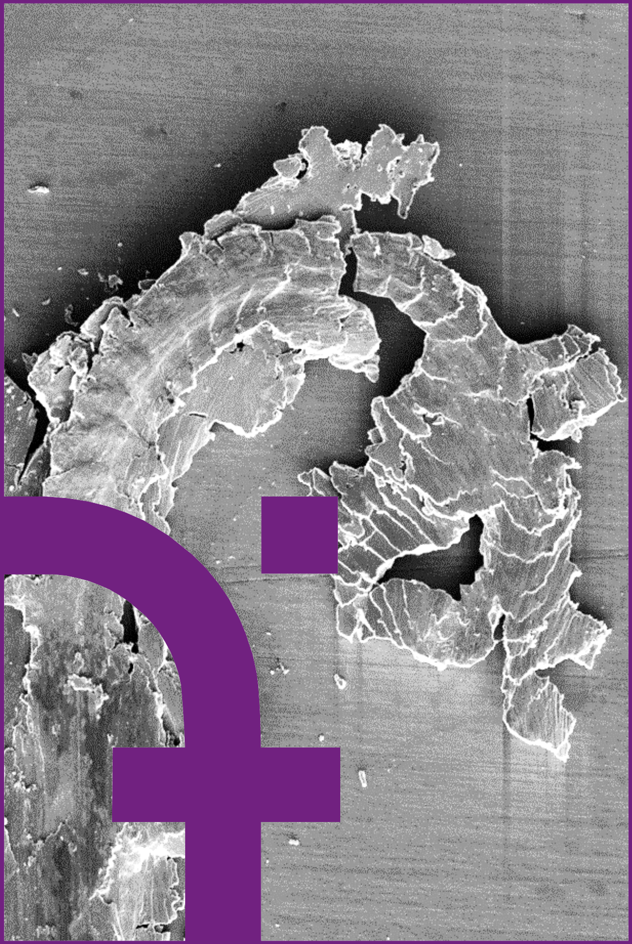
STRONG DEPENDENCE ON RELATIVE HUMIDITY OF THE TRIBOLOGICAL BEHAVIOR OF Cu-Zr BASED BMGs IN AMBIENT AIR



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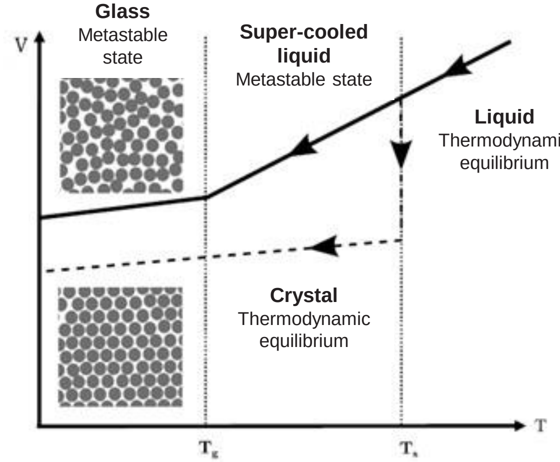
INTRODUCTION

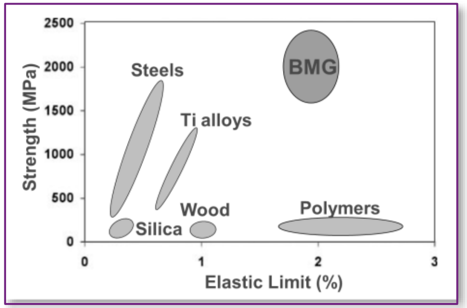


What is the nature of Bulk Metallic Glasses (BMGs)?

- **Metallic alloys with an amorphous structure**
- Since the 1980s: thanks to a fast cooling process + complex chemical composition

What are their main interests?

- **Exceptional mechanical properties** (high yield strengh, elastic strain, fracture toughness, fatigue resistance)
- **Corrosion resistance**
- **Net-shaped molding at microscale (low shrinkage)**



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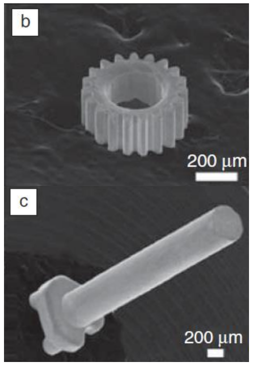


[2]

Industrial applications?

- Various engineering fields which involve **contact applications**: biomedical, micromechanics (microgears)
- **Which performances of BMGs under tribological conditions?**

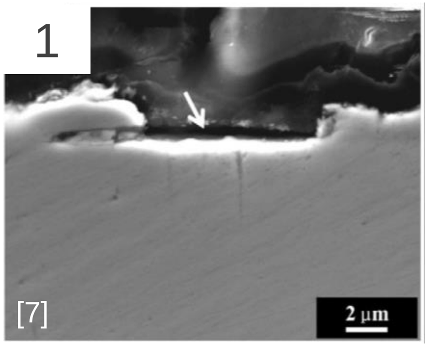
PROBLEMATIC RAISED

Tribological behavior of BMGs still poorly understood

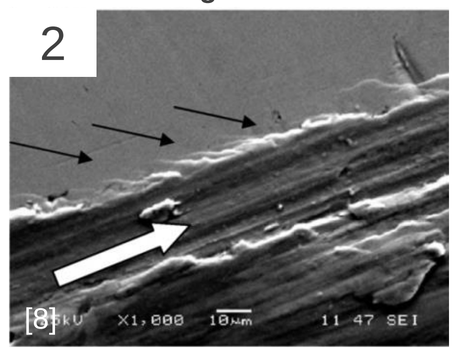
Most studies try to connect **tribological behavior** of BMGs to **mechanical properties** (hardness [3], toughness [4], bulk modulous [5])
→ **but no common agreement arises**

Salehan et al [6] (2019) suggested a **classification of wear mechanisms** of BMGs into 3 categories:

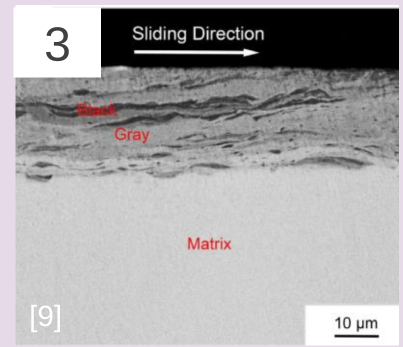
Microcracks, delamination and abrasive wear



Shear banding and work-softening



Oxide tribolayer formation and material transfer



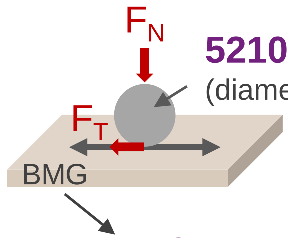
Raises the questions of…

oxide formation on BMG surface & **the impact of environmental conditions**

rarely questioned in the literature → **A potential impact of the humidity rate ?**

EXPERIMENTAL APPROACH

In-house designed ball-on plate tribometer (reciprocating linear)

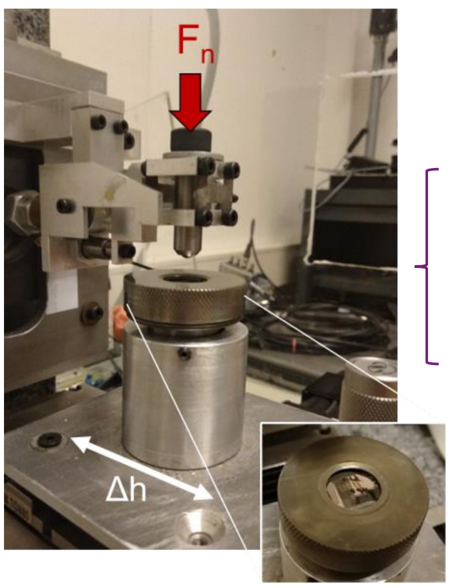


52100 steel (= 100Cr6)
(diameter 5 mm)

- $Cu_{47}Zr_{46}Al_7$
- $Cu_{44}Zr_{45}Al_9Nb_2$
- $Zr_{60}Cu_{28}Al_{12}$
- $Zr_{61}Cu_{25}Al_{12}Ti_2$

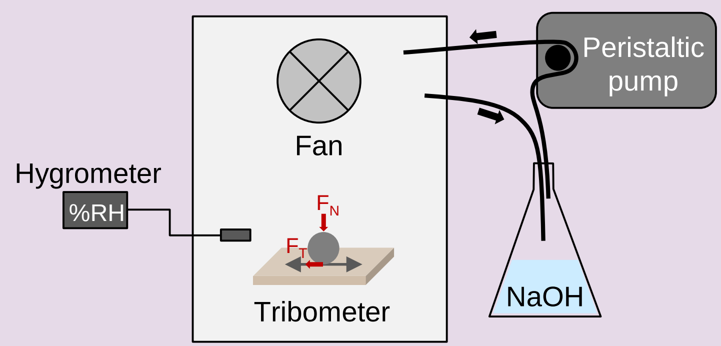
(15 x 10 x 1 mm^3)

Samples preparation:
- Polishing with sandpaper (Sa = 0.07 µm)
- Ultrasonically cleaned in isopropyl-alcohol for 3 min



Δh = ±1 mm
f = 1 Hz
Sliding speed = 4 mm/s
F_N = 1 N (dead weight)
5,000 friction cycles

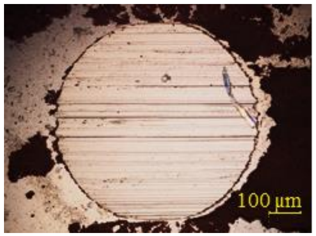
Humidity Control: from 20 %RH to 80 %RH



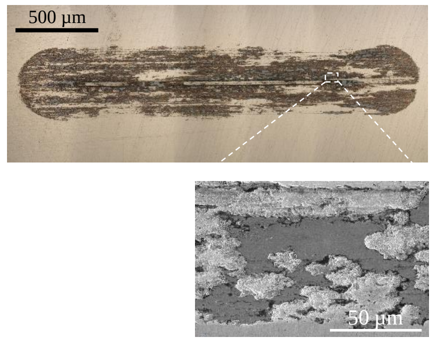
EXPERIMENTAL APPROACH

Surface characterization:

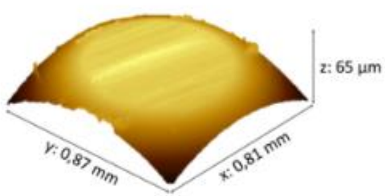
52100 ball

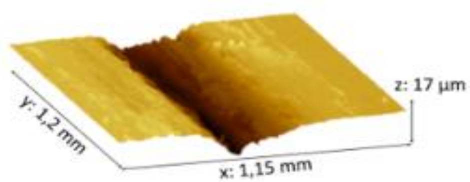


BMG plate



Optical & SEM observations

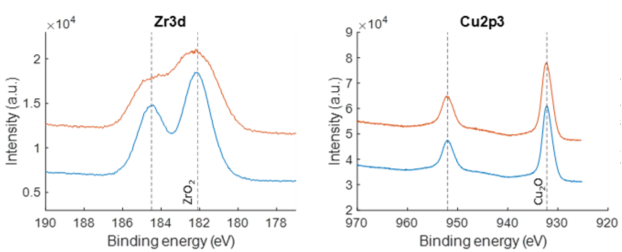




3D surface topography

variable focus optical microscope (InfiniteFocus, Alicona Imaging GmbH)

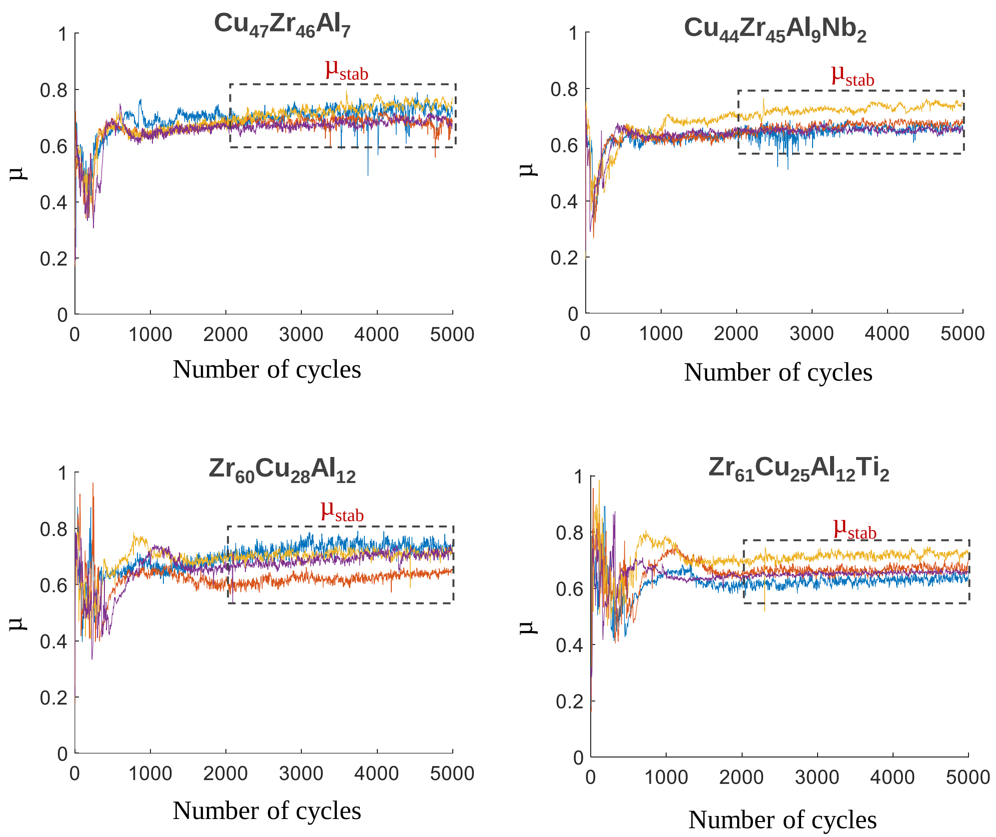
➔Which impact of relative humidity on the wear mechanisms?



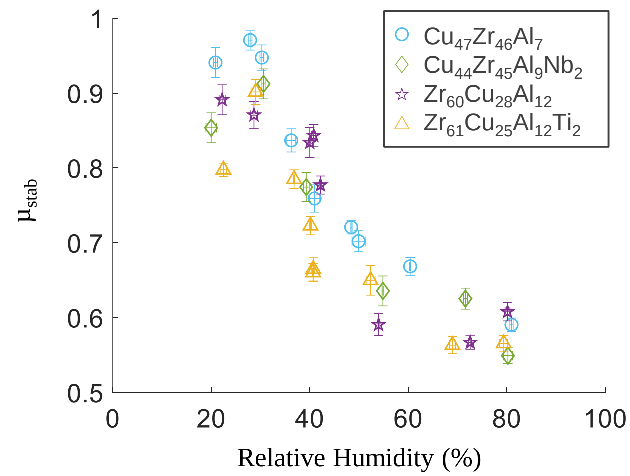
Chemical analyses: EDS, XPS

RESULTS – Humidity impact on the friction coefficient

4 tests per BMG plate were achieved at 50 %RH to assess results reproducibility:



μ_{stab} at varying relative humidities:

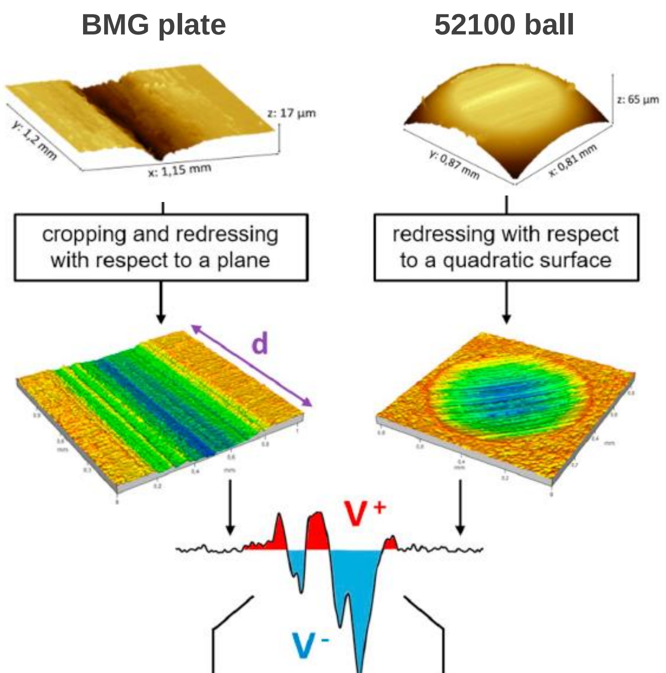


➔ **μ_{stab} highly dependent to relative humidity**

$\Delta h = \pm 1$ mm at 1 Hz, v = 4 mm/s, F_N = 1 N, 5000 friction cycles

RESULTS – Humidity impact on the wear volume

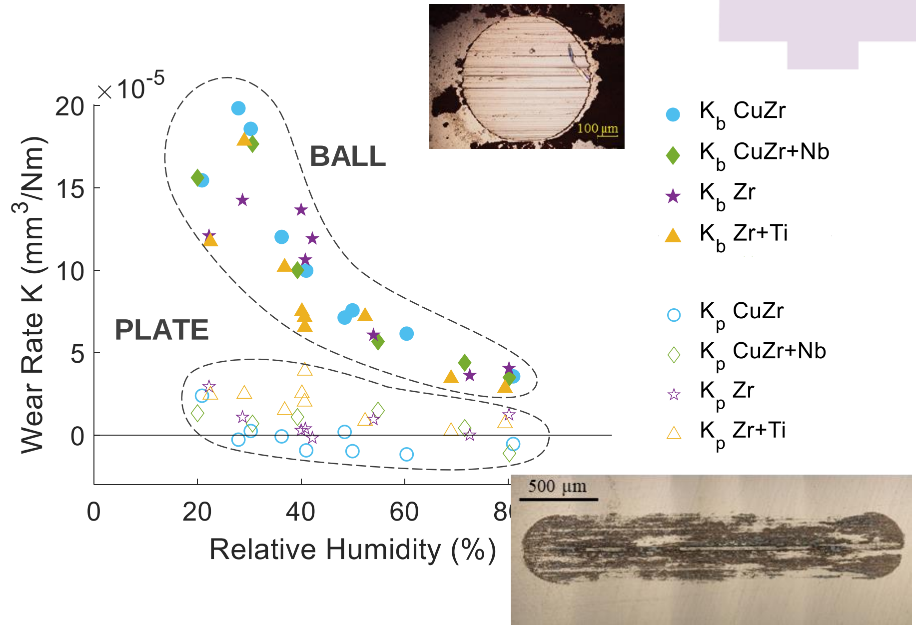
Definition of wear rate K: lost volume of matter per unit of normal force and sliding distance



$$K_p = \frac{V^- - V^+}{2*d*N_{cycles}*F_N}$$

$$K_b = \frac{V^- - V^+}{2*d*N_{cycles}*F_N}$$

K_p and K_b at varying relative humidities:



➔ $K_{ball} >> K_{BMG}$
$H_{ball} >> H_{BMG}$ ➔ ***counter-intuitive…***
(820 HV and 450 HV)

➔ High dependency of K_{ball} to the relative humidity

?

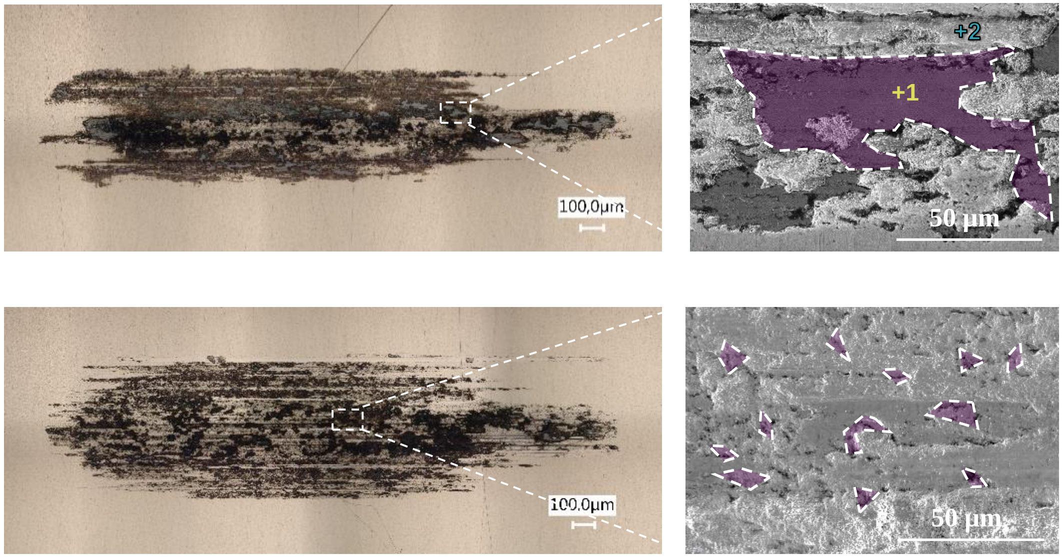
RESULTS – The role of third bodies

Optical and SEM observations, EDS and XPS analyses:

Fe_2O_3 particles traped into the contact area → agglomerate into 3rd body patches

80 %RH

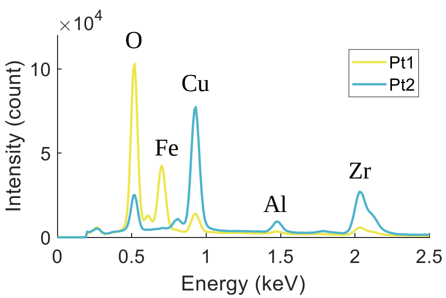
20 %RH

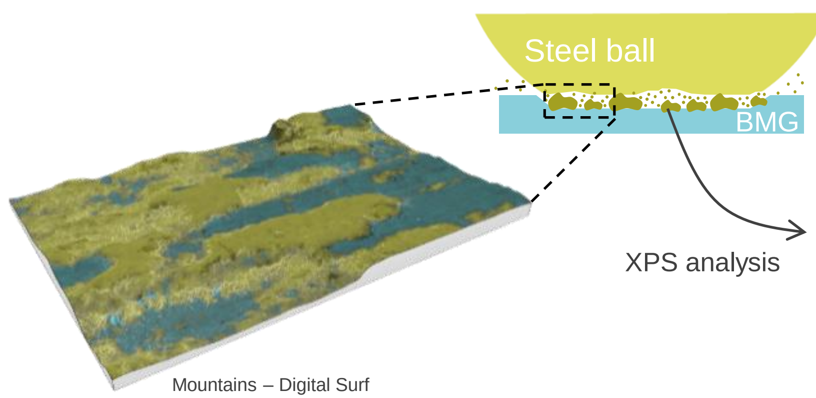


	Morphology of patches	Nature of the oxide
80 %RH	Smooth & dense	Fe_2O_3
20 %RH	Rough & scattered	Fe_2O_3

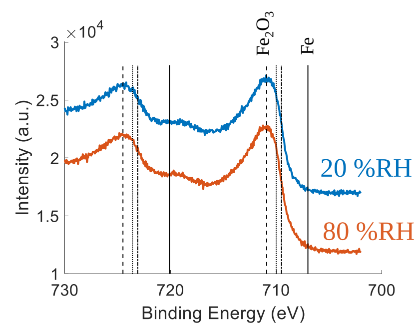
Responsible of:

- **small K_{BMG}** (protective 3rd body layer)
- **large K_{ball}**

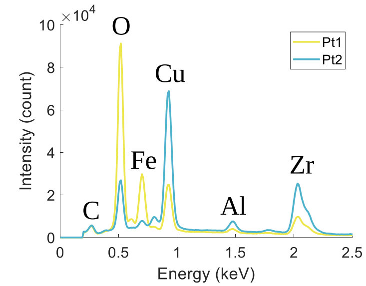




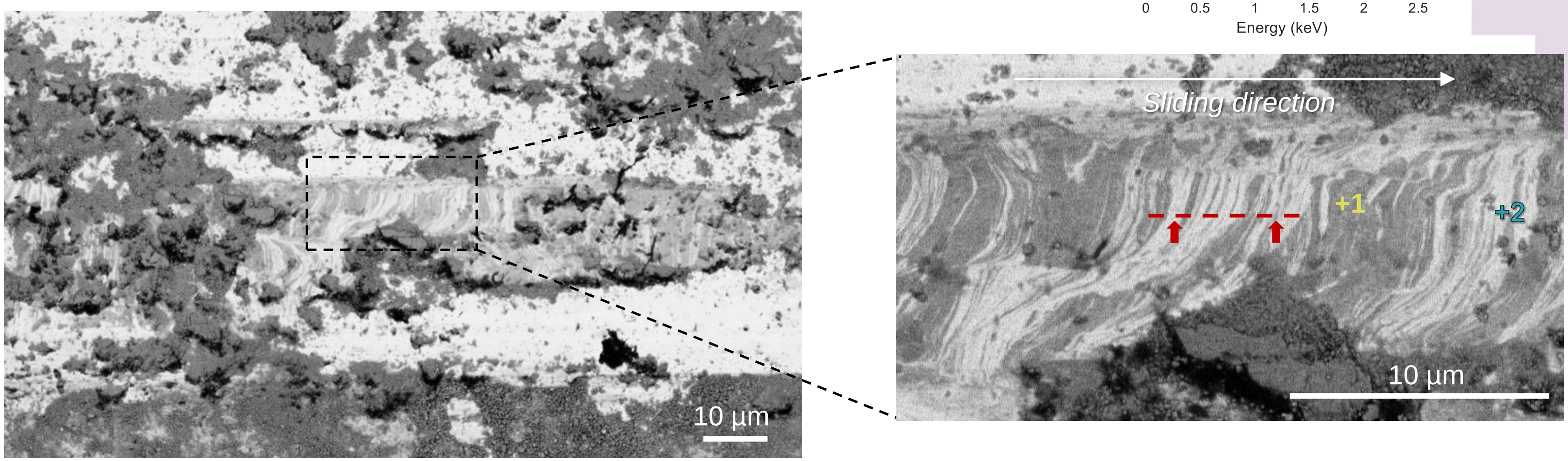
Mountains – Digital Surf



RESULTS – The role of third bodies

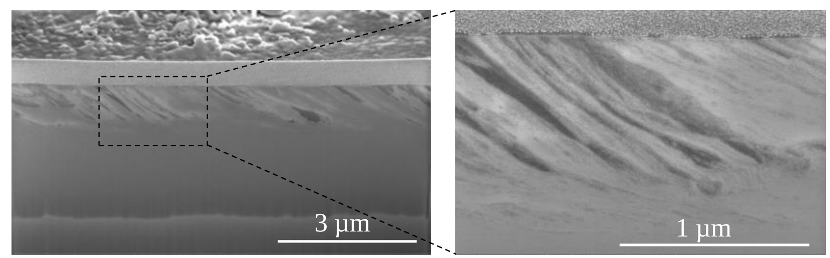


Surprising aspect of some **"zebra-striped" patches** …



- ➔ **mixed composition**:
  Fe-oxides (dark stripes) & Zr-Cu-oxides (bright stripes)
- ➔ **depth greater than 1 µm**
- ➔ Mophology suggests **high plastic deformation and surface ductility**

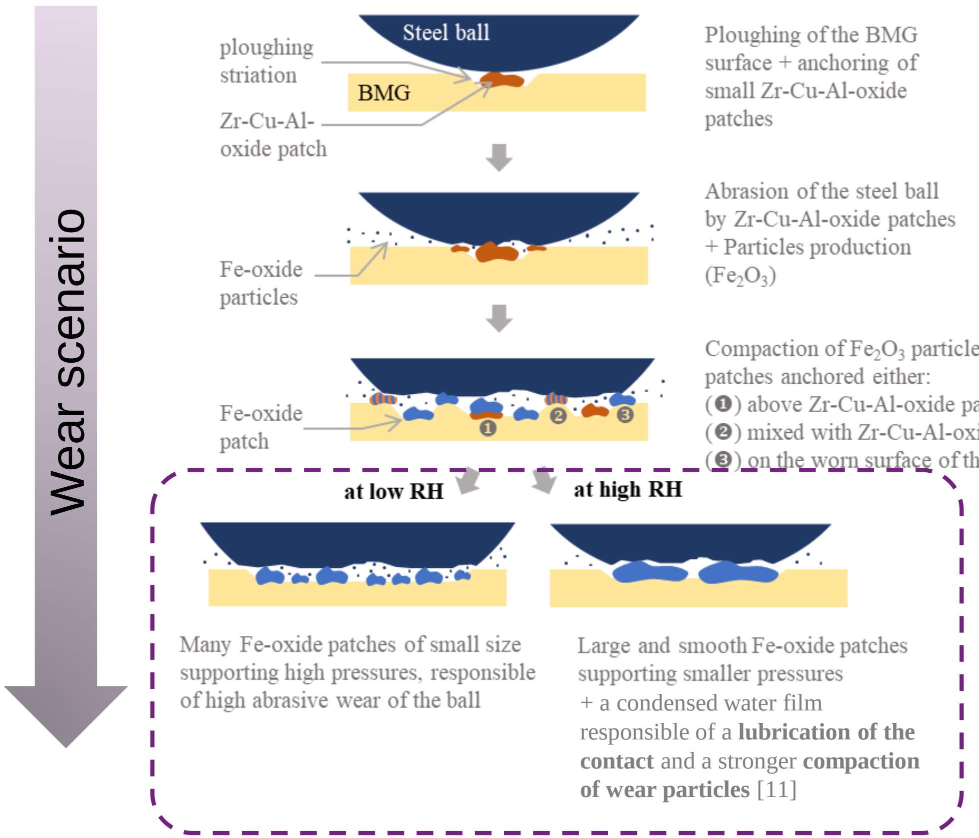
FIB cross section:

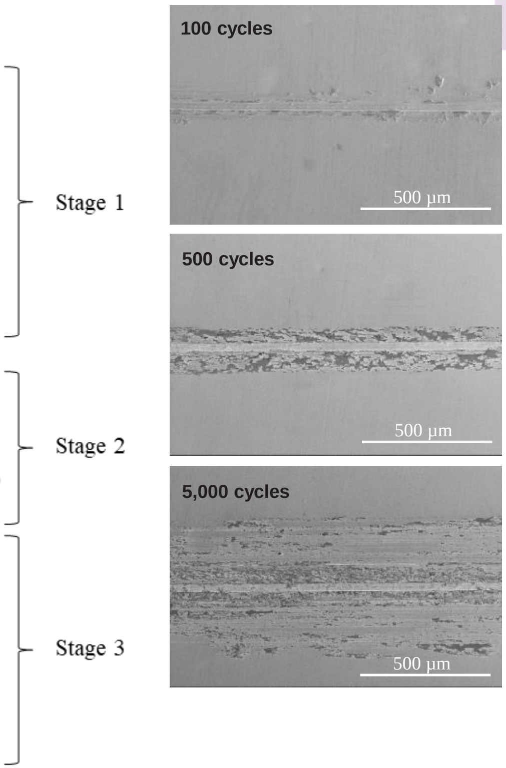


CONCLUSION

➔ Wear behavior of BMGs is **not related to the hardness** of the two materials in contact

➔ **Tribochemical wear mechanisms** leading to material transfer from the steel ball to the BMG plate:

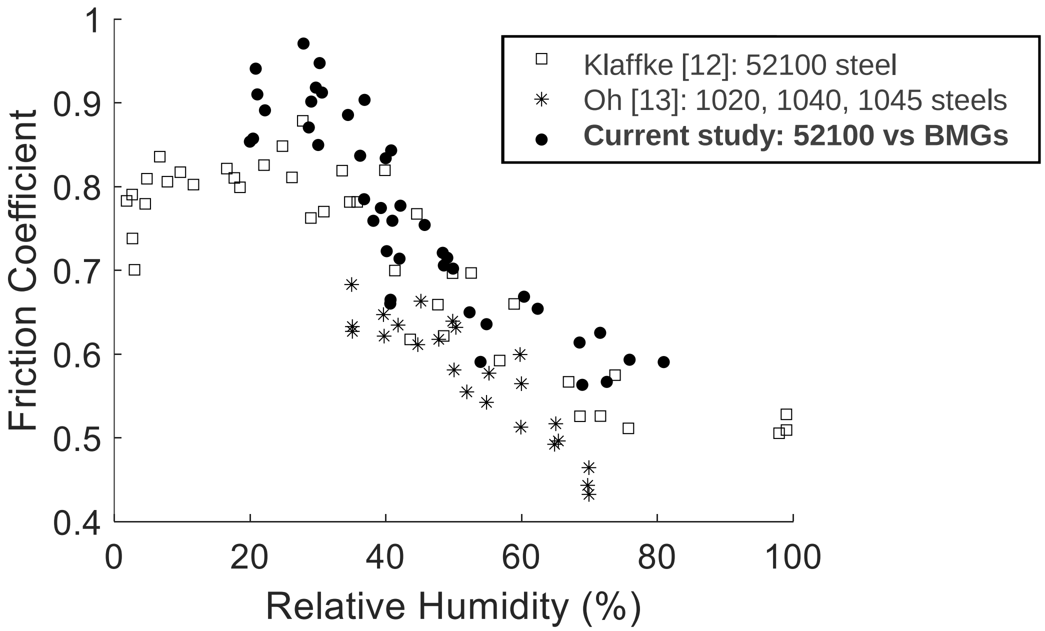




➔ Rises the question of the role of **the counterface** during friction between BMG / 52100

CONCLUSION

➔ A look to the literature…



➔ dependency to RH highly correlated to the **steel counterface**

➔ future works will focus on the **impact of the counterface material**

THANKS FOR YOUR ATTENTION

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