

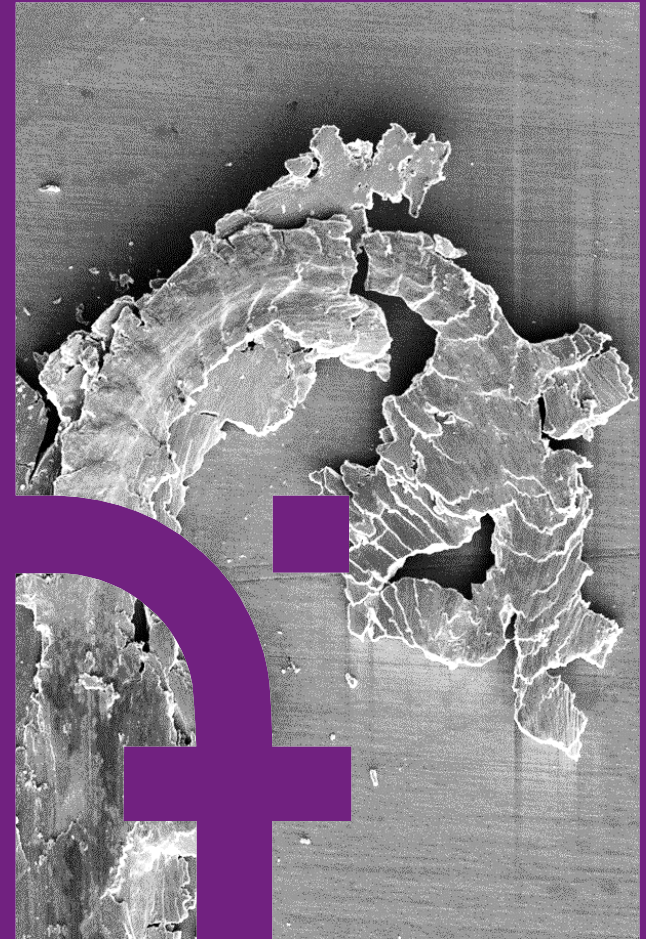
STRONG DEPENDENCE ON RELATIVE HUMIDITY OF THE TRIBOLOGICAL BEHAVIOR OF Cu-Zr BASED BMGs IN AMBIENT AIR

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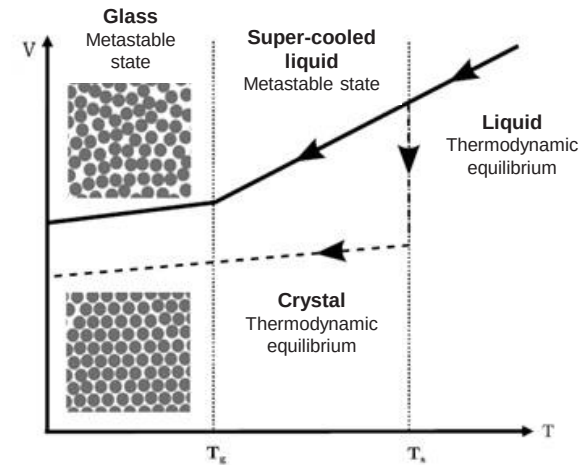
³⁾ Vulkam Inc. Amorphous metal micro casting / www.vulkam.com / France



INTRODUCTION

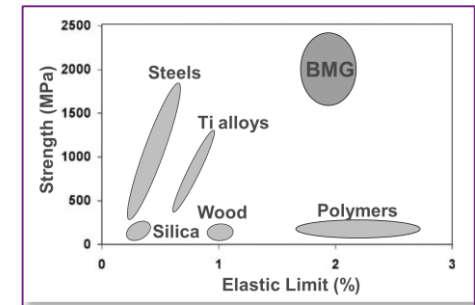
What is the nature of Bulk Metallic Glasses (BMGs)?

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

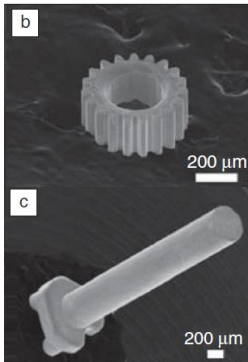


What are their main interests?

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



[1]



[2]

Industrial applications?

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

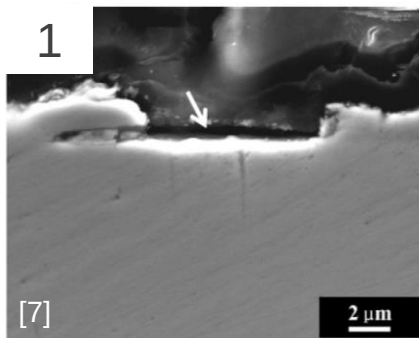
PROBLEMATIC RAISED

▶ Tribological behavior of BMGs still poorly understood

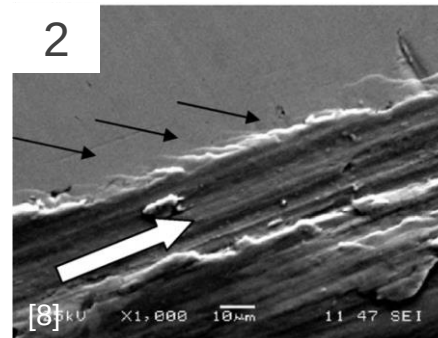
▶ Most studies try to connect **tribological behavior** of BMGs to **mechanical properties** (hardness [3], toughness [4], bulk modulus [5])
→ **but no common agreement arises**

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

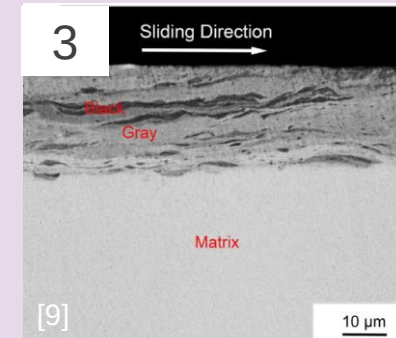
Microcracks, delamination and abrasive wear



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)



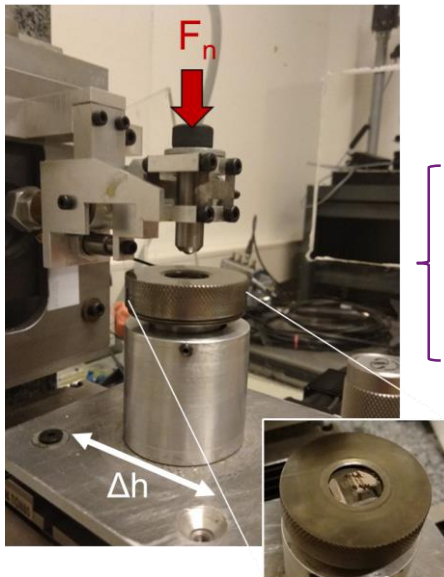
52100 steel (= 100Cr6)
(diameter 5 mm)

- $\text{Cu}_{47}\text{Zr}_{46}\text{Al}_7$
- $\text{Cu}_{44}\text{Zr}_{45}\text{Al}_9\text{Nb}_2$
- $\text{Zr}_{60}\text{Cu}_{28}\text{Al}_{12}$
- $\text{Zr}_{61}\text{Cu}_{25}\text{Al}_{12}\text{Ti}_2$

(15 x 10 x 1 mm³)

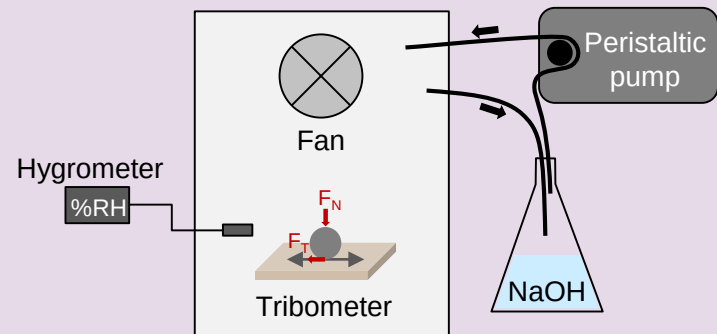
Samples preparation:

- Polishing with sandpaper ($S_a = 0.07 \mu\text{m}$)
- Ultrasonically cleaned in isopropyl-alcohol for 3 min



- $\Delta h = \pm 1 \text{ mm}$
- $f = 1 \text{ Hz}$
- Sliding speed = 4 mm/s
- $F_N = 1 \text{ N}$ (dead weight)
- 5,000 friction cycles

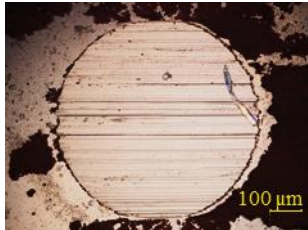
Humidity Control: from 20 %RH to 80 %RH



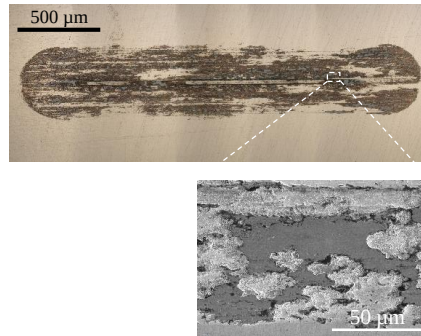
EXPERIMENTAL APPROACH

Surface characterization:

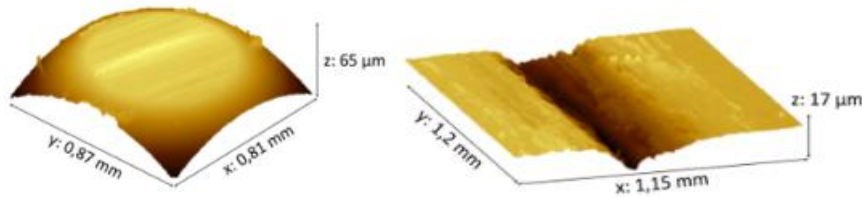
52100 ball



BMG plate



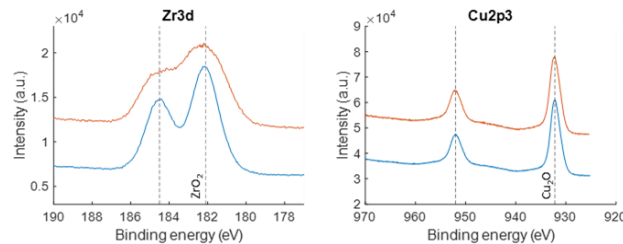
Optical & SEM observations



3D surface topography

variable focus optical microscope (InfiniteFocus, Alicona Imaging GmbH)

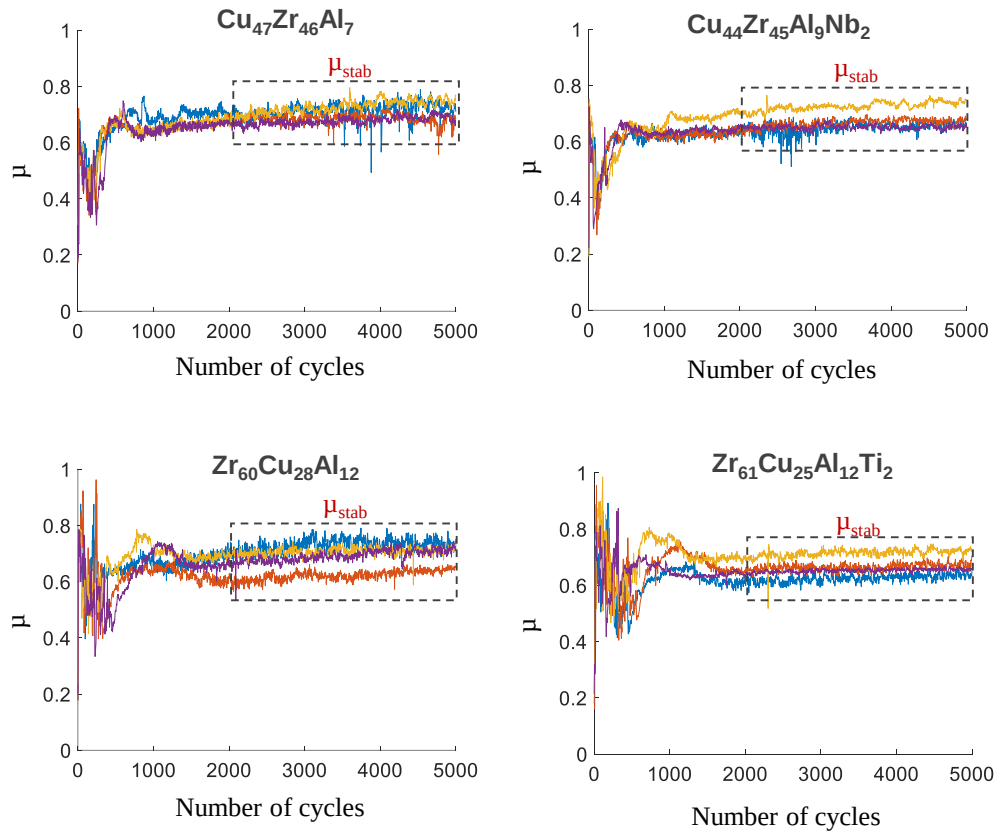
→ Which impact of relative humidity on the wear mechanisms?



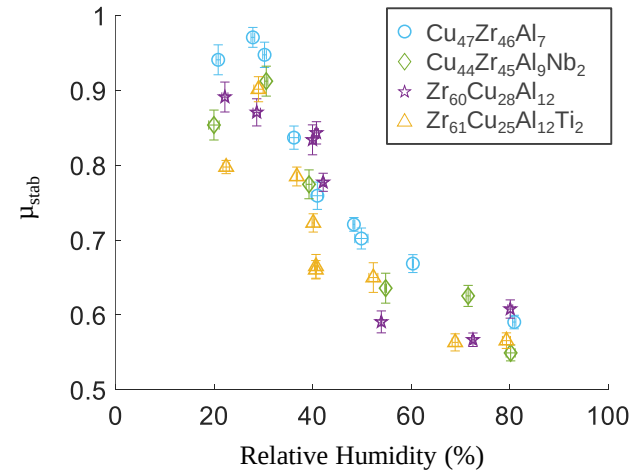
Chemical analyses:
EDS, XPS

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:

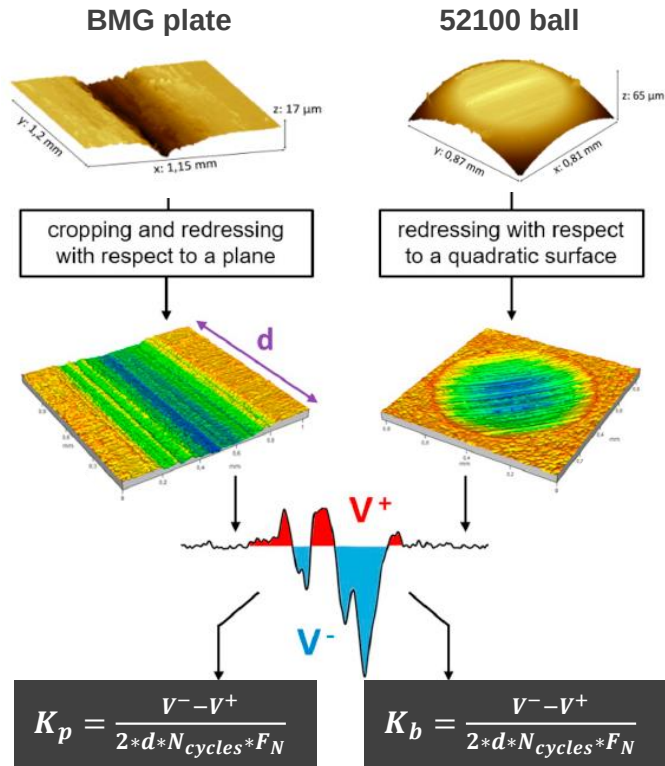


→ μ_{stab} highly dependent to relative humidity

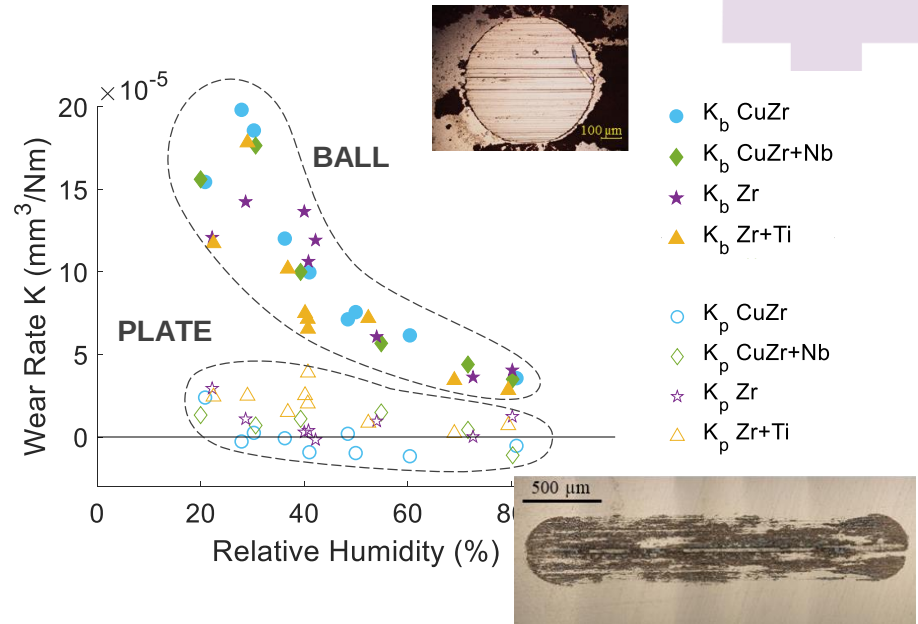
$\Delta h = \pm 1 \text{ mm}$ at 1 Hz, $v = 4 \text{ mm/s}$, $F_N = 1 \text{ N}$, 5000 friction cycles

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 and K_b at varying relative humidities:



$\rightarrow K_{ball} \gg K_{BMG}$
 $H_{ball} \gg H_{BMG} \rightarrow$ *counter-intuitive...*
 (820 HV and 450 HV)

$\rightarrow$ High dependency of K_{ball} to the relative humidity

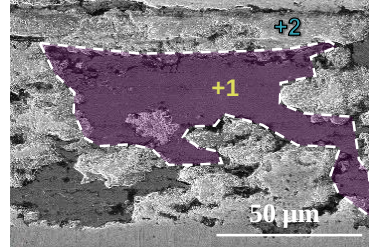
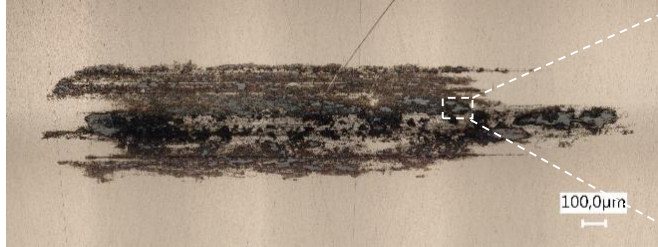
?

RESULTS – The role of third bodies

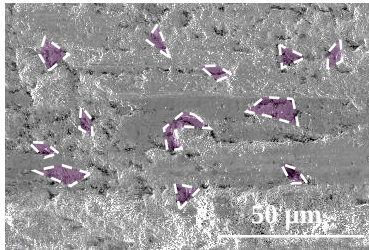
Optical and SEM observations, EDS and XPS analyses:

Fe_2O_3 particles trapped into the contact area $\rightarrow$ agglomerate into 3rd body patches

80 %RH



20 %RH



Morphology of patches

Nature of the oxide

Smooth & dense

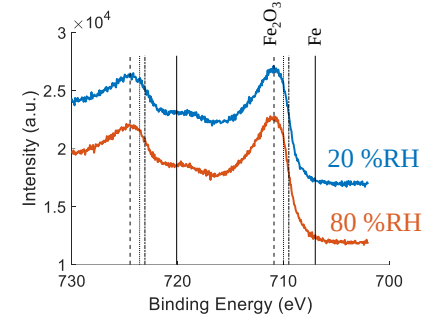
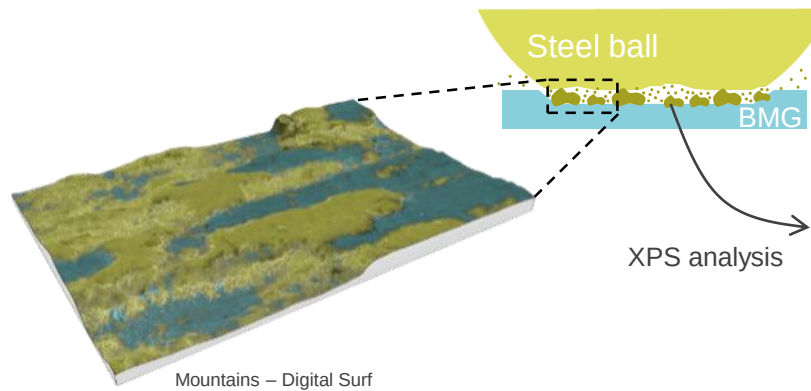
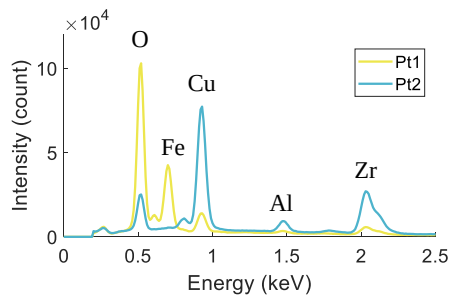
Fe_2O_3

Rough & scattered

Fe_2O_3

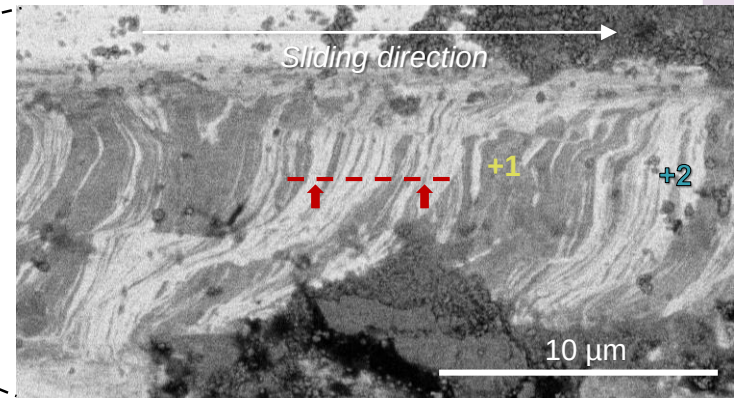
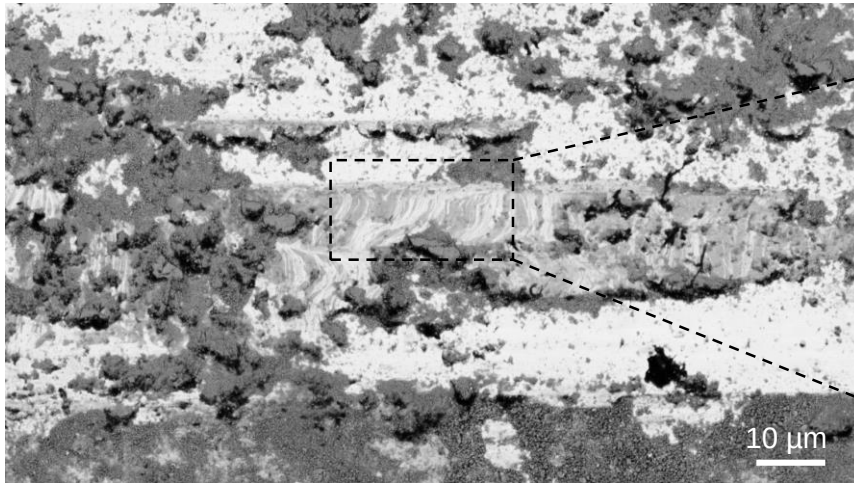
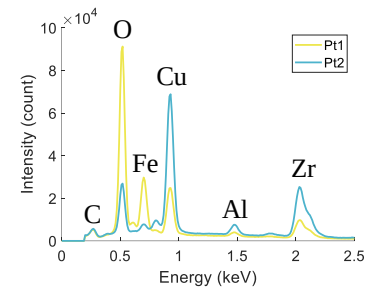
Responsible of:

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



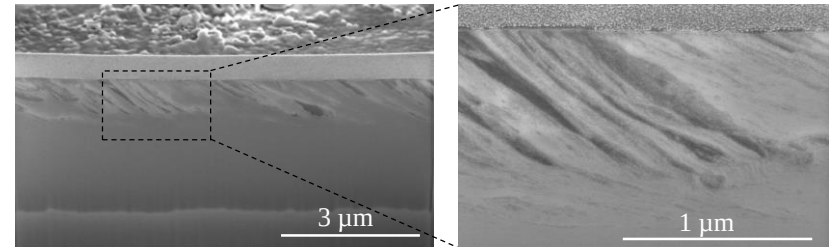
RESULTS – The role of third bodies

Surprising aspect of some “zebra-striped” patches ...



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

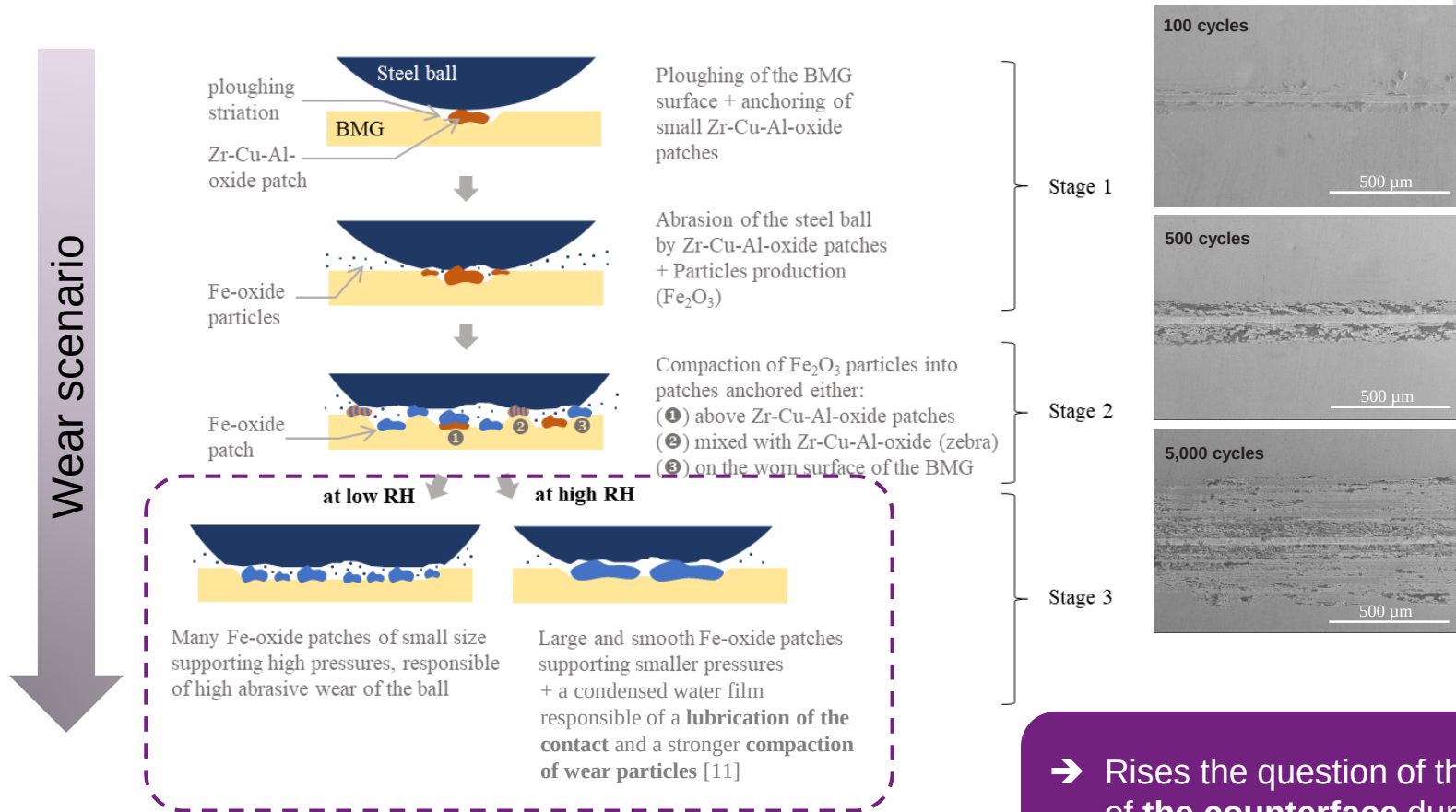
FIB cross section:



CONCLUSION

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

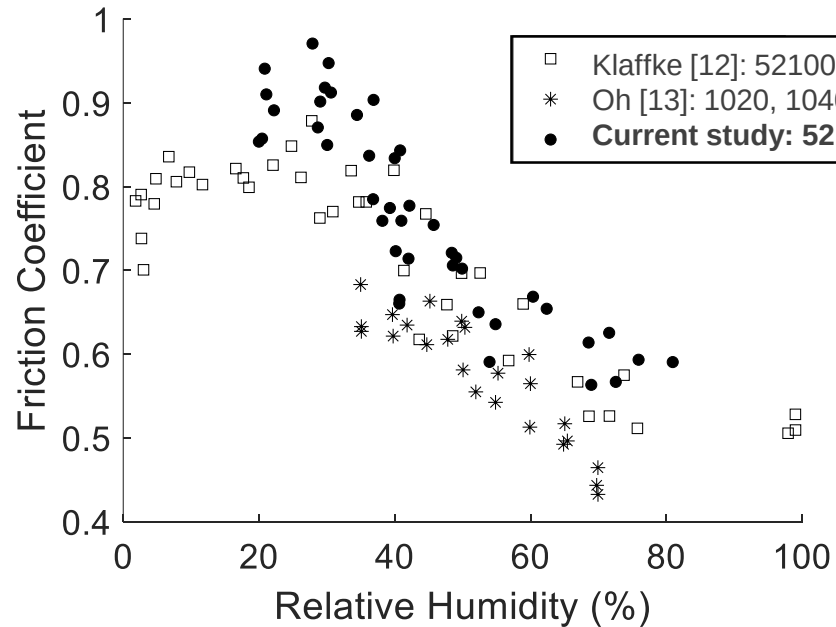
→ **Tribochemical wear mechanisms** leading to material transfer from the steel ball to the BMG plate:



→ Raises 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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