



# Joining Alumina to Ti6Al4V Alloy Using Rolled Brazing Fillers

Omid Emadinia<sup>1,2</sup>, F. Viana<sup>1,2</sup>, M.F. Vieira<sup>1,2</sup>, Aníbal Guedes<sup>3</sup>, Sónia Simões<sup>1,2</sup>

<sup>1,2</sup>Department of Metallurgical and Materials Engineering, University of Porto, Rua Dr. Roberto Frias, 4200-465 Porto, Portugal

<sup>1,2</sup>LAETA/INEGI - Institute of Science and Innovation in Mechanical and Industrial Engineering, Rua. Dr. Roberto Frias, 4200-465 Porto, Portugal

<sup>3</sup>CMEMS, Department of Mechanical Engineering, University of Minho, Portugal

November 5<sup>th</sup> 2020

# Motivation

## Increasing the applications of advanced ceramics for functional structures

- Having high thermal stability, stiffness and wear resistance
- Applications in aerospace, automotive, and chemical industries, etc.
- However, production cost & manufacturing large or complex components are challenging

## Joining ceramic materials to metallic parts is a solution

- It is not an easy task because metals & ceramics are different in chemical compositions, having different properties, e.g.:
  - Coefficient of thermal expansion
  - Wettability with liquid metal

## Brazing can be a reliable method

- This technique involves lower temperature, pressure and holding time that it is required for diffusion bonding process
- Brazing has a merit of joining irregular dimensions
- Generally, it leads to the development of lower residual stresses than other joining processes

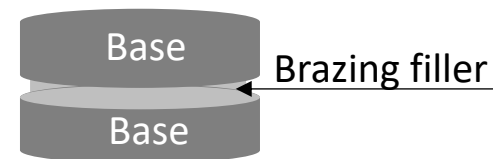
# Motivation

## Brazing involves

- Joining two components by melting a brazing filler ( $> 450\text{ }^{\circ}\text{C}$ ) that wets and reacts with both base materials, it is traditionally carried out by a torch and the brazing filler

## Diffusion brazing involves

- Placing a brazing filler between two base materials under optimized conditions:
  - Proper brazing filler
  - Adequate heating apparatus
  - Proper heating temperature
- During the heating period, the brazing filler material reacts with the components resulting in
  - The formation of phases with higher melting temperatures



# Motivation

## Brazing fillers

- Titanium base compositions such as
  - Ti-Cu-Ni system
- Silver base compositions like
  - Ag-Cu system
    - ❖ Non-rigid reaction products in the interface, such as (Ag), can buffer residual stresses developed throughout the interface though, the operating temperature of joints cannot exceed 300/350 °C
- Etc.

## A comparison

- Ti base brazing fillers require higher brazing temperatures (~1000 °C) than Ag base brazing fillers (~800 °C)

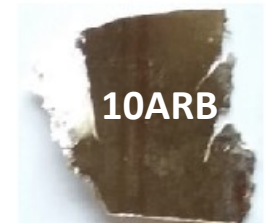
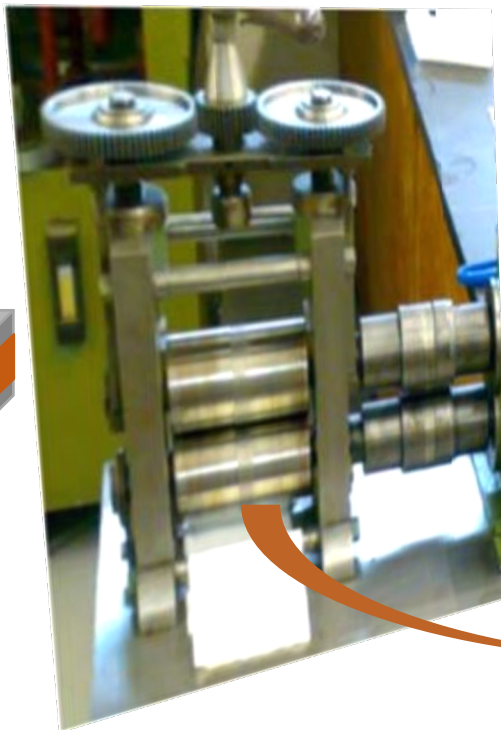
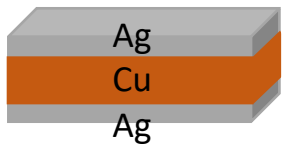
# Objectives

## This study involves

- Producing Ag-28Cu fillers by rolling processes in two conditions:
  - A Cu sheet clad by Ag sheets
  - Multilayered Ag-Cu sheet
- Diffusion brazing of  $\text{Al}_2\text{O}_3$  to Ti6Al4V by the use of
  - Rolled Ag-Cu fillers
  - Commercial Ag-28Cu filler
- Microstructural characterization of the brazed interface by scanning electron microscopy technique (SEM/BEI/EDS) to understand:
  - The influence of Ag-Cu layers on the microstructure evolved at the joint interface
- The effect of microstructure on the mechanical properties of the joints

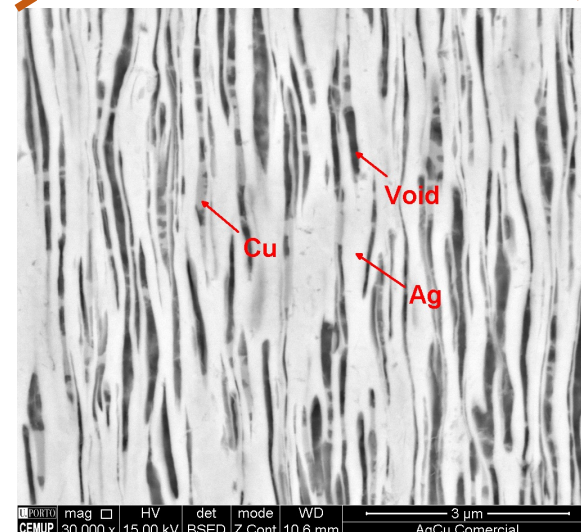
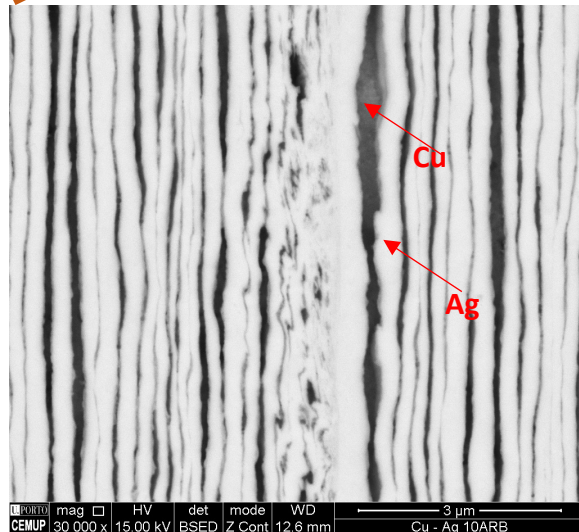
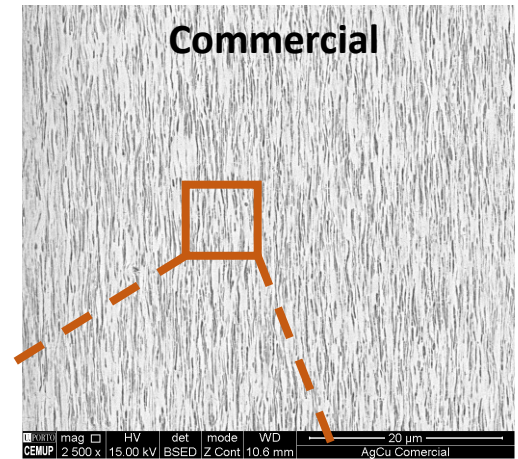
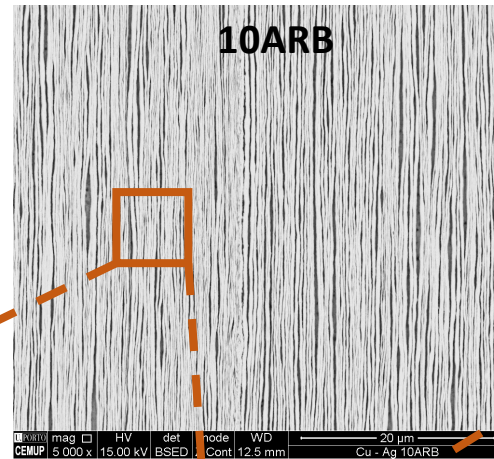
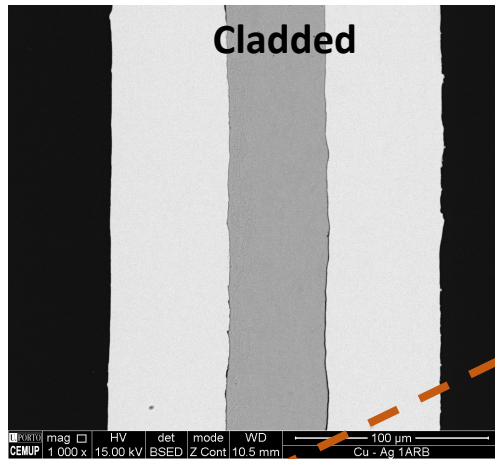
# Rolling process

Binding between each layer is obtained by a total reduction of 50% in Roll Bonding and in Accumulative Roll Bonding (ARB) processes.



$\dot{\epsilon} = 20 \text{ s}^{-1}$

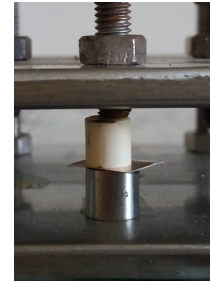
# Fillers: microstructure



# Experimental procedure

## Preparation

- Cutting primary alumina and the Ti alloy rods into small disks
- Grinding until 1000 mesh
- Washing by acetone, alcohol and drying
- Assembling with brazing filler

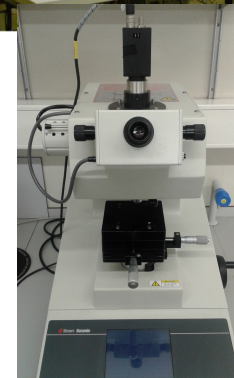
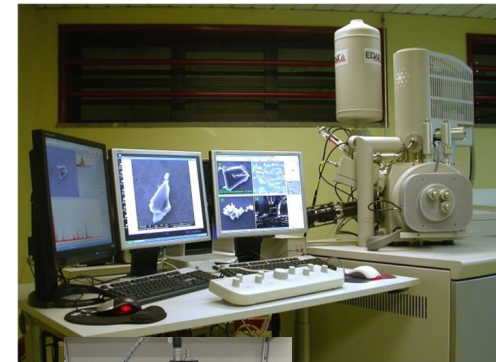


## Brazing

- Heating in a resistance furnace, metallic tube, assembled with a high vacuum pump
  - 830 °C for 30 min in a vacuum better than  $10^{-4}$  Pa

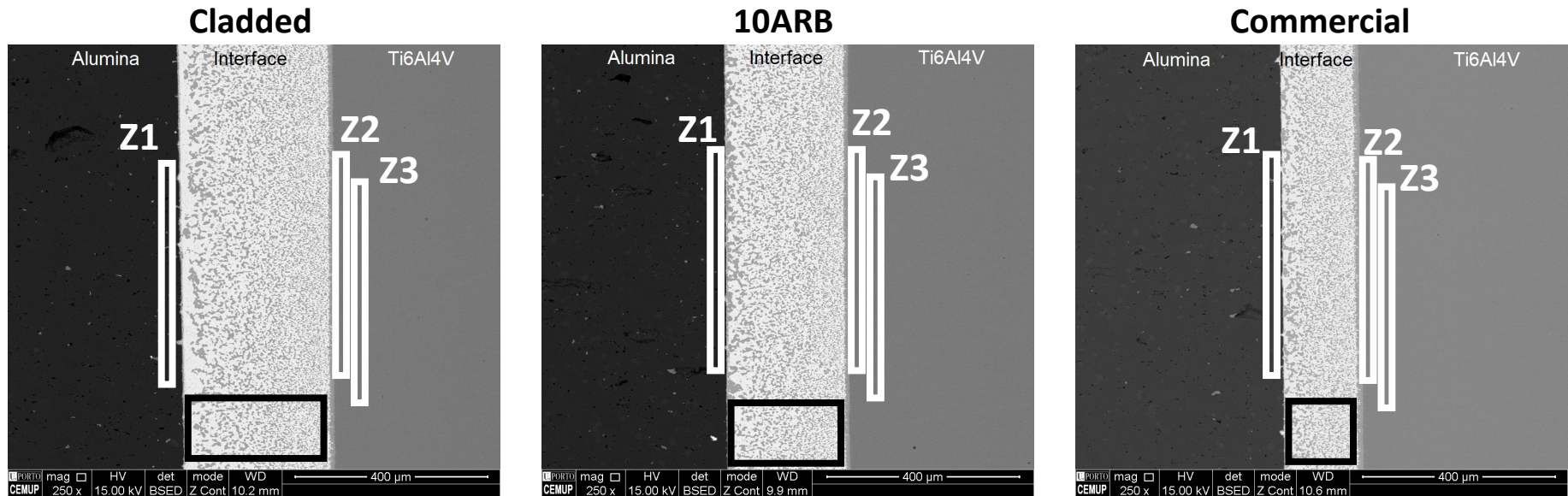
## Evaluations

- Grinding and polishing joints for microscopic observations by
  - Optical Microscope
  - SEM/BEI/EDS techniques for phase identifications
- Providing hardness maps of the interfaces by microhardness technique ( $F=98$  mN (HV0.01))



# Diffusion in base materials

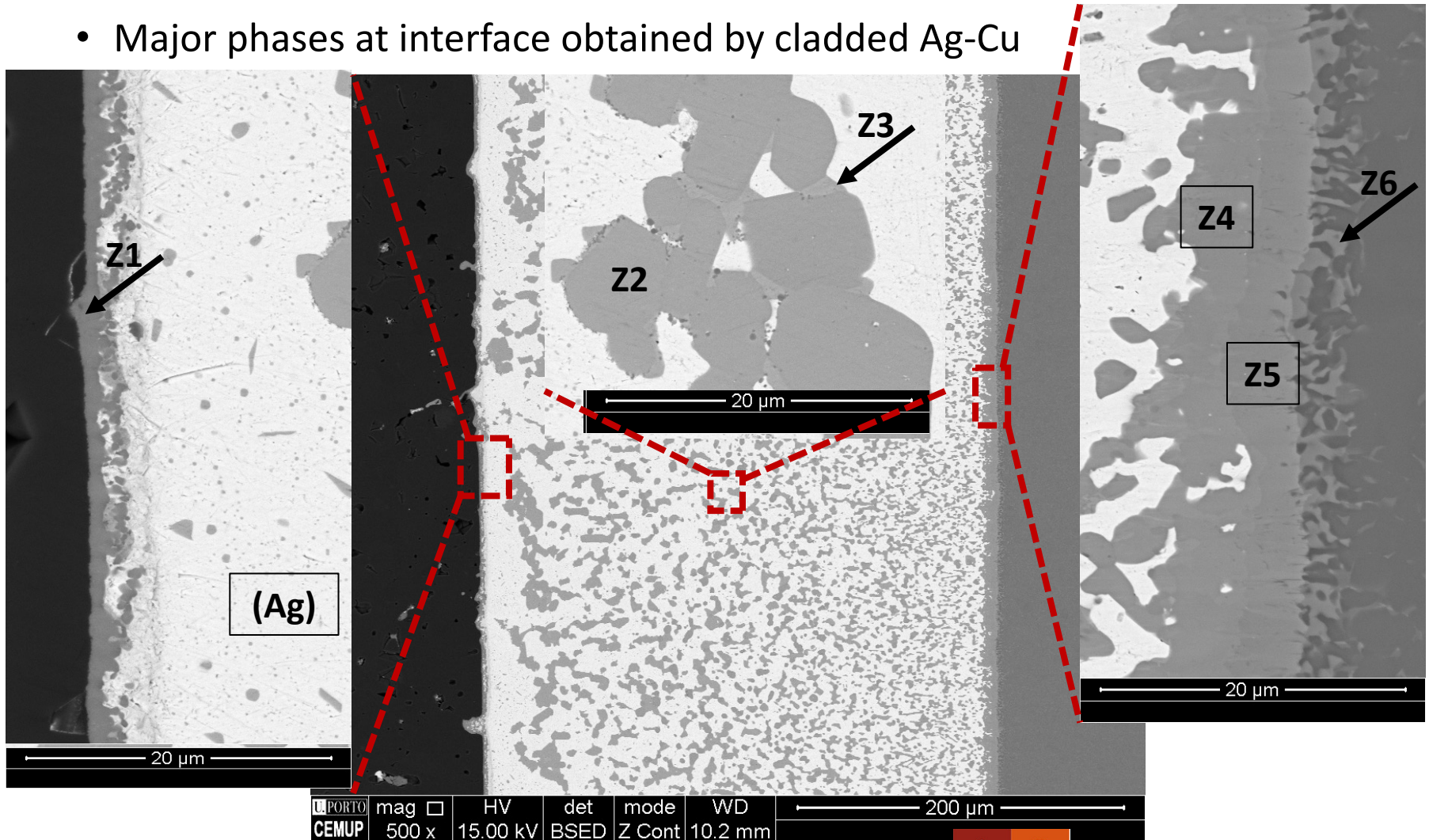
- Sound Al<sub>2</sub>O<sub>3</sub> / Ti6Al4V joints, brazing at 830 °C / 30min / ~10<sup>-4</sup> Pa



| Zone       | Distribution of Ag or Cu               |
|------------|--|
| Interfaces | Eutectic composition (40 at.%)         |
| Z1         | Alumina without any traces of Ag or Cu |
| Z2         | Ag is 0, and Cu is 4.8 at.%            |
| Z3         | Both Ag and Cu are 0                   |

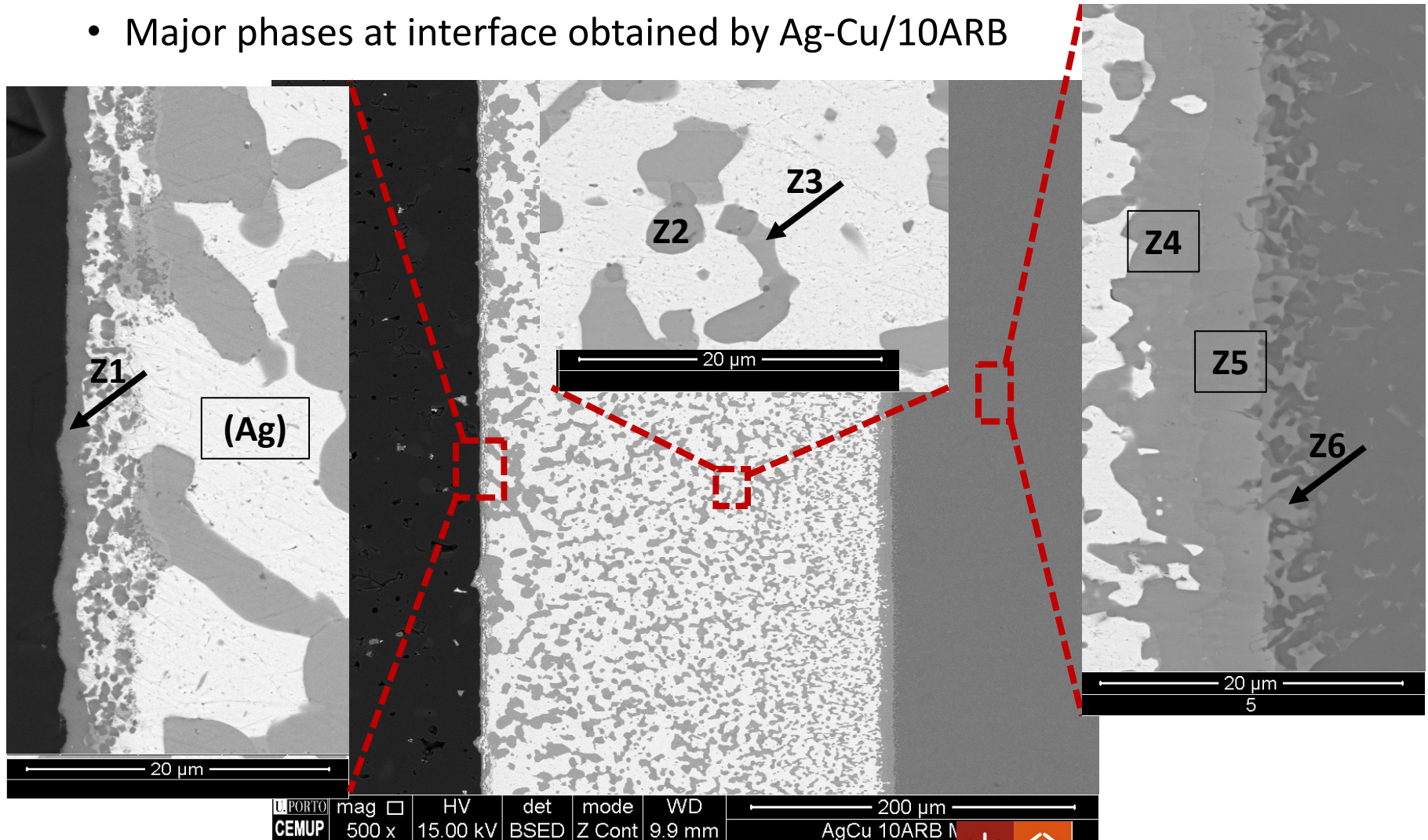
# Microstructure in interfaces

- Major phases at interface obtained by cladded Ag-Cu



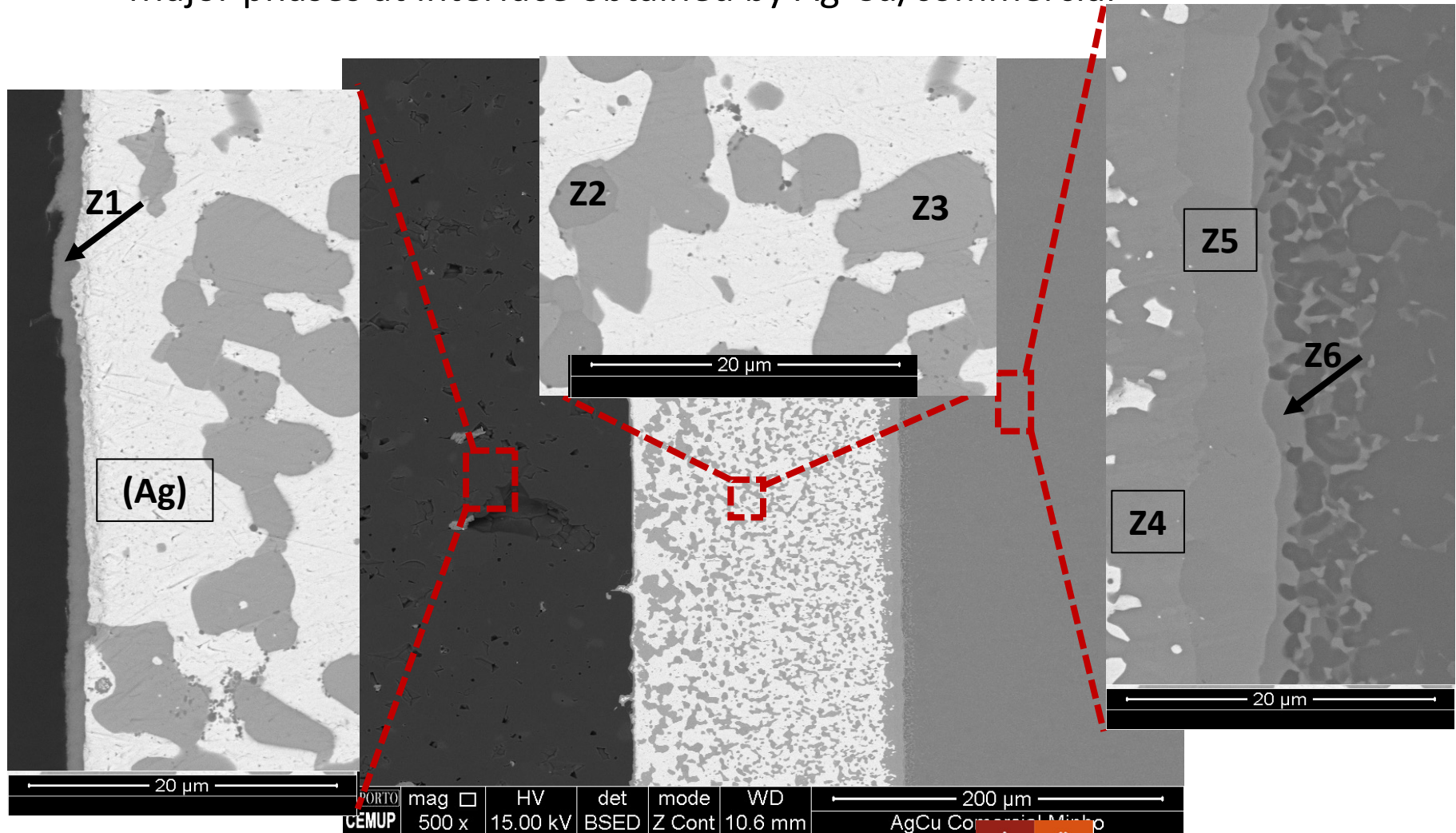
# Microstructure in interfaces

- Major phases at interface obtained by Ag-Cu/10ARB



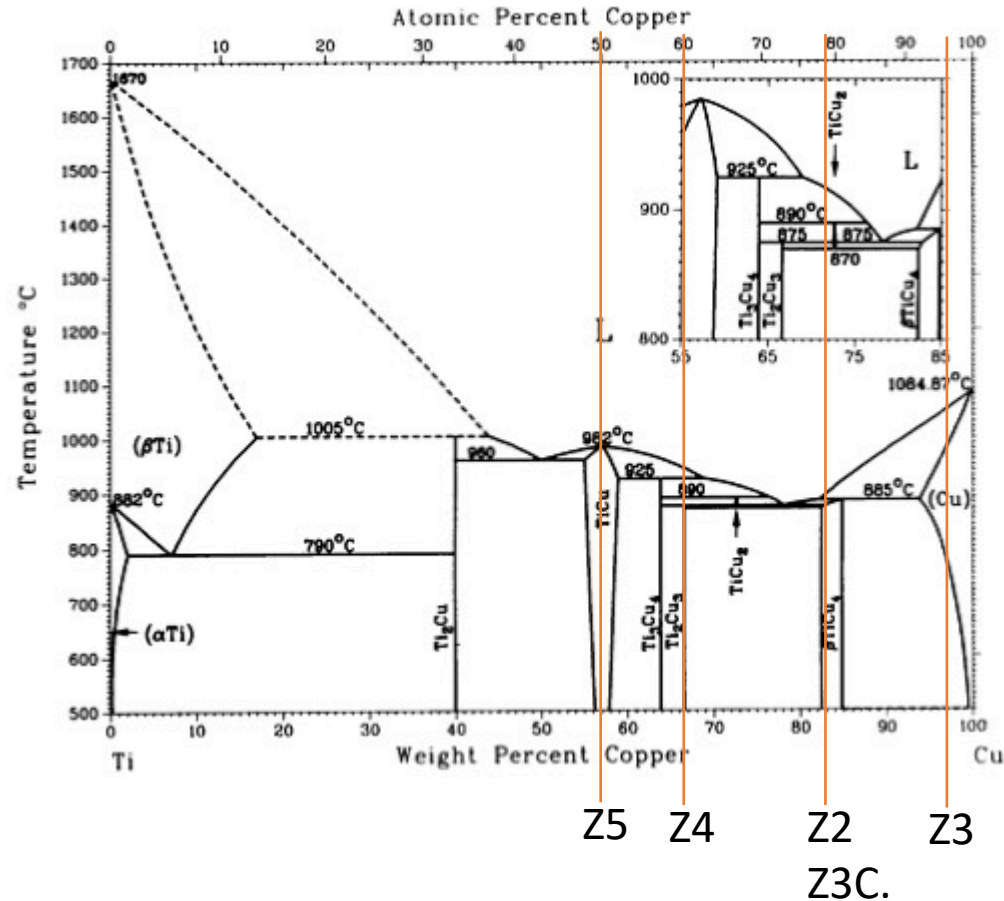
# Microstructure in interfaces

- Major phases at interface obtained by Ag-Cu/commercial



# Possible phases in interfaces

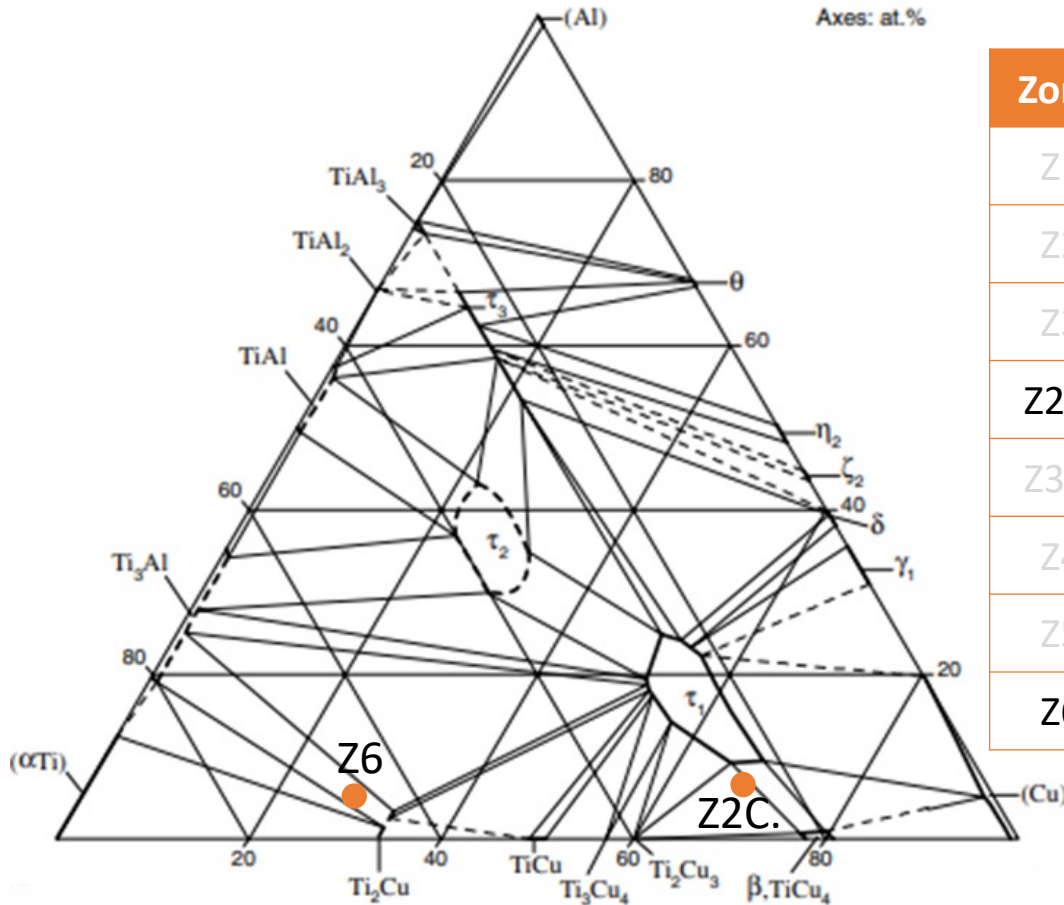
- Determination by the means of phase binary/ternary phase diagrams



| Zone | Possible phases  |
|------|--|
| Z1   | A complex oxide of Ti-Cu-Al                                |
| Z2   | 1.8Ag-19.9Ti-78.3Cu: TiCu <sub>4</sub>                     |
| Z3   | 1.7Al-1.9Ag-1.8Ti-94.6Cu: (Cu)                             |
| Z2C. | 7.1Al-1.5Ag-24Ti-67.4Cu: TiCu <sub>4</sub>                 |
| Z3C. | 1.6Ag-19.7Ti-78.7: TiCu <sub>4</sub>                       |
| Z4   | 3.5Al-2.1Ag-35.5Ti-58.9Cu: Ti <sub>2</sub> Cu <sub>3</sub> |
| Z5   | 1.0Al-2.1Ag-48.2Ti-48.7Cu: TiCu                            |
| Z6   | 5.6Al-1.1Ag-65.1Ti-28.2Cu: Ti <sub>2</sub> Cu              |

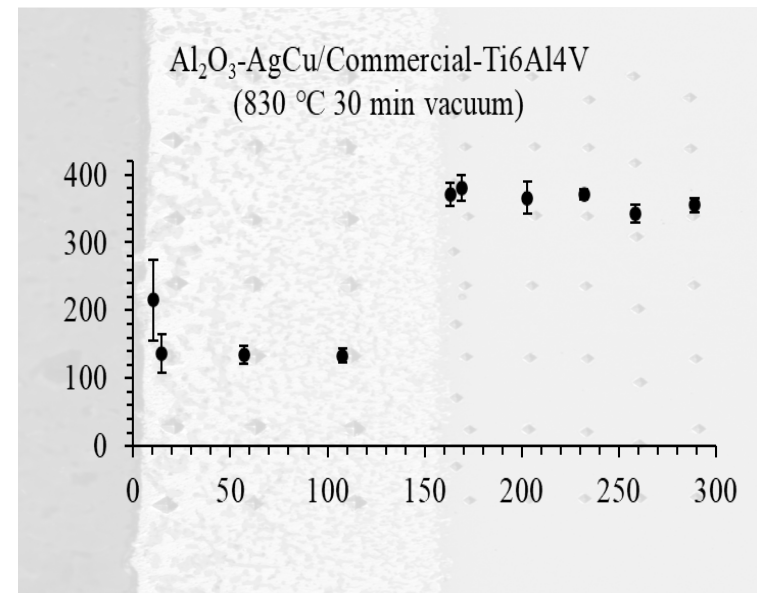
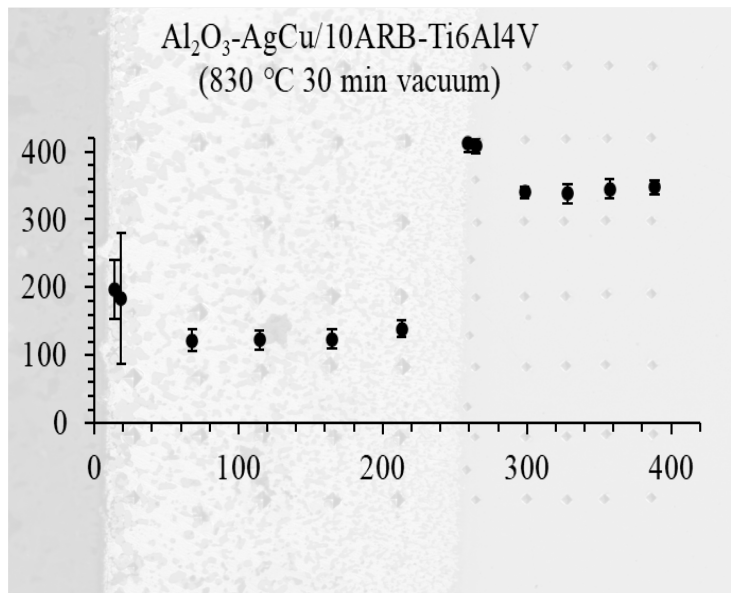
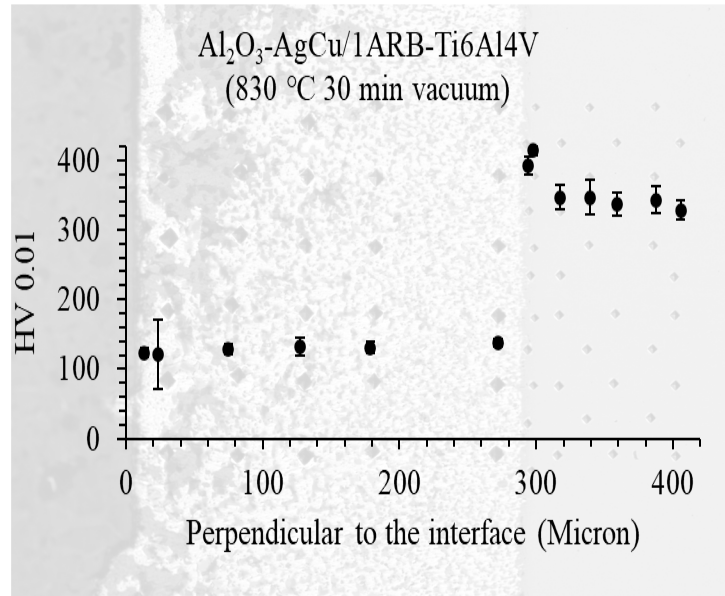
# Possible phases in interfaces

- Determination by the means of phase binary/ternary phase diagrams



| Zone | Possible phases  |
|------|--|
| Z1   | A complex oxide of Ti-Cu-Al                                |
| Z2   | 1.8Ag-19.9Ti-78.3Cu: TiCu <sub>4</sub>                     |
| Z3   | 1.7Al-1.9Ag-1.8Ti-94.6Cu: (Cu)                             |
| Z2C. | 7.1Al-1.5Ag-24Ti-67.4Cu: TiCu <sub>4</sub>                 |
| Z3C. | 1.6Ag-19.7Ti-78.7: TiCu <sub>4</sub>                       |
| Z4   | 3.5Al-2.1Ag-35.5Ti-58.9Cu: Ti <sub>2</sub> Cu <sub>3</sub> |
| Z5   | 1.0Al-2.1Ag-48.2Ti-48.7Cu: TiCu                            |
| Z6   | 5.6Al-1.1Ag-65.1Ti-28.2Cu: Ti <sub>2</sub> Cu              |

# Hardness of interfaces



# Conclusions

- Cladded and multilayered Ag-28Cu sheets were respectively produced by Roll Bonding and ARB for 10 cycles.
- The diffusion brazing process was performed for joining Al<sub>2</sub>O<sub>3</sub> to Ti6Al4V by using these rolled brazing fillers also by a commercial filler, with a similar composition, at 830 °C for 30 min in a vacuum better than 10<sup>-4</sup> Pa
- The brazing process did not cause any defect (such as pores or crack) at the joints` interfaces
- The interfaces were essentially composed of (Ag), TiCu<sub>4</sub>, Ti<sub>2</sub>Cu<sub>3</sub>, TiCu and Ti<sub>2</sub>Cu. The only difference detected, was the presence of (Cu) in the form of small particles at the interfaces obtained by the rolled fillers.
- The hardness transition from the alumina towards the Ti6Al4V base material presents:
  - The interfaces have less hardness values than the Ti6Al4V base material
  - Small inclination is observed close to the alumina at the interfaces produced by 10ARB or commercial filler
  - The hardness slightly increases in the vicinity of the Ti6Al4V base material at the joints obtained by the rolled fillers, then the hardness becomes similar to the Ti base material.

# Future works

- EDS map analysis close to the  $\text{Al}_2\text{O}_3$
- Shear strength test
- SEM & XRD analyses on fractured surfaces
- Influence of thermal post treatments on the strength and microstructure

# Acknowledgments

This work was financially supported by: Project NanoTiC-POCI-01-0145-FEDER - funded by FEDER funds through COMPETE2020 - Programa Operacional Competitividade e Internacionalização (POCI) and by national funds (PIDDAC) through FCT/MCTES.

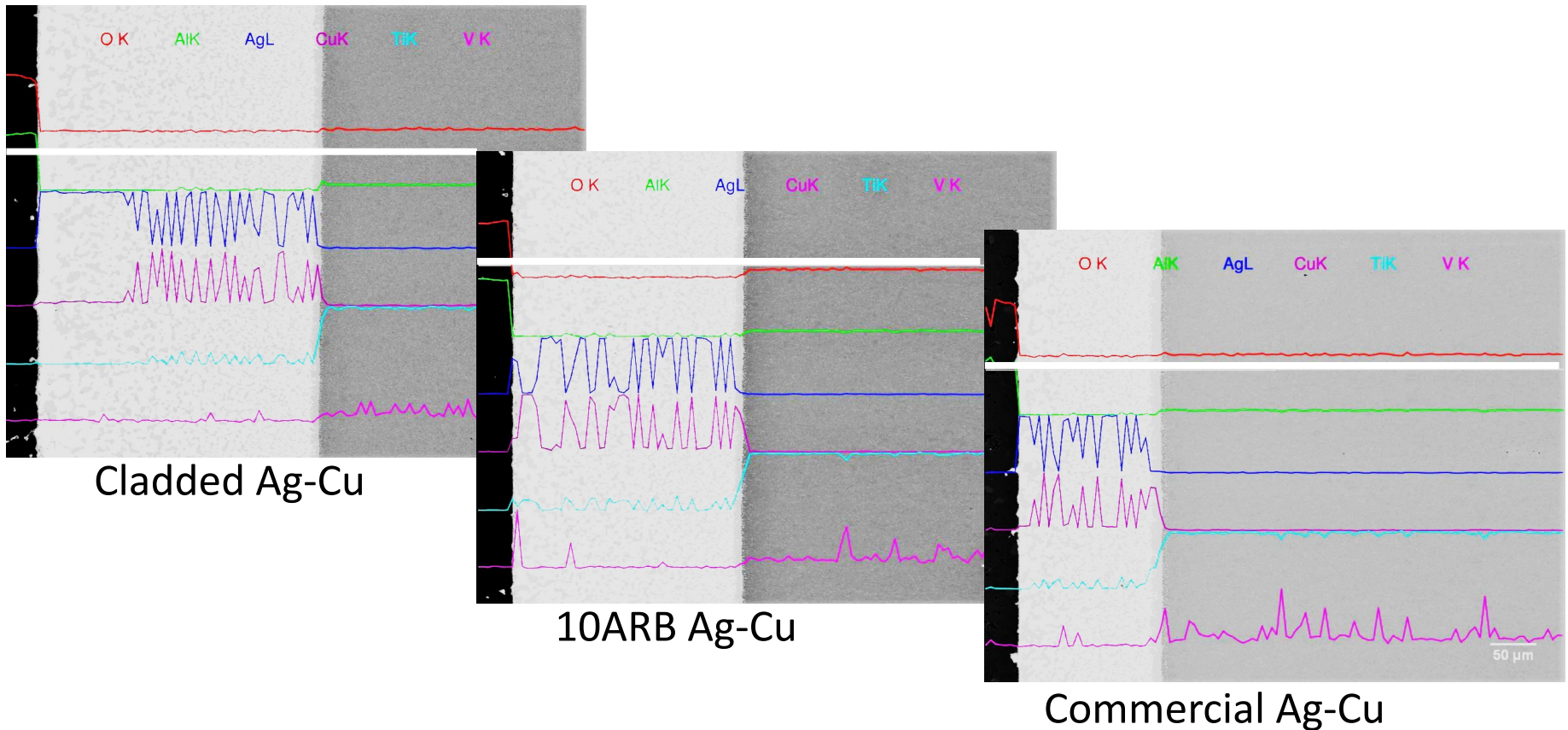


***Thanks for your attention***



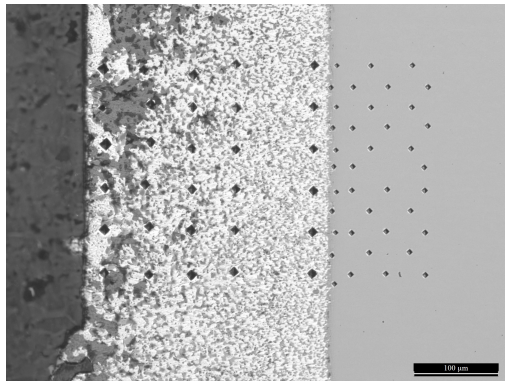
# Microstructural characterizat

SEM/EDS map of a selected zones in the Al<sub>2</sub>O<sub>3</sub> / Ti6Al4V joints obtained by:

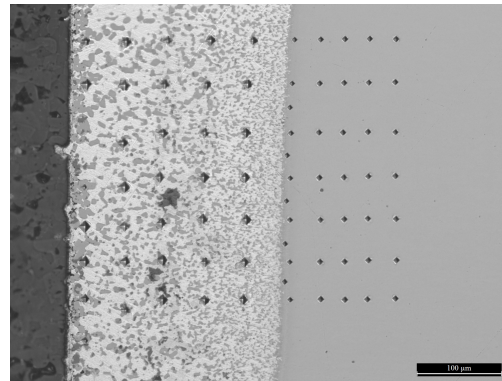


# Microhardness map

Cladded Ag-Cu



10ARB Ag-Cu



Commercial Ag-Cu

