4th DOCTORAL CONGRESS IN ENGINEERING

28 - 29 JUNE 2021
FEUP
PORTO - PORTUGAL

Joining Ti6Al4V to Alumina by diffusion bonding using titanium thin film

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1. MOTIVATION / OBJECTIVES

- J***oining of Ti alloys to ceramic materials*** can contribute to overcome the limitations that titanium alloys present when the application requires operating temperatures above 550 °C.

- However, processing of high quality and high strength dissimilar joints between Ti alloys and ceramic materials constitutes a major challenge!
- ***Brazing*** and ***diffusion bonding*** are the most reported technologies for metal to ceramic joining.

- Applying interlayers between of the base materials have been successfully used for similar and dissimilar joining of metals as well between metals and ceramics by diffusion bonding.

1. MOTIVATION / OBJECTIVES

The objective of the present work is to study of the feasibility of joining of Ti6Al4V to Al_2O_3 by diffusion bonding using Ti thin film and to compare with joints processed using Ti foils, in addition to apply reduced pressure.

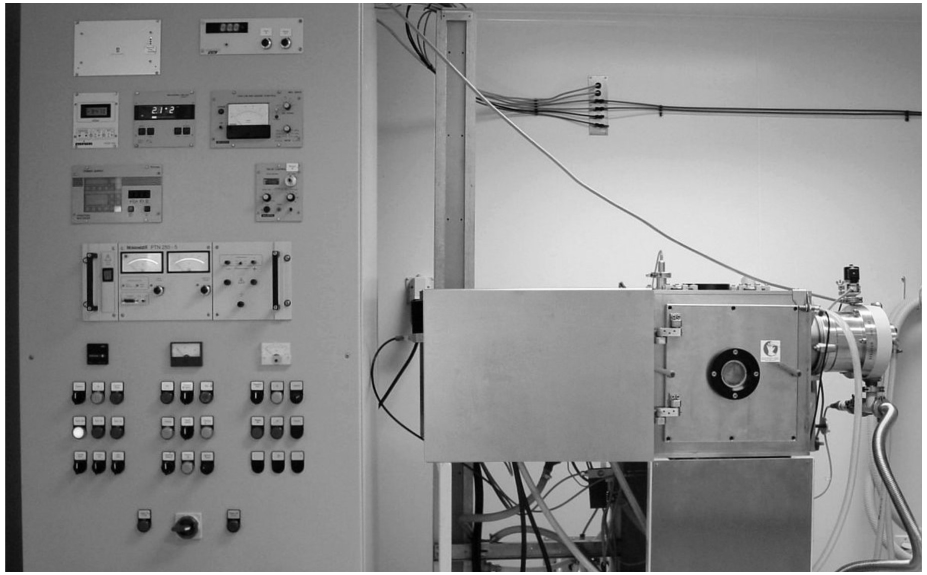
Interlayer materials selected:

i) Ti thin films (≅ 1 μm thick)

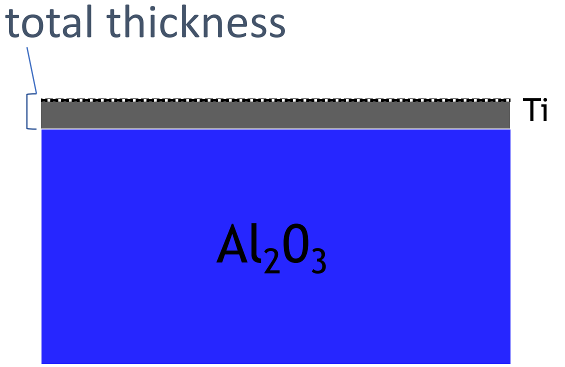
ii) Ti foils (≅ 5 μm thick)

2. DEPOSITION TECHNIQUE

➢ Deposited onto the alumina base material by ***magnetron sputtering***



- DC magnetron sputtering
- High purity Ti target
- Base pressure < $5x10^{-4}$ Pa
- Substrates cleaned by Heating/Etching
- Deposition pressure = 0.4 Pa
- Power density: 6.70 x 10^{-2} $W.mm^{-2}$
- Total thickness = 1.0 μm

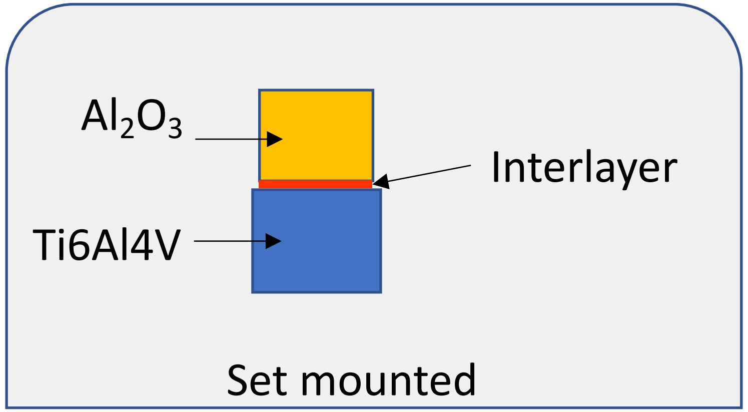


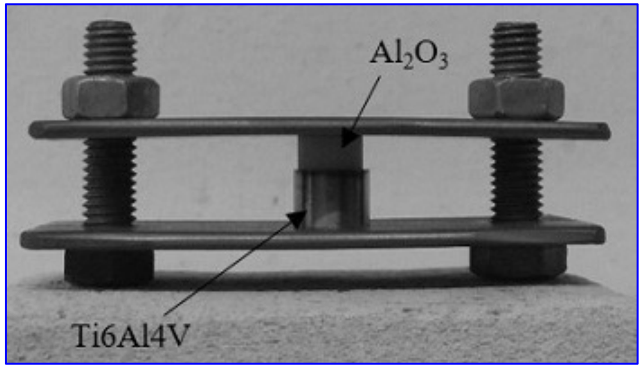
➢ The titanium foil (5 μm) was purchased from Goodfellow and cutted in rectangular parts with dimensions of 7 x 7 mm.

3. JOINING BY DIFFUSION BONDING

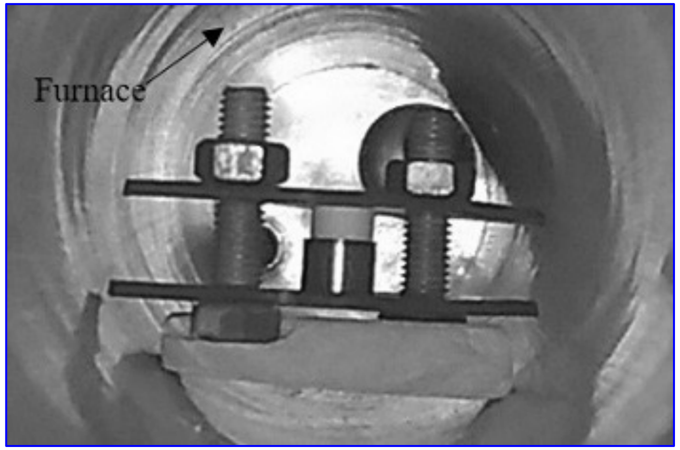
Parameters:

- Vacuum better than 10^{-2} Pa;
- Temperature 900, 950 and 1000 °C;
- Heating rate 5 °C/min and cooling 3 °C/min;
- Dwell time 60 minutes;
- Contact pressure.





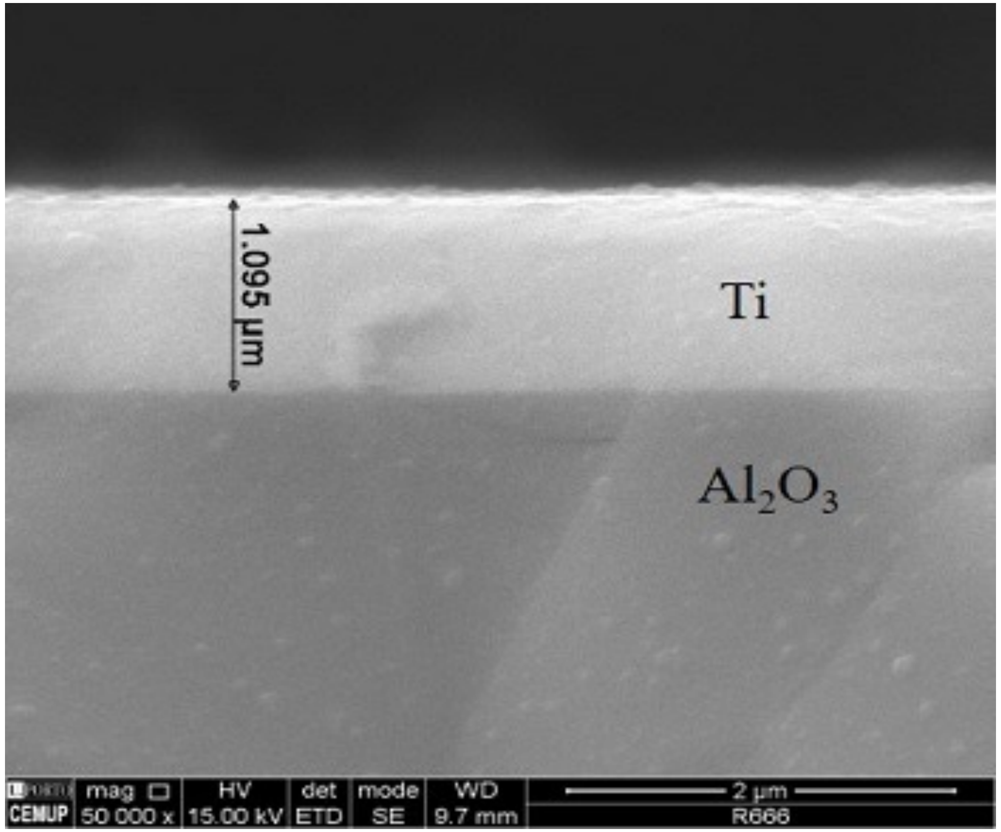
Device (stainless steel) used to keep the pressure contact of faying surfaces during the experiments



Set mounted in the furnace

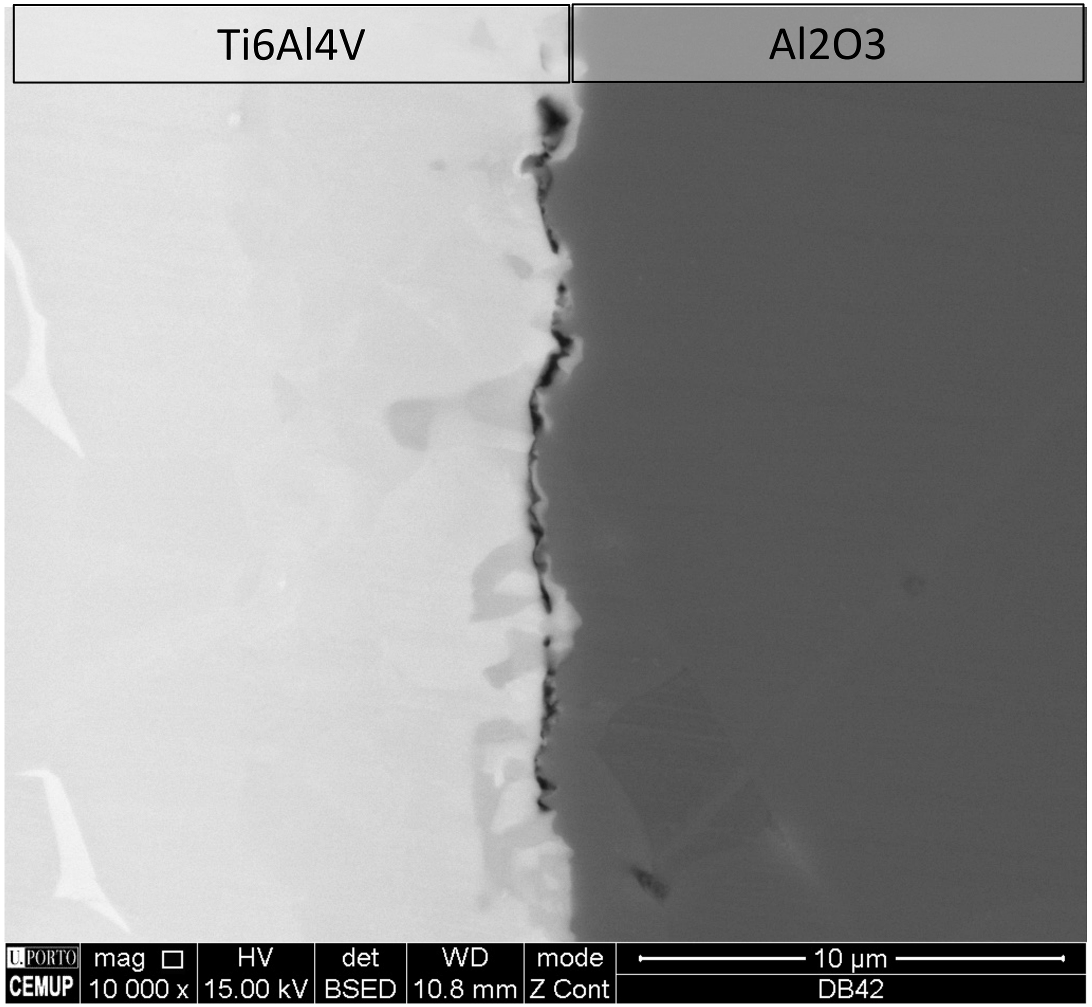
4. Results and Discussion

4.1 Titanium thin film as deposited



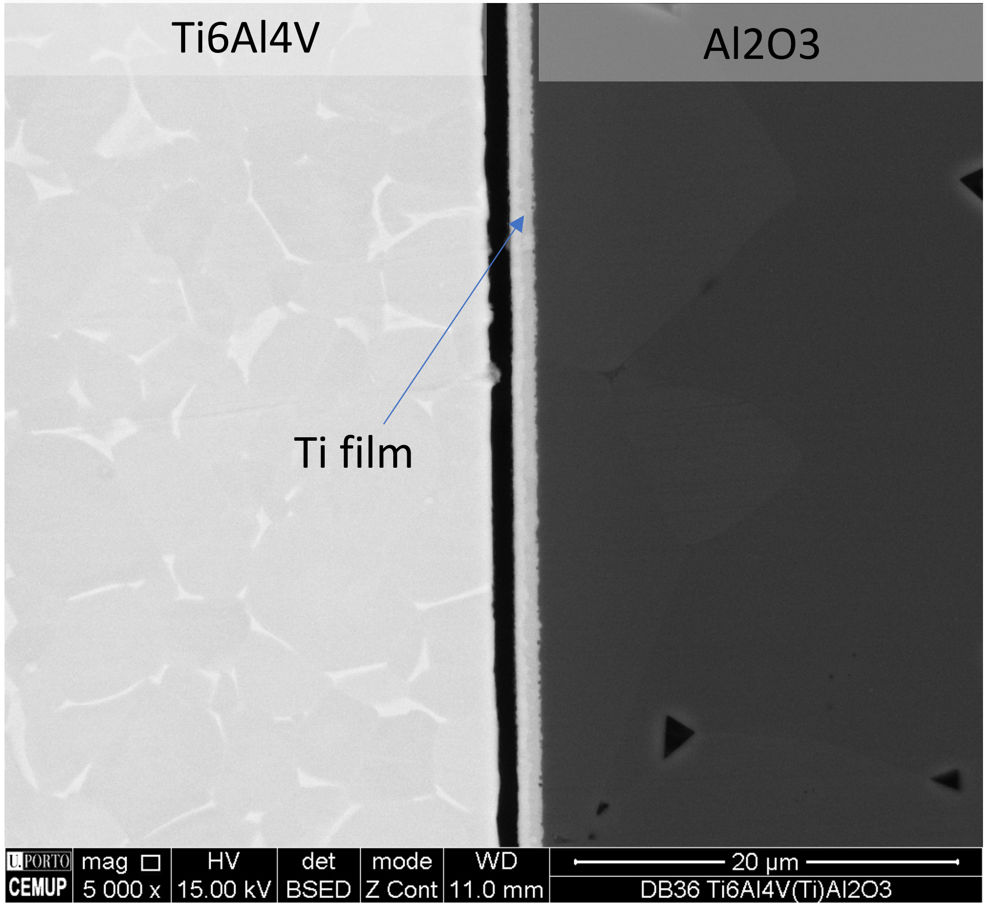
SEM image of cross-section as-deposited Ti thin film onto Al_2O_3 with total thickness close to 1 μm.

4.2 Joining Ti6Al4V/ without interlayer / Al2O3 (1000 °C/ 60 min/ contact pressure)



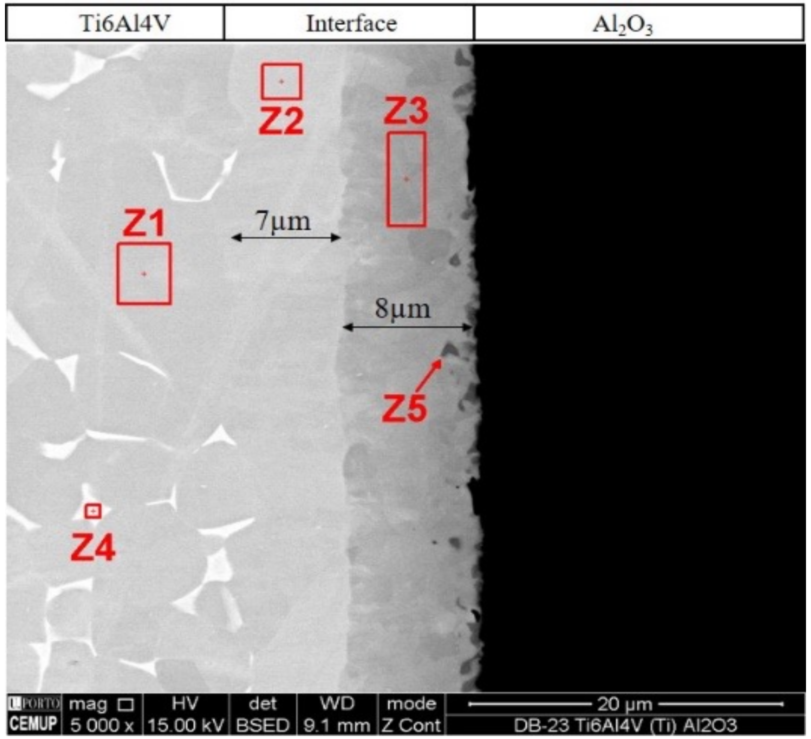
SEM cross-section images of the joining

4.3 Joining Ti6Al4V/ Ti (1 µm)/ Al2O3 (900 °C/ 60 min/ contact pressure)



SEM cross-section images of the interface with interlayer

4.4 Joining Ti6Al4V/ Ti (1 μm)/ Al_2O_3 (950 °C/ 60 min/ contact pressure)



SEM cross-section images of the interface with interlayer

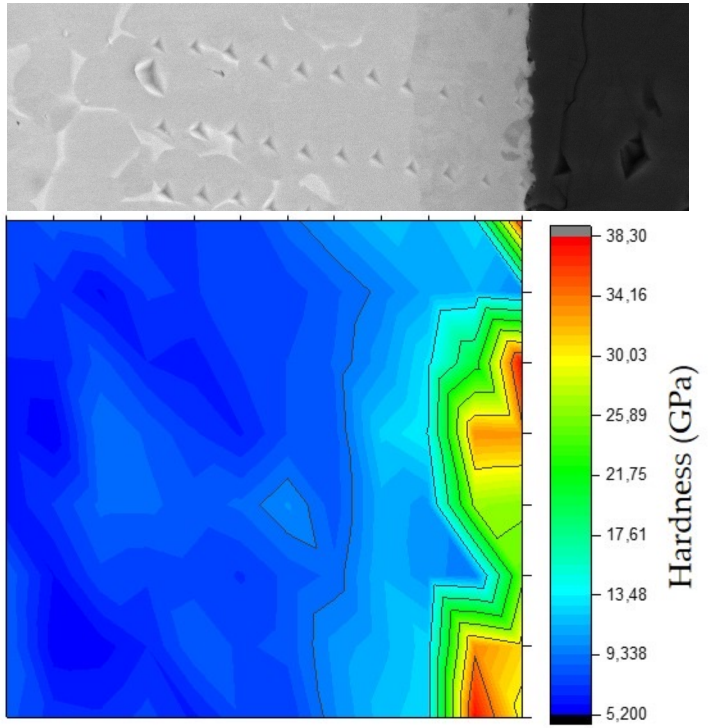
Chemical composition by EDS of the zones

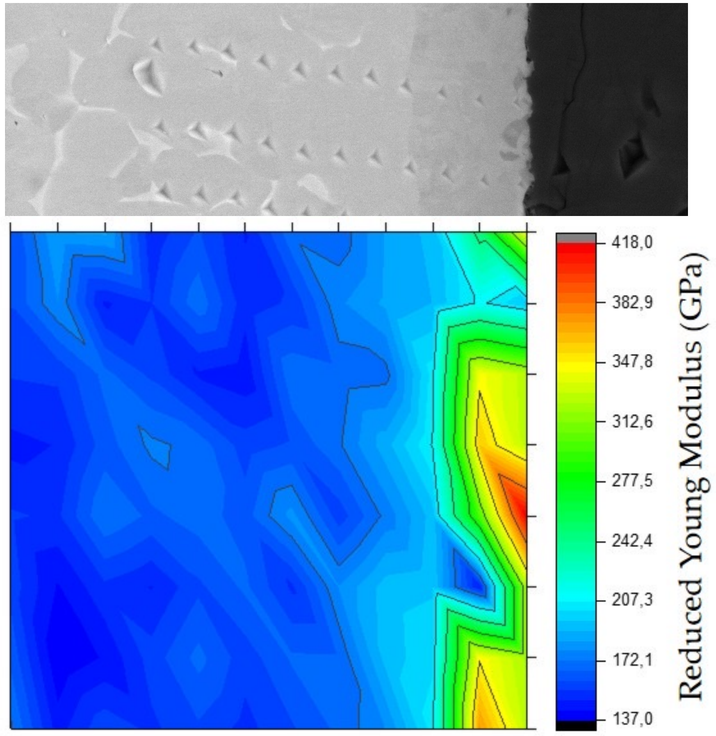
	Ti (at. %)	Al (at. %)	V (at. %)	Possible Phases
Z1	88.4	10.4	1.2	α-Ti
Z2	88.3	10.2	1.5	α-Ti
Z3	76.6	22.3	1.1	Ti_3Al
Z4	80.3	6.7	13.0	β-Ti
Z5	65.1	33.7	1.2	Ti_3Al

4.4 Joining Ti6Al4V/ Ti (1 µm)/ Al2O3 (950 °C/ 60 min/ contact pressure)

- Nanoindentation

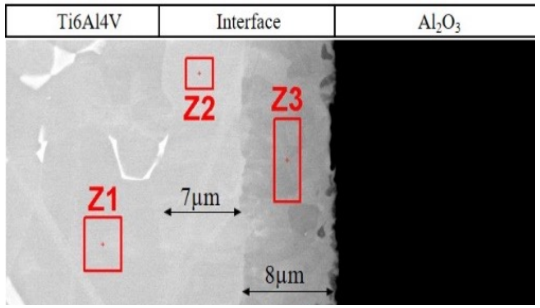
Matrix 8x12 L_{max} = 5 mN
Distance between rows = 5 µm
Distance between columns = 3 µm



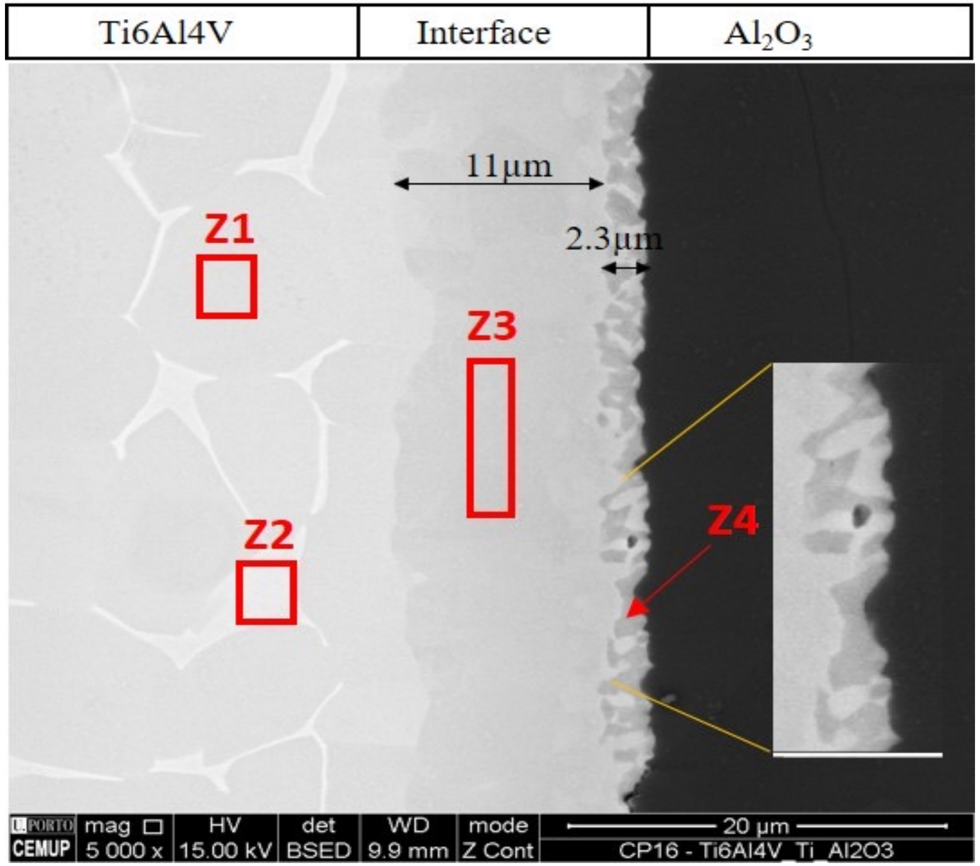


Average value of hardness and E_r by nanoindentation tests in the zones

Parameters	Zone (Z)	Hardness (GPa)	Reduced Young's modules (GPa)
950 °C/ 60 min	1	7	158
	2	8	160
	3	11	183



4.5 Joining Ti6Al4V/ Ti (1 µm)/ Al2O3 (1000 °C/ 60 min/ contact pressure)



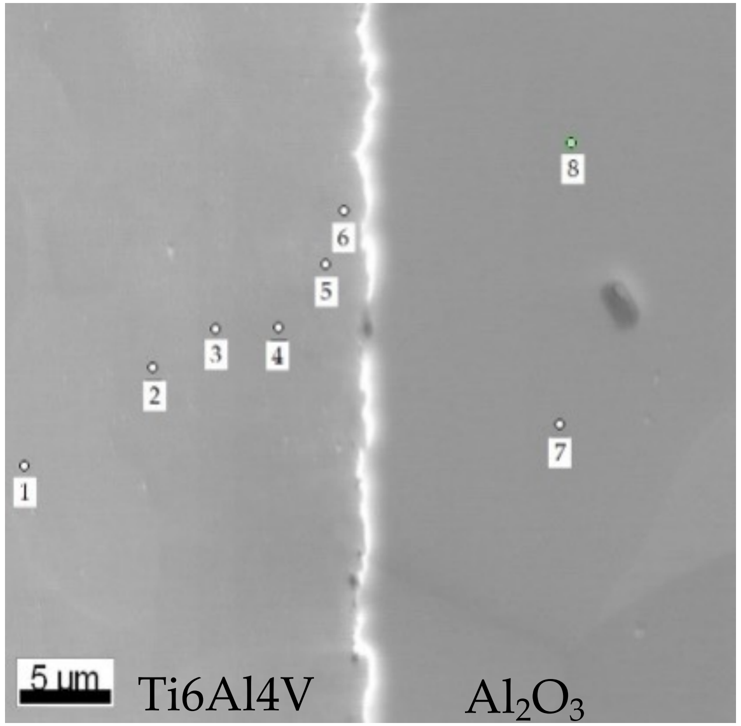
SEM cross-section image of the interface with interlayer

Chemical composition by EDS of the zones

	Ti (at. %)	Al (at. %)	V (at. %)	Possible Phases
Z1	88.3	11.7	–	α-Ti
Z2	77.2	8.9	16.0	β-Ti
Z3	74.5	25.5	–	Ti_3Al
Z4	57.6	42.4	–	TiAl + Ti_3Al

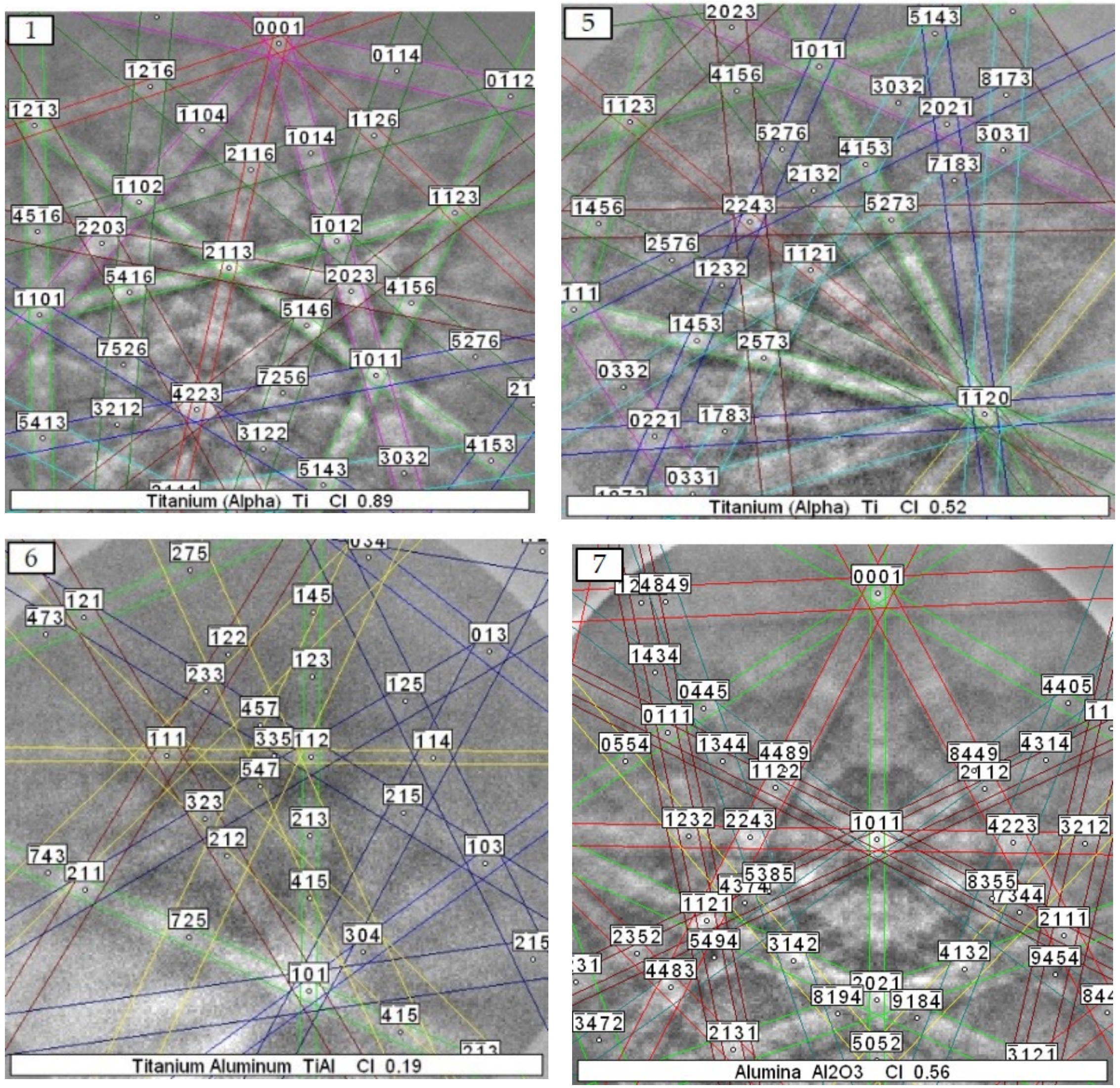
4.5 Joining Ti6Al4V/ Ti (1 µm)/ Al2O3 (1000 °C/ 60 min/ contact pressure)

➢ EBSD Kikuchi pattern indexation



Chemical composition by EDS of the zones

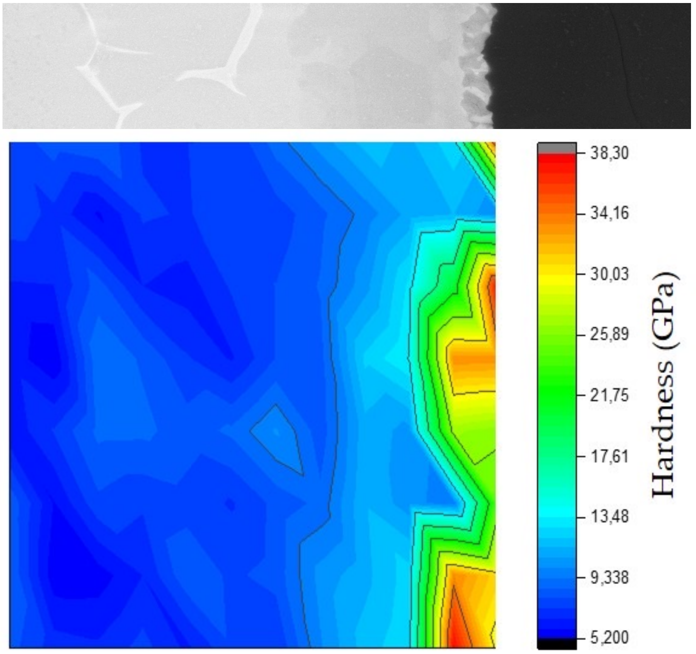
	Ti (at. %)	Al (at. %)	V (at. %)	Possible Phases
Z1	88.3	11.7	–	α-Ti
Z2	77.2	8.9	16.0	β-Ti
Z3	74.5	25.5	–	Ti_3Al
Z4	57.6	42.4	–	TiAl

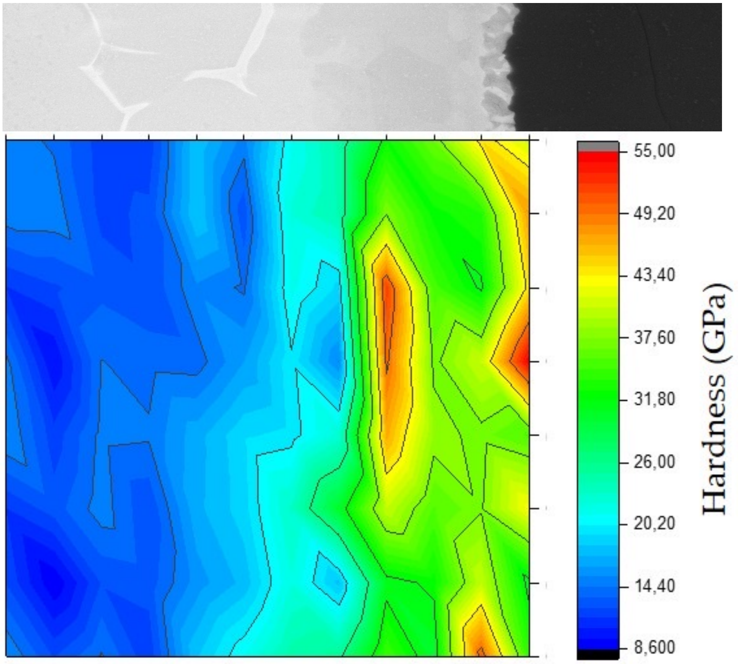


4.6 Joining Ti6Al4V/ Ti (1 μm)/ Al2O3 (1000 °C/ 60 min/ contact pressure)

- Nanoindentation

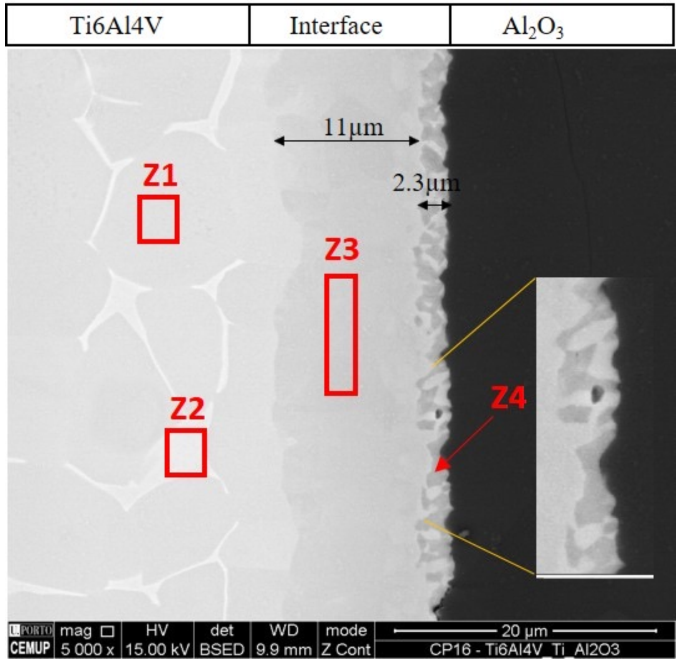
Matrix 8x12 L_{max} = 5 mN
Distance between columns = 3 μm
Distance between rows = 5 μm



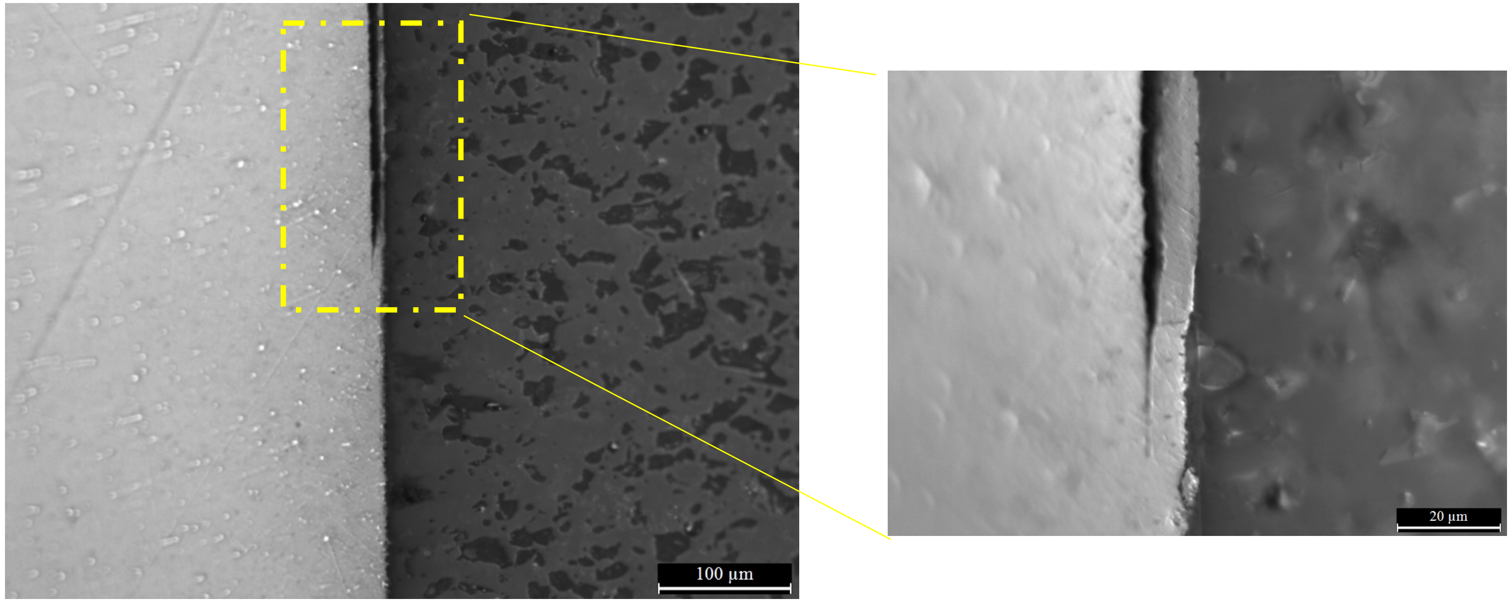


Average value of hardness and E_r by nanoindentation tests in the zones

Parameters	Zone (Z)	Hardness (GPa)	Reduced Young's modules (GPa)
1000 °C/ 60 min	1	13	210
	2	*	*
	3	17	230
	4	21	290



4.7 Joining Ti6Al4V/ Ti foil (5 µm)/ Al2O3 (950 °C/ 60 min/ contact pressure)



OM cross-section images of the interface with interlayer

5. Conclusions

- Using monolithic thin films as interlayer material sound joints were obtained at 950 and 1000°C, just by putting the Ti coated alumina in contact with the Ti6Al4V base material.
- Due to diffusion a reaction zone constituted by titanium aluminides forms, whose thickness increases with temperatures and holding time.
- The hardness and reduced Young modulus maps obtained by nanoindentation corroborate the microstructural characterization and allowed the different reaction layers composing the interface to be clearly distinguished.

5. ACKNOWLEDGEMENTS

This work was financially supported by Project NanoTiC (POCI-01-0145-FEDER-031579) funded by FEDER funds through COMPETE2020 - Programa Operacional Competitividade e Internacionalização (POCI) and by national funds (PIDDAC) through FCT/MCTES.

COMPETE 2020 PORTUGAL 2020 UNIÃO EUROPEIA Fundo Europeu de Desenvolvimento Regional FCT Fundação para a Ciência e a Tecnologia