# Design of metal-ceramic interfaces for high temperature applications


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*A combined experimental/thermodynamic approach is used.*
***Phase diagrams** obtained by the **CALPHAD** method show the equilibria between the metallic phase and the ceramic substrates. Even if the systems are studied under dynamic conditions, a comparison with phase equilibrium calculations is a useful way to understand high temperature interactions and phase transformations.*

***Wetting of $ZrB_2$ by Ni-B alloys***
Interfacial microstructures of cross-sectioned wetting samples in relation to phase diagram

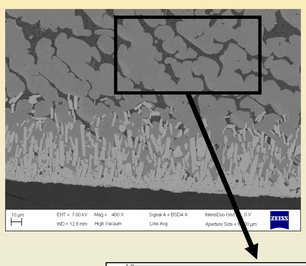

Suppressed dissolution

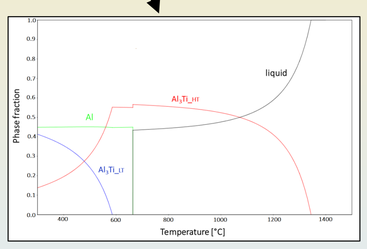



Dissolution of the ceramic substrate


B-Ni-Zr isothermal section at 1500°C

***Al-C-Si-Ti system***
Determination of the cooling path of the liquid phase to optimize wetting of SiC by AlTi brazing alloys





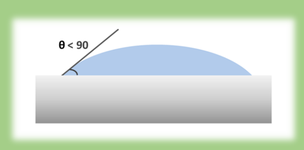

**Thermodynamic assessment of metal-ceramic interfaces by CALPHAD**

## Wettability

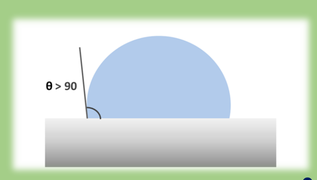
tendency of a liquid to contact a solid surface.

It is measured in terms of **contact angle** and interfacial energies

**Sessile Drop**

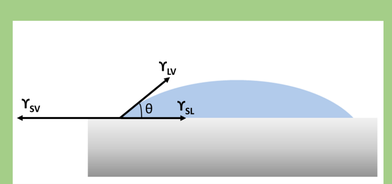



**Wetting, θ < 90°**




**Non wetting, θ > 90°**

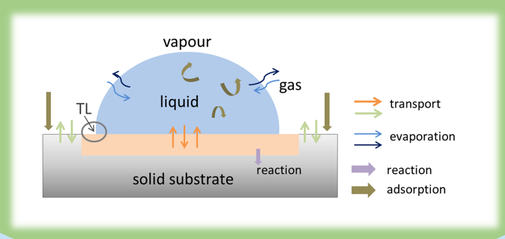
**Young's equation**
equilibrium contact angle in relation with the interfacial tensions between the three phases



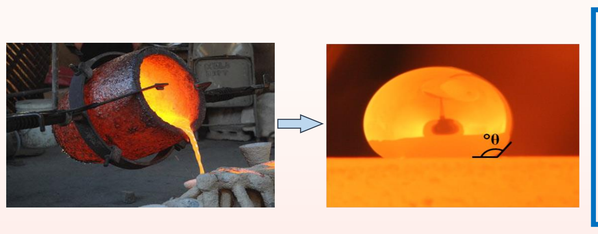

$\gamma_{sv} = \gamma_{LS} + \gamma_{LV} \cos\theta$
$\gamma_{ij}$ : interfacial tension
θ : contact angle

**Types of interfacial reactions at high temperatures**

- Formation of new compounds at the S/L interface
- dissolution of the solid into the liquid
- penetration/diffusion of the liquid components into the solid
- adsorption of elements at the interfaces




**Liquid metal-ceramic interactions in casting processes**

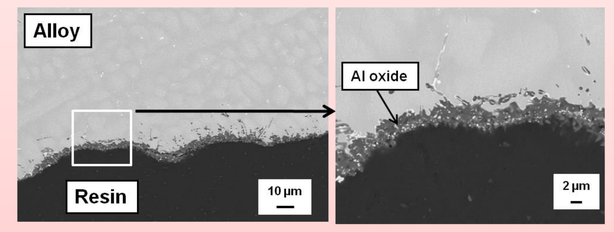


*In **casting processes**, interactions between liquid superalloys (Ni-, Co- based) and ceramic mould materials must be studied in order to select the most proper materials combination and to avoid wetting and defects.*

***CMSX 486 (Ni-based, with 5.7 at% of Al and 0.4 at% of Hf)***

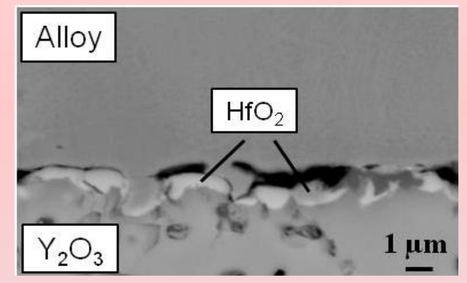
**Interactions with mullite-based material ($3Al_2O_3 \cdot 2SiO_2$) – T = 1500°C**

**S/L interface**
$Al_2O_3$ layer (≈ 2 µm) and inclusions of $HfO_2$



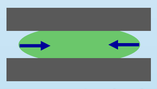

**Interactions with yttria-based material – T = 1500°C**

**S/L interface:**
small inclusions of $HfO_2$ (≈ 1µm)

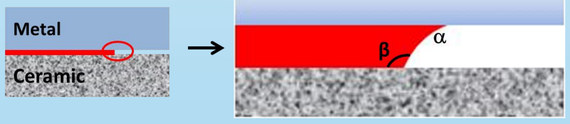



$Y_2O_3$ based mould material are more inert than mullite based materials

*Liquid based **joining processes** (e.g. brazing, transient liquid phase bonding, soldering) rely on **capillarity** to distribute the liquid alloy along the adjoining interfaces*




**Conditions for spontaneous liquid infiltration**

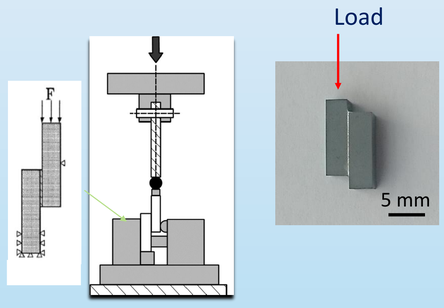



$\alpha + \beta < 180°$

**Joining of ceramic materials through liquid based processes**

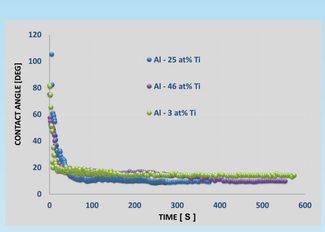
***Mechanical characterization of joints***

Single lap offset shear test

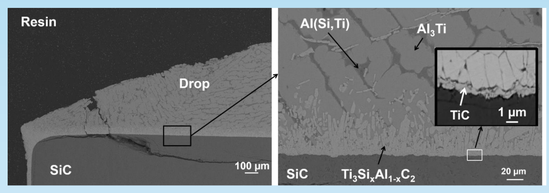



Collaboration with Politecnico di Torino – DISAT
(Prof. M. Ferraris, Prof. M. Salvo, Prof. V. Casalegno)

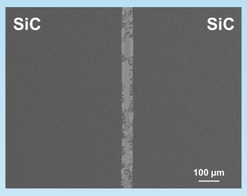
***SiC – SiC joining using Al-Ti interlayers at 1200-1500°C***




Wetting kinetics
(Al-Ti alloys on SiC)

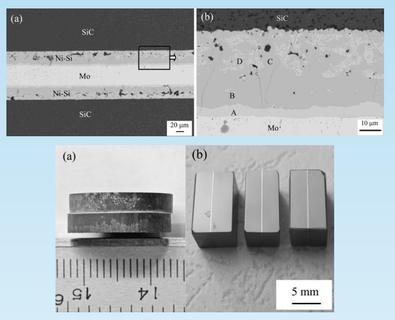



Interfacial microstructure of $Al_3Ti$ alloy on SiC after wetting test

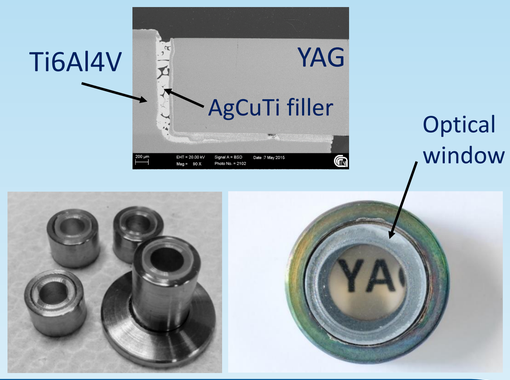



SiC-SiC joint obtained by capillary infiltration of $Al_3Ti$

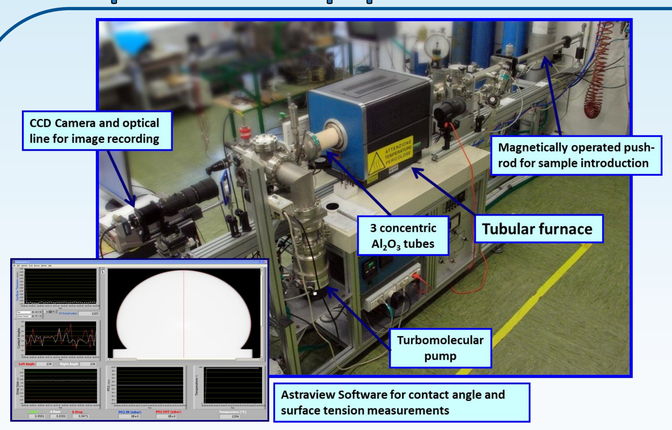
***SiC-SiC joining by Ni-Si alloys and Mo interlayer at 1350°C***



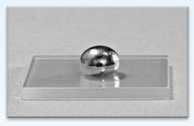

***YAG/Ti6Al4V joints with AgCuTi interlayers***




## Experimental equipment



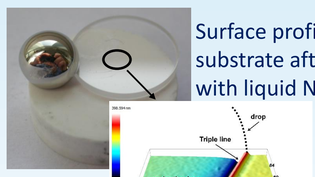

Example of sessile drop during test (θ < 90°)



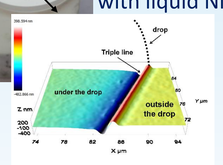
Example of sessile drop after cooling (θ>90°)

**Experimental complex for wetting tests**
$T_{max}$ = 1550°C, operating under gas (Ar, $Ar/H_2$, $O_2$) or vacuum ($10^{-4}$ Pa @1500°C)
Samples may be introduced into the experimental chamber through an external manipulator, i.e. very fast heating and cooling conditions (30s from RT to melting)

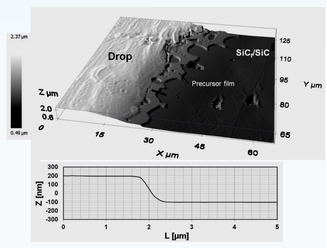

**3D Profilometer** Sensofar S-Neox
confocal+interferometric+focus variation
Lateral resolution of the order of nm



Surface profile of a sapphire substrate after interaction with liquid Ni at 1500°C




Protruding foot of a wetting sessile drop Ag-Cu-Ti on SiC.




**Arc Melting** Bühler MAM-1
Melting of highly reactive/high melting point metals and alloys.

**Microindenter** Leica VMHT MOT
Microhardness of metal-ceramic interfaces