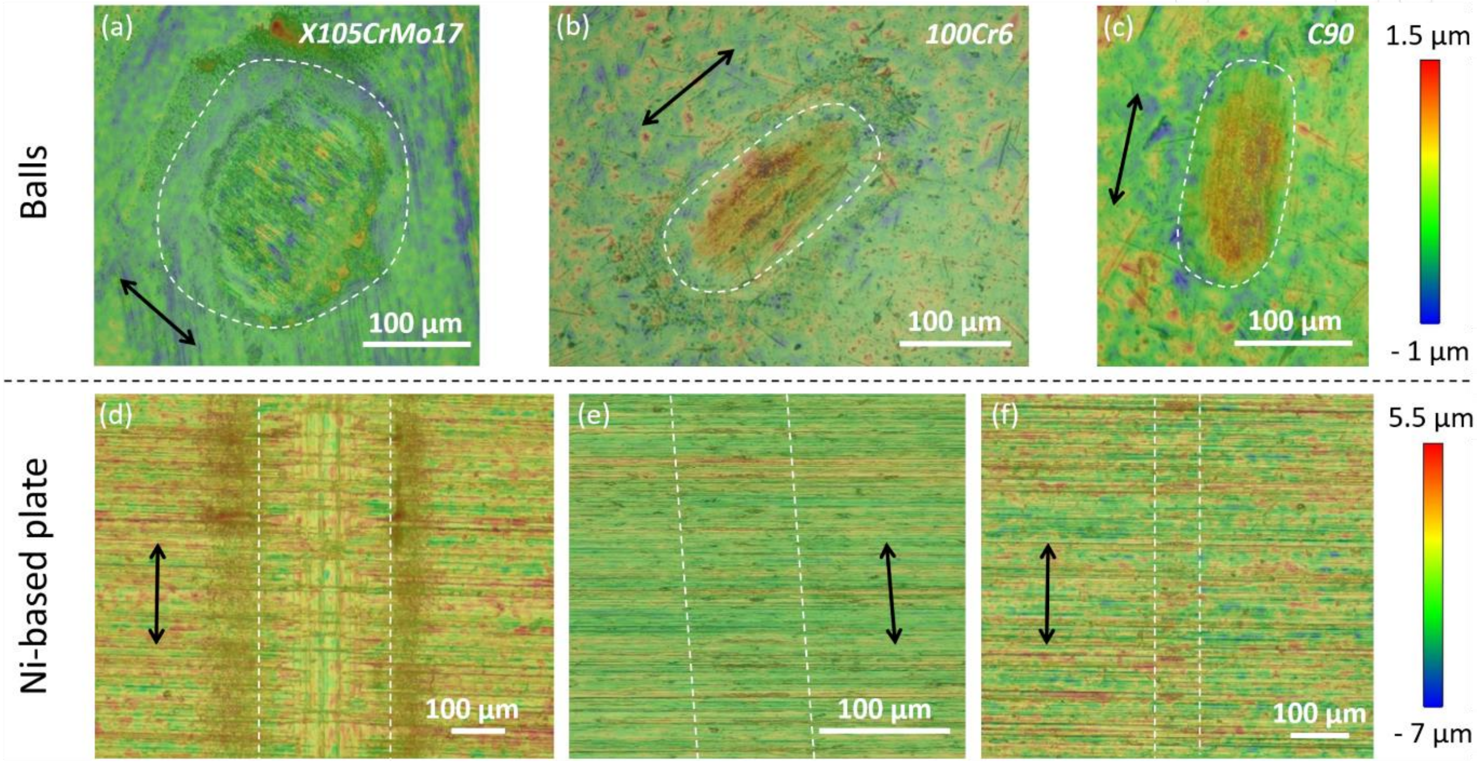
RESULTS – Friction coefficient



Increased Friction in line with increased Cr content ?

=> Confirmation of the effect of Cr content on Ni based BMG tribological behaviour ?

RESULTS – Wear

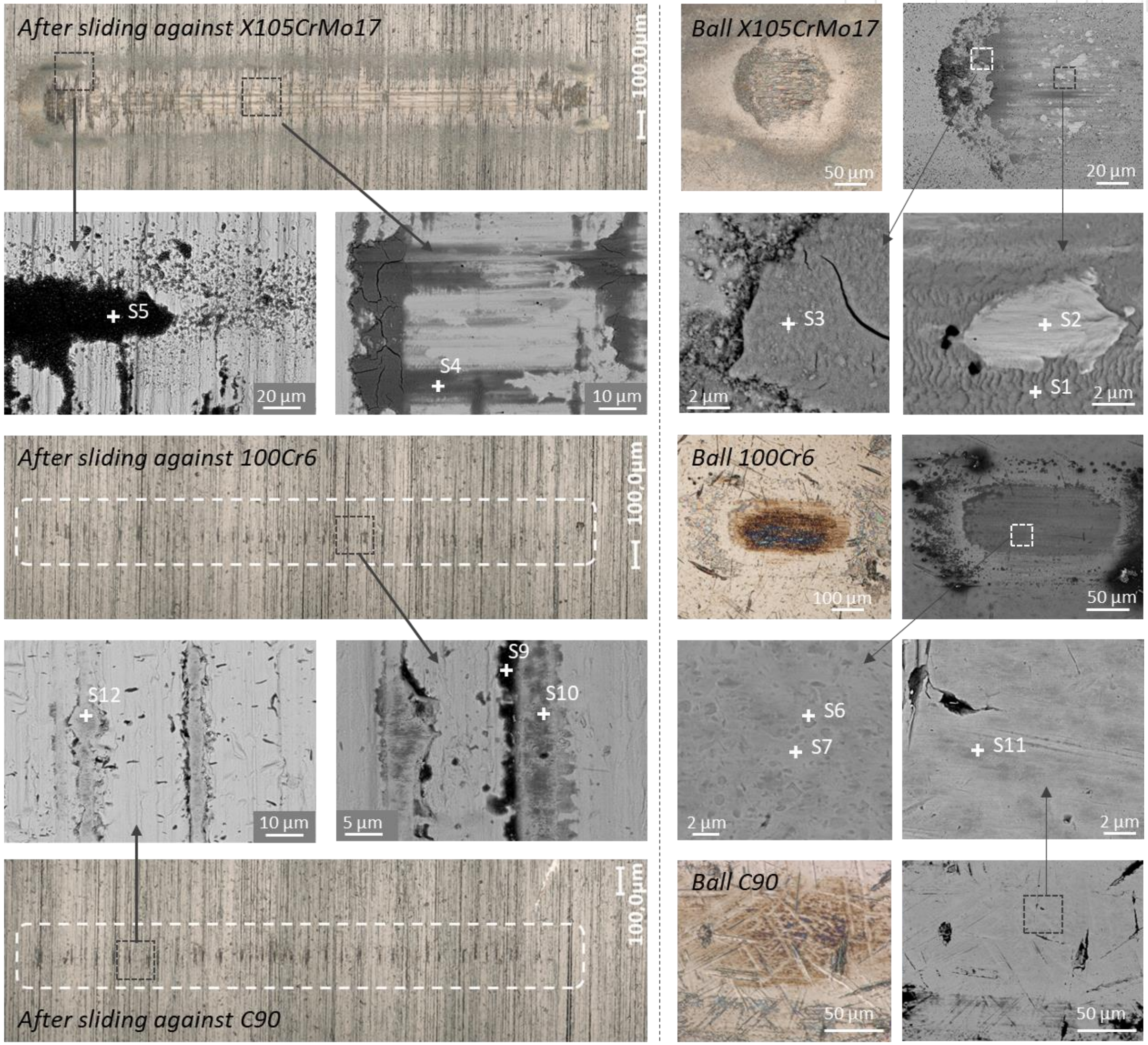


Extremely low wear, impossible to evaluate wear volumes

Even for test with X105CrMo17

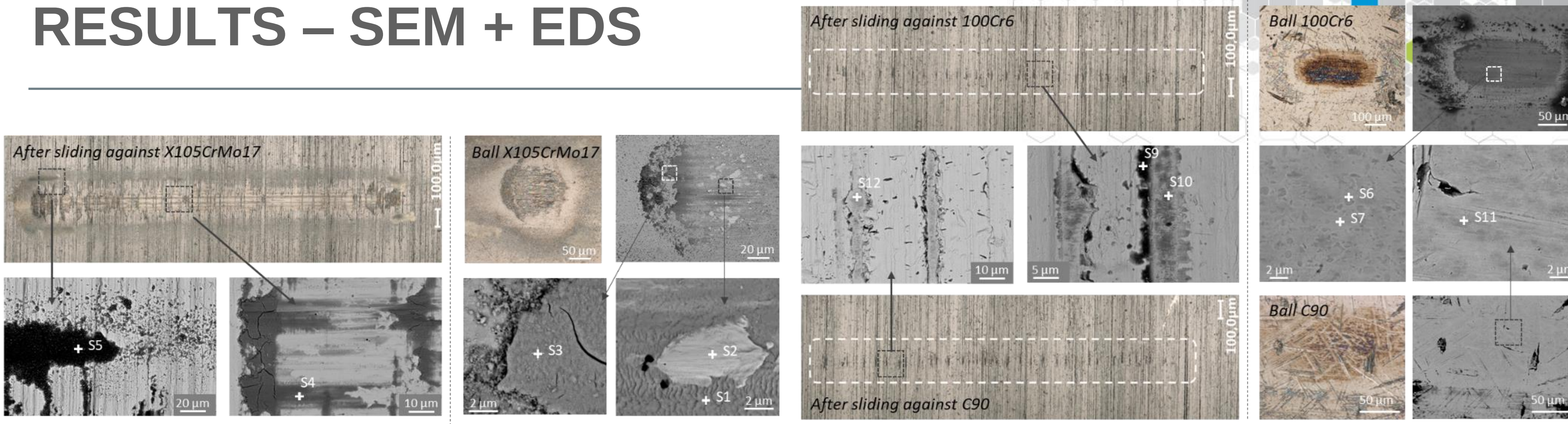
=> But visible patches of material inside tracks (all) and on the edges (X105CrMo17)

RESULTS – SEM



After sliding against X105CrMo17
100.0µm
S5
20 µm
S4
10 µm
After sliding against 100Cr6
100.0µm
S12
10 µm
S9
S10
5 µm
100.0µm
After sliding against C90
Ball X105CrMo17
50 µm
20 µm
S3
2 µm
S2
S1
2 µm
Ball 100Cr6
100 µm
50 µm
S6
S7
2 µm
S11
2 µm
Ball C90
50 µm
50 µm

RESULTS – SEM + EDS



Counterpart	Sample	Spectrum	Elemental composition (atomic %)						
			Ni	Nb	Zr	Fe	Cr	O	C
X105CrMo17	Ball	S1	***16.9***	5.7	1.0	***15.1***	***3.4***	***48.0***	10.0
		S2	***69.4***	1.5	0	***6.5***	***1.4***	6.8	14.5
		S3	***13.0***	***12.6***	2.1	***3.0***	***0.7***	***63.0***	6.7
	Plate	S4	***18.2***	12.6	2.2	***4.8***	***1.0***	***54.4***	6.9
		S5	***12.2***	***17.7***	3.1	***4.3***	***1.1***	***51.6***	10.0
100Cr6	Ball	S6	***4.4***	0.8	0.1	***62.0***	4.5	8.0	***19.8***
		S7	***3.3***	0.7	0.1	***76.8***	0.8	5.12	***12.3***
		S8	0.3	0	0	***56.6***	0.7	0.9	***41.0***
	Plate	S9	6.1	3.7	0.1	2.3	0.1	***16.4***	***70.5***
		S10	***11.4***	***11.0***	2.0	***11.5***	0.5	***58.2***	4.3
C90	Ball	S11	***6.6***	1.3	0.2	***63.8***	0.2	***16.3***	***11.0***
	Plate	S12	***24.3***	***20.9***	3.7	3.6	0	***39.1***	8.4

Ratio of at% signficantly changed

Ni transfers a lot on X105CrMo17

O highly detected

Cr detected ?

Low wear and EDS is an analysis « in volume »

RESULTS – XPS

Top Surface analysis (5 nm in depth), averaging over Ø200µm spot

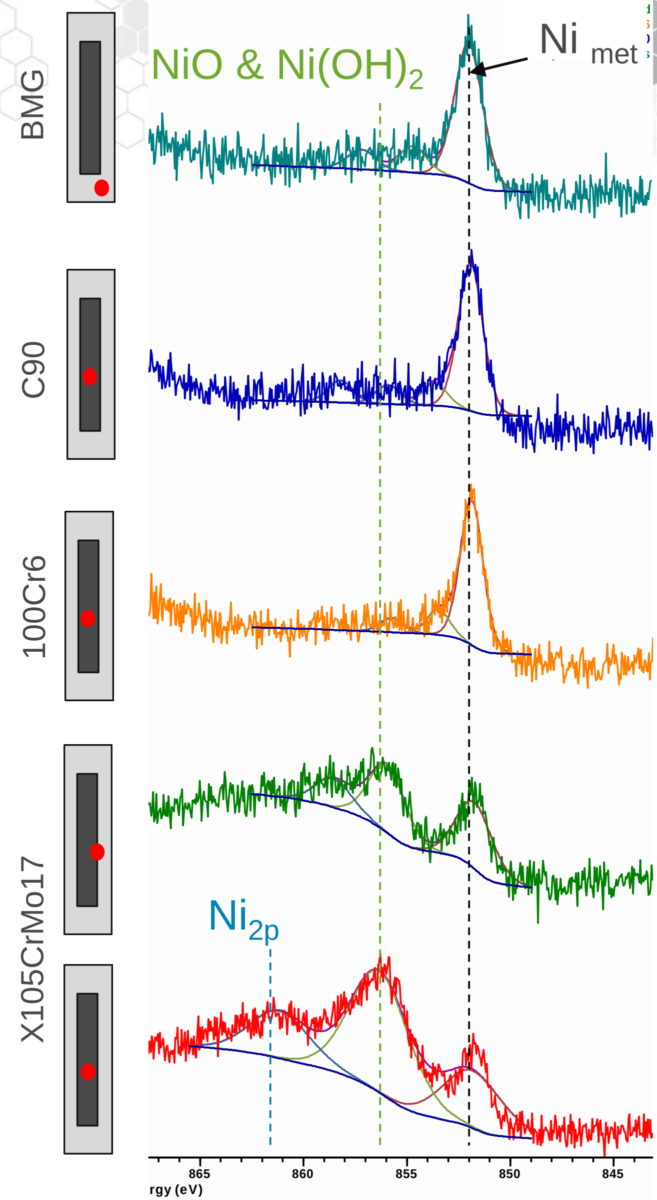
⇒ X105CrMo17 :
- ⇒ oxide et hydroxyde of Ni more detected than Ni metal inside the track and on the edge of it

⇒ C90 et 100Cr6 :
- ⇒ Ni met >> oxide and hydroxyde Ni
- ⇒ Detection similar to the outside

⇒ O and C heavily detected => contaminations + oxides ?
⇒ Cr not detected => hidden by C contaminations ?
- *⇒ Agree with EDS except Cr was slightly detected*

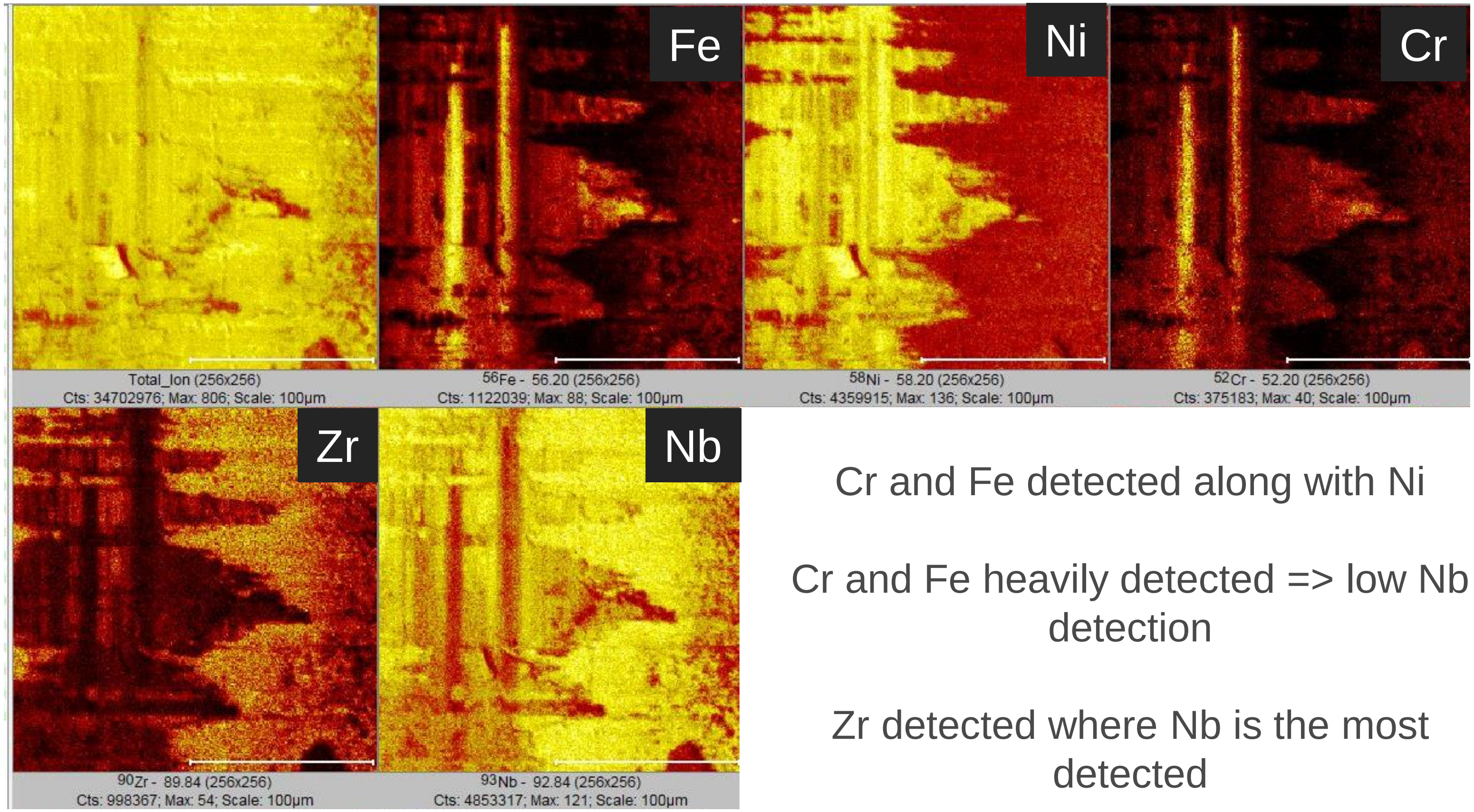
⇒ Native oxide of BMG : Nb_2O_5 & ZrO_2 => OK

⇒ Nb_2O_5 and ZrO_2 detected inside friction tracks as well
- *⇒ Large spot size and very low wear*



RESULTS – NanoSIMS

Analysis over 2 to 5 nm in depth, Ø few µm



Cr and Fe detected along with Ni

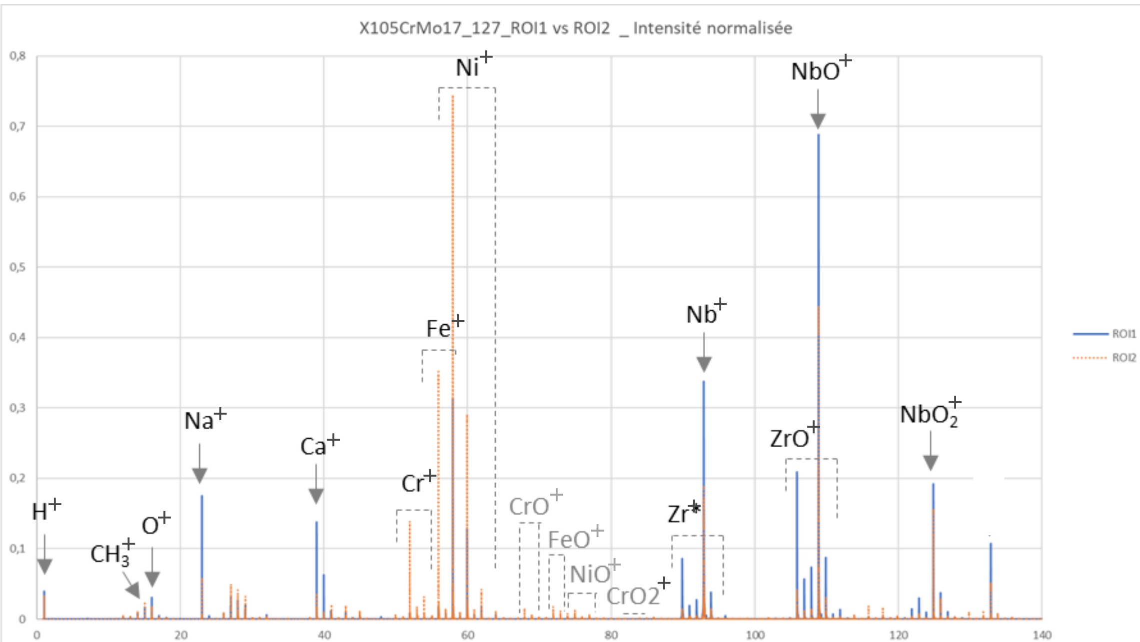
Cr and Fe heavily detected => low Nb detection

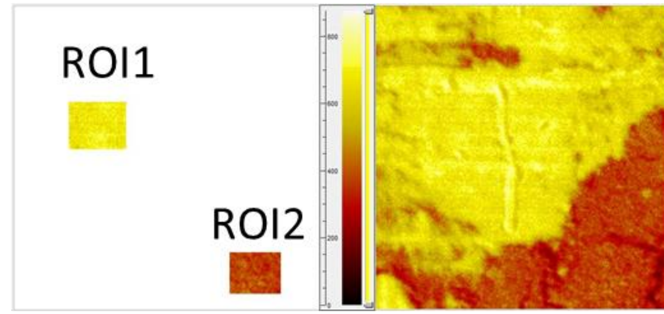
Zr detected where Nb is the most detected

RESULTS – NanoSIMS

Definition of region of interest and in depth analysis of spectra

In both positive and negative analysis modes to get access to all fragments





ROI 1 : almost pristine BMG

ROI 2 : patch of worn/transfered material

⇒ Clear evidence of reverse detection of Ni vs ZrO_2 and Nb_2O_5 between pristine and transfered material

⇒ Ni detected along with Fe and Cr.

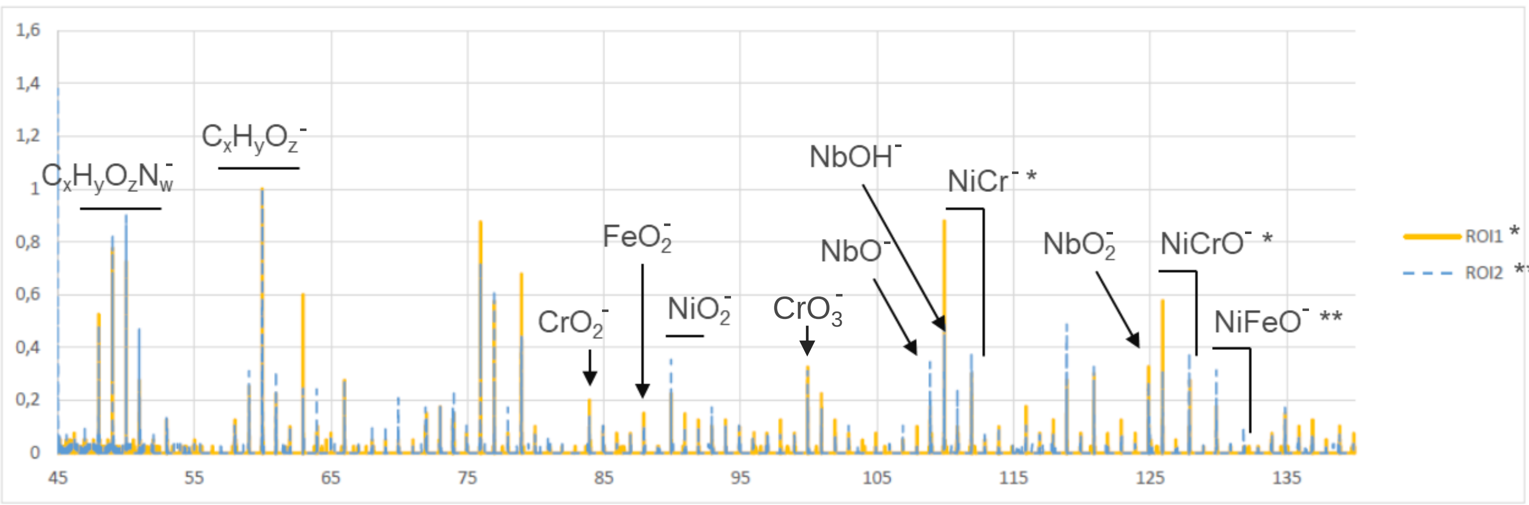
⇒ + Detection of hydrocarbones contaminant.

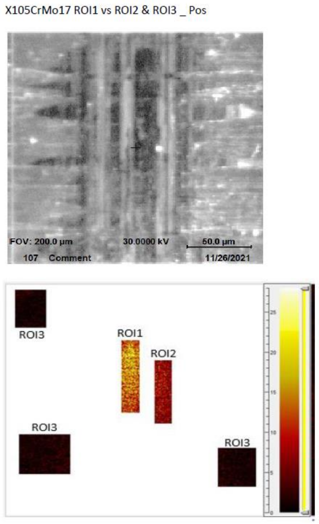
Agree well with EDS and XPS

RESULTS – NanoSIMS

⇒ X105CrMo17
  - ⇒ Clear evidence of reverse detection of Ni vs ZrO_2 and Nb_2O_5 between pristine and transfered material
  - ⇒ Ni detected along with Fe and Cr.
  - ⇒ + Detection of hydrocarbones contaminant.
  - ⇒ Detection of NiO, NiCrO, and NiFeO coumpounds, some Cr oxide.

Agree well with EDS and XPS





⇒ C90 and 100Cr6
  - ⇒ No reverse detection: differences inside/outside tracks on Fe and Fe oxide
  - ⇒ Nb_2O_5 is mostly detected in C90 friction tracks, followed by 100Cr6, then X105CrMo17
  - ⇒ 100Cr6: very low detection of Cr oxide and NiCrO compound

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RESULTS – Raman (532nm , power < 1 mW)

⇒ No peaks for C90 and 100Cr6 tests

⇒ X105CrMo17

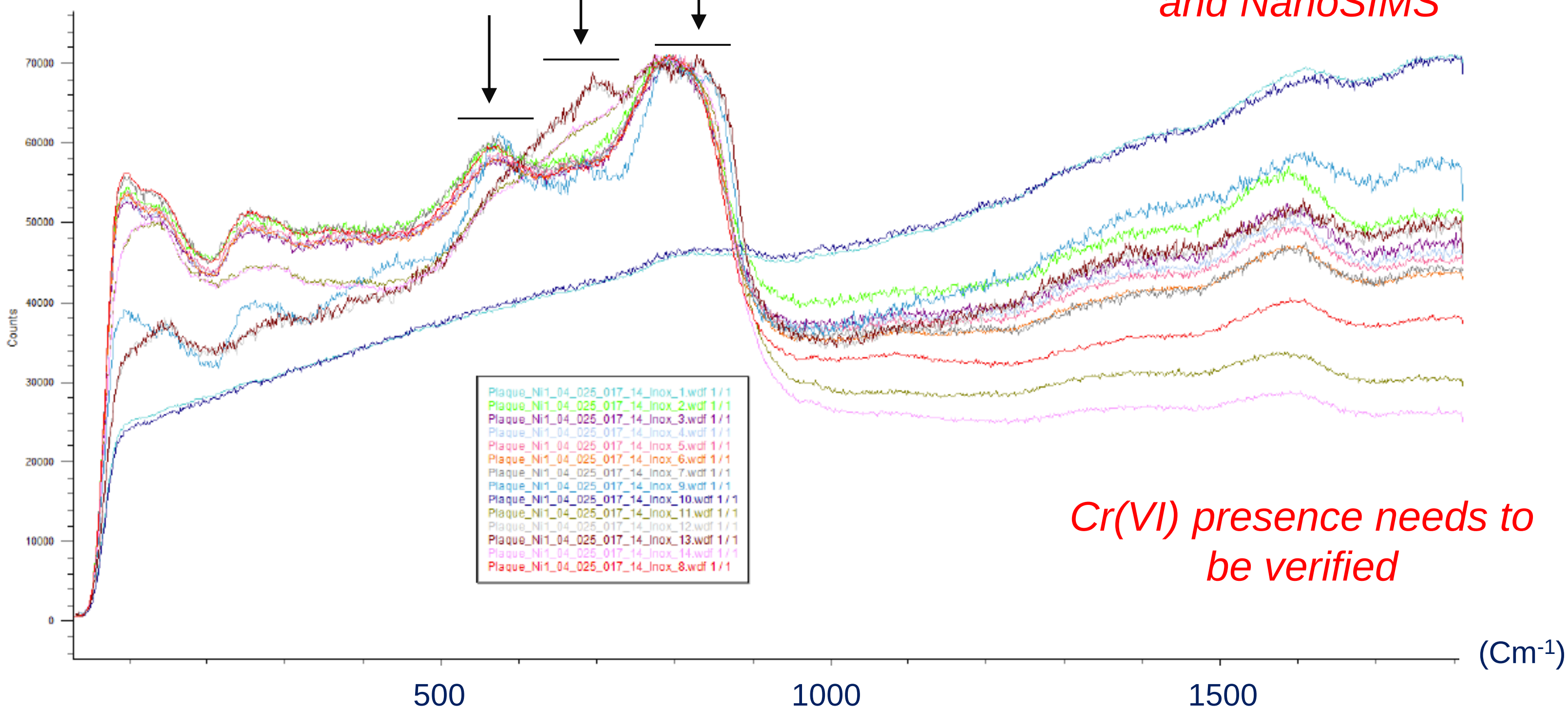
NiFeCrO with residual stress ?

NiCrO

Cr(VI) oxide ?

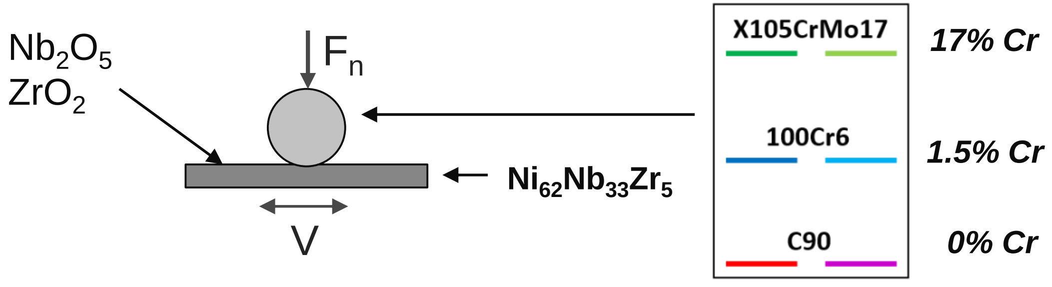
NiO, CrOOH

Agree well with EDS, XPS, and NanoSIMS



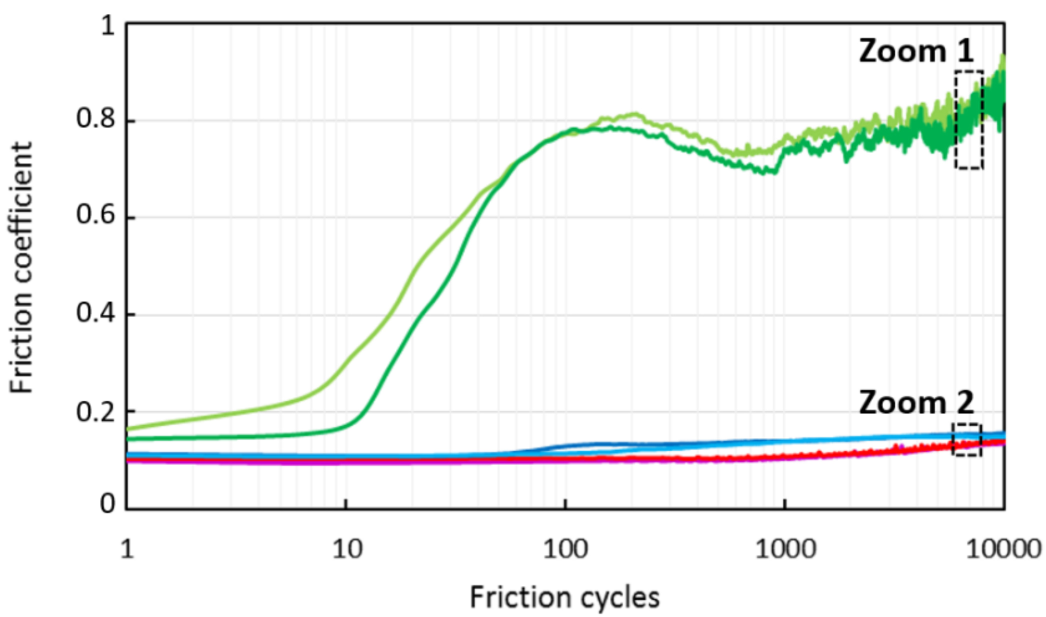
Cr(VI) presence needs to be verified

CONCLUSION



Optical profilometry = no wear

SEM/EDS
XPS
Raman
NanoSIMS



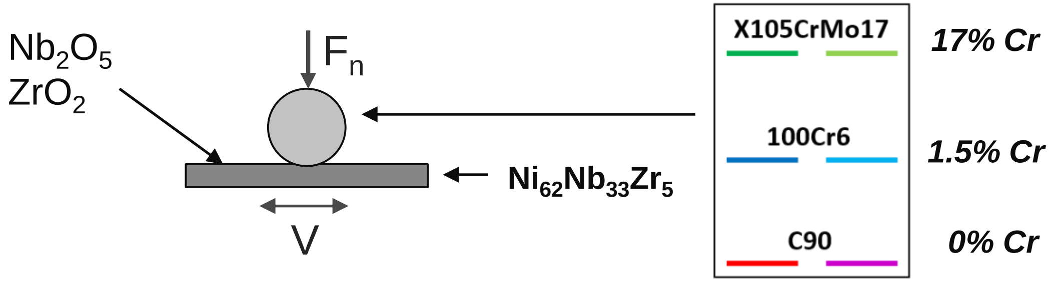
CoF

- Ni ↑ ↑ ↑, Nb_2O_5 + ZrO_2↓ ↓ ↓,
- Fe, Cr, NiO(H), NiCrO, NiFeO
- traces of Fe oxide, and Cr oxide

- Ni ↑ and Fe, Nb_2O_5 + ZrO_2↓,
- traces of Cr, Fe oxide, Cr oxide, NiCrO

- Ni ↑ and Fe, Nb_2O_5 + ZrO_2↓,
- traces of Fe oxide

CONCLUSION



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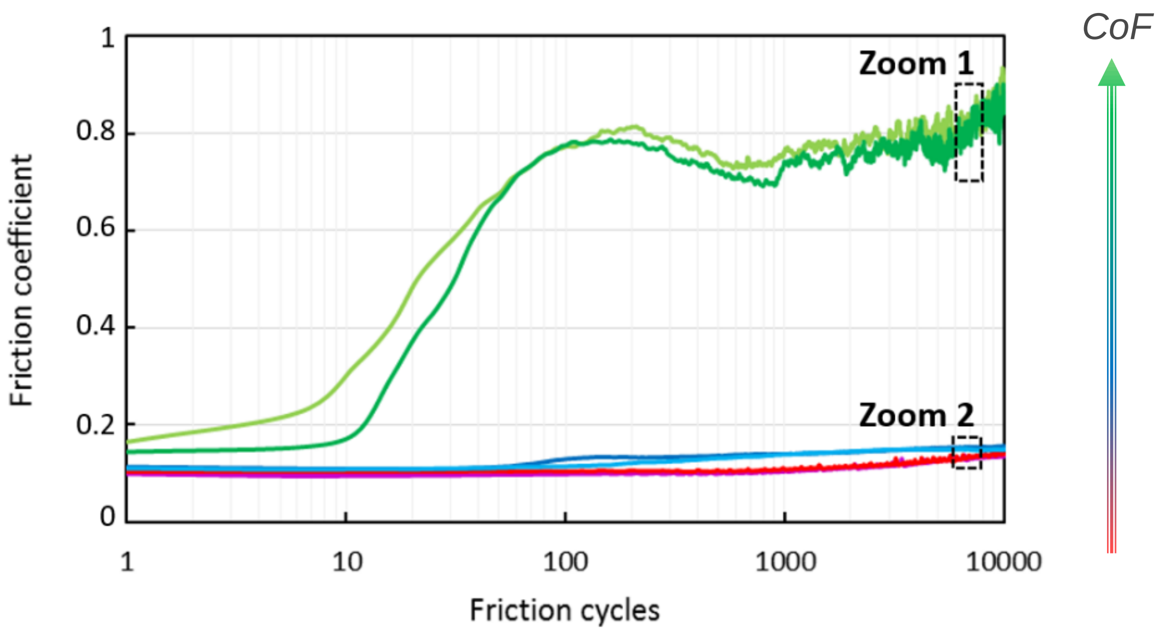

Increased Cr content

▼

Favors Ni selection inside the contact

▼

Loss of Nb_2O_5 which is ductile (potentially good lubricant)

Creation of NiCrO, NiFeO, NiO(H), Cr oxide (obviously less lubricious)

Remains… why Cr(VI)?

Thanks for your attention