

Laser additive manufacturing of metal matrix composites

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Outline

- Introduction
 - Metal matrix composites
 - Additive manufacturing for processing metal matrix composites
 - Laser Cladding
 - Objectives
- Experimental methods
- Results and discussion
 - Stainless steel 316L reference
 - SS 316L + SiC
 - SS 316L + WC
- Concluding remarks

Introduction (1)

Metal matrix composites (MMCs)

Composite = a material, such as reinforced concrete, **made of two or more distinct materials** (Collins)

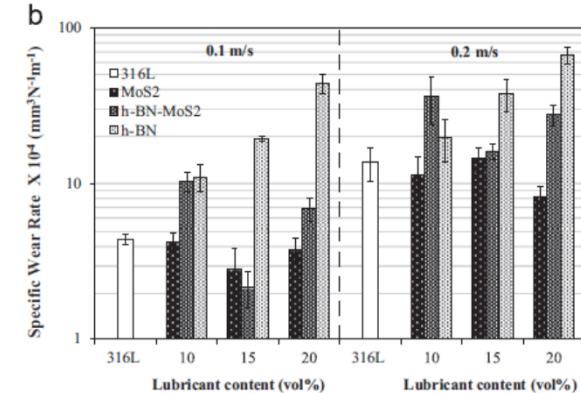
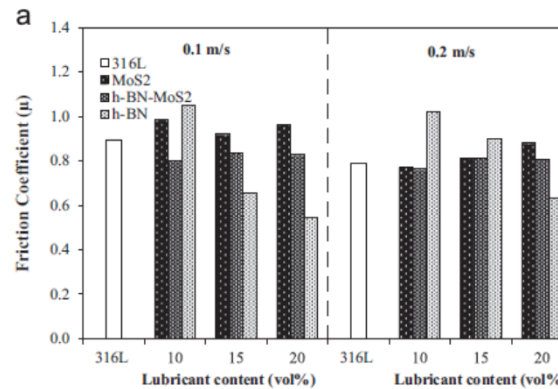
Composite = matériau formé de **plusieurs composants** élémentaires dont l'association confère à l'ensemble des **propriétés** qu'aucun des composants pris séparément ne possède (Larousse)

⇒ **New properties that none of the constituents would exhibit on its own.**

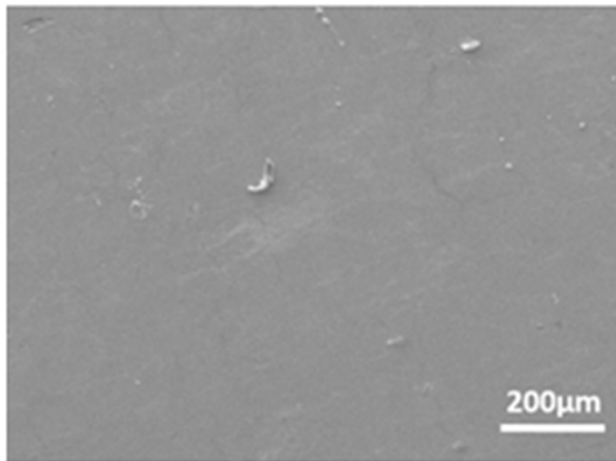
Introduction (2)

Metal matrix composites (MMCs)

Self lubricating material exhibiting simultaneously a low friction coefficient and a low wear rate: hBN and MoS₂ in SS 316L



[Mahathanabodee, 2014]



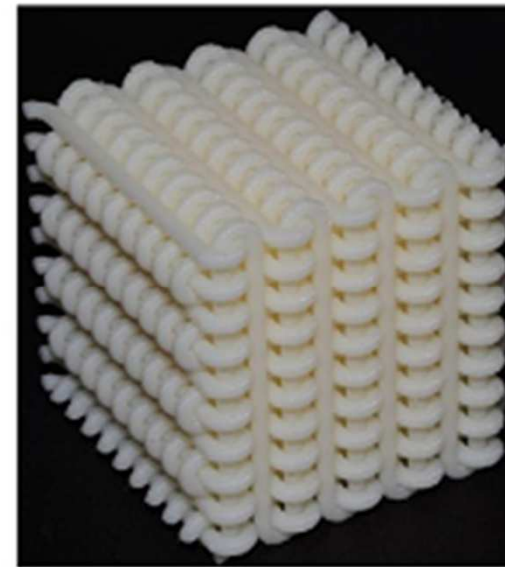
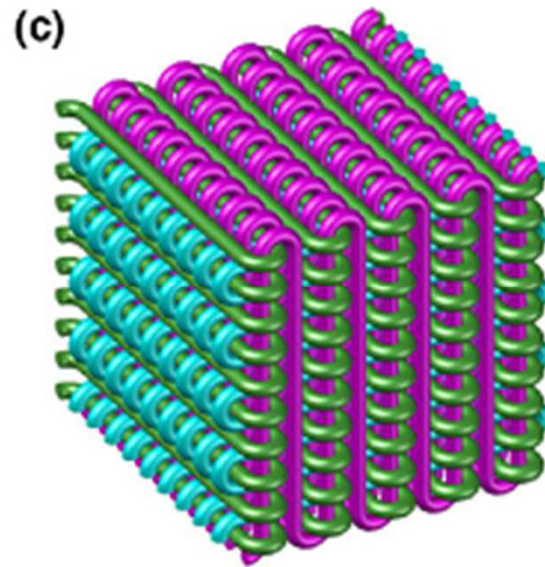
Nano Hydroxyapatite coating on SS 316L
Compatibility ensured through a graded SS 316L + nHA composite layer

[Wei, 2015]

Introduction (3)

(Powder-based) additive manufacturing of MMCs

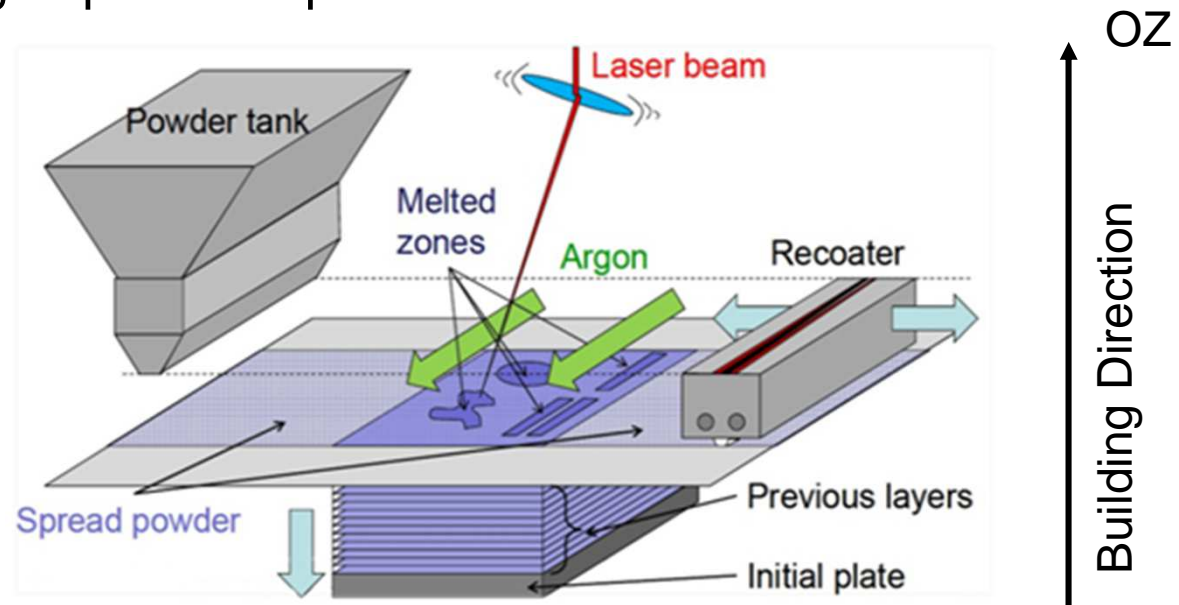
- Allows the production of composite part with complex shape
- Potential for the production of 3D preform with optimised out-of-plane properties
- Limited to particulate reinforcements



Introduction (4)

(Powder-based) additive manufacturing of MMCs

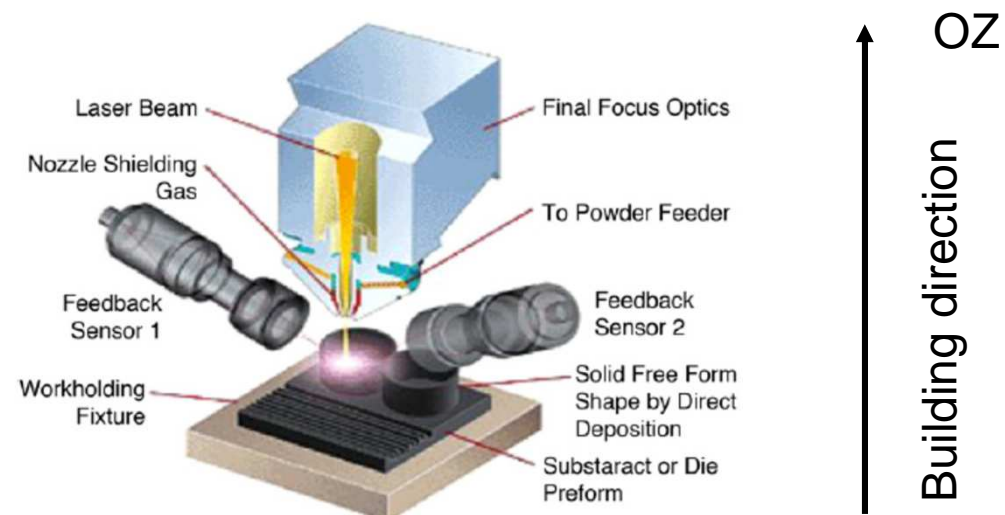
- Laser Beam Melting
- Well suited for the production of MMCs with complex shapes
- Requires the pre-mixing of the reinforcement particles with the metallic powder
 - Risk: reinforcement particles may settle down due to difference in density leading to poor compositional control.



Introduction (5)

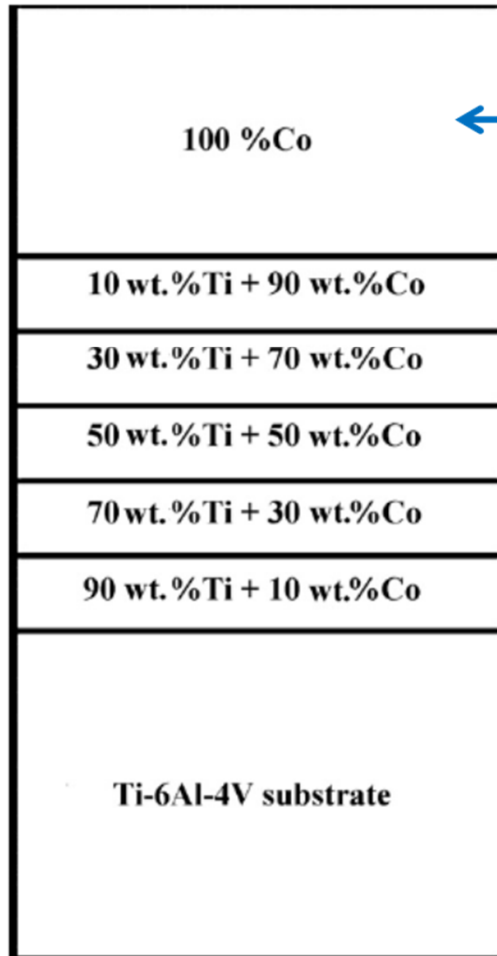
(Powder-based) additive manufacturing of MMCs

- **Laser Cladding**
- Not so well suited for the production of MMCs with complex shapes
- Pre-mixing of the reinforcement particles and metallic powder is possible but not compulsory
- Allows the production of Functionally Graded Materials



[Bhattacharya et al., 2011]

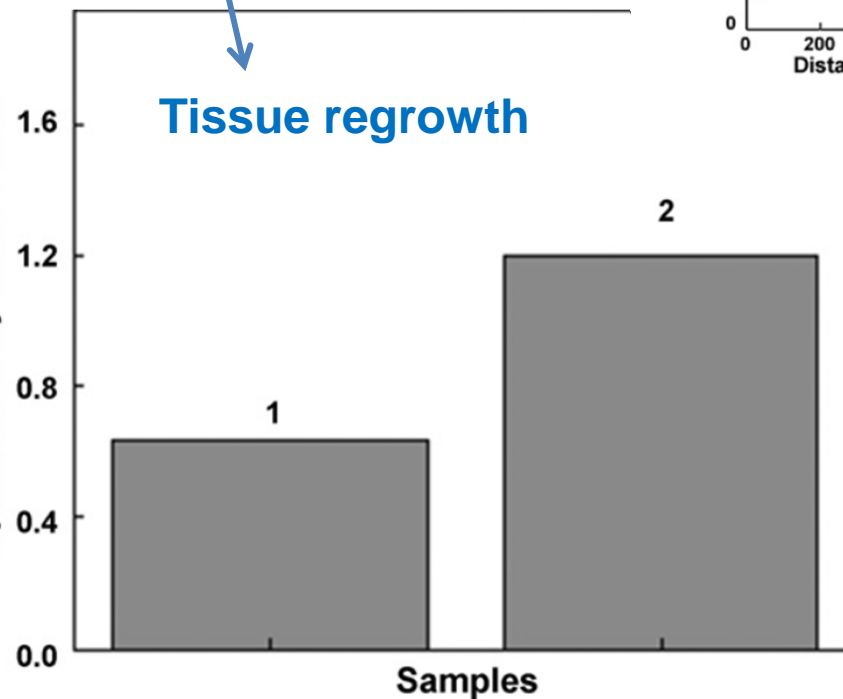
Introduction (6) – Laser Cladding Functionally Graded Materials



[Dutta Majumdar et al., 2009]

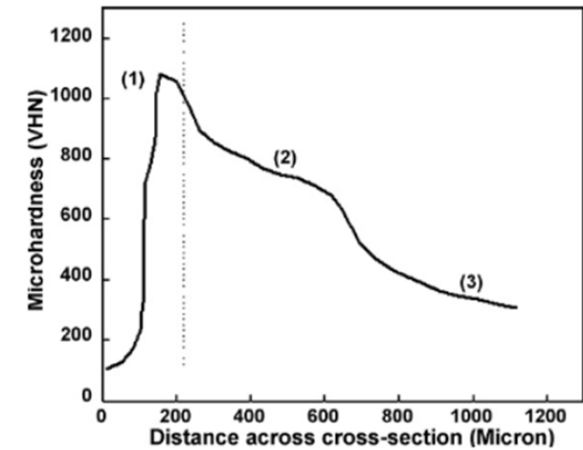
Better
biocompatibility
(hip prosthesis)

Optical Density of MTT Test



Tissue regrowth

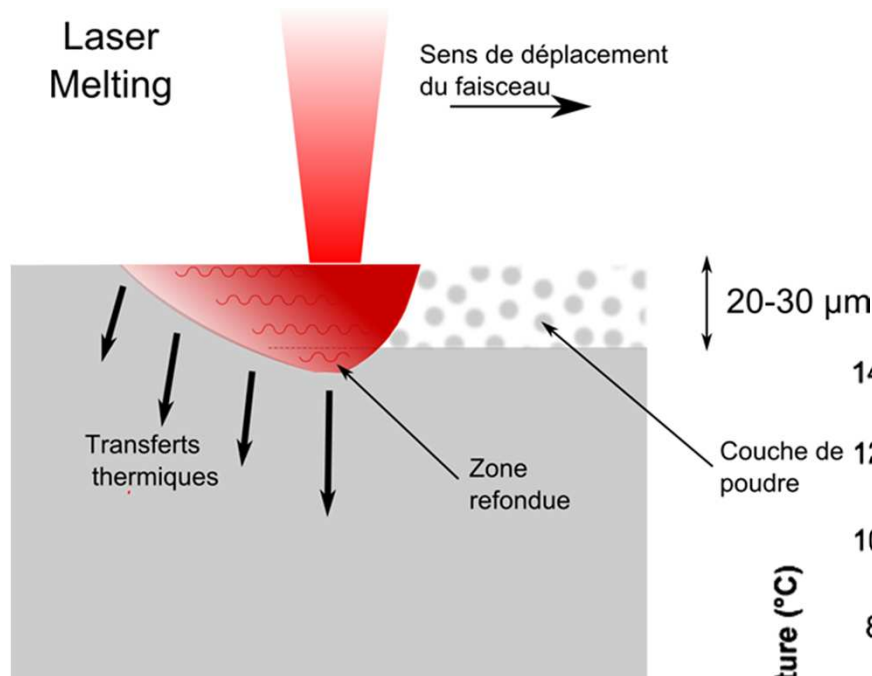
Ti6Al4V/Co



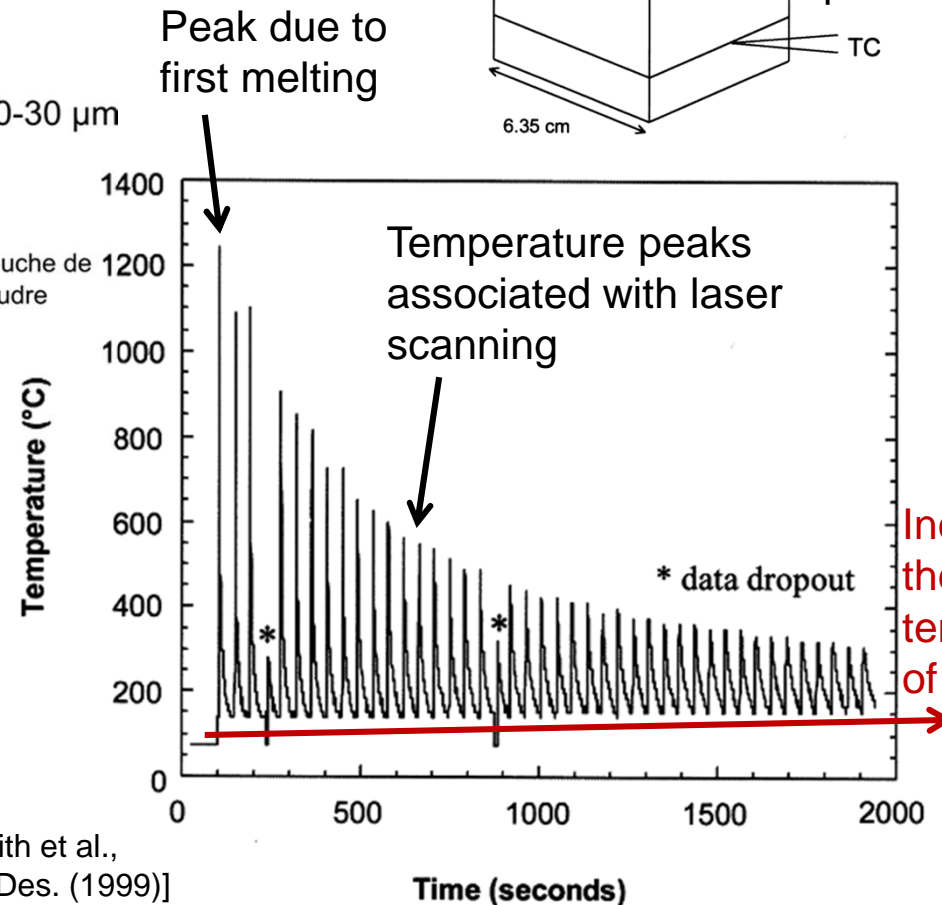
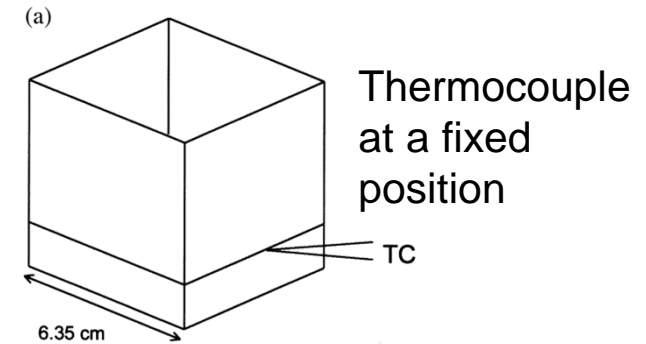
Hardness ↑↑

Introduction (7) – Laser Cladding

Complex thermal history



[Q.Contrepois, ULg]



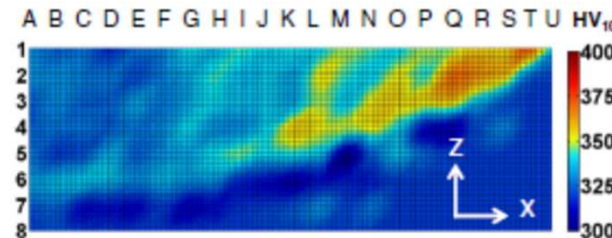
[M.L.Griffith et al.,
Mater. & Des. (1999)]

Introduction (8) – Laser Cladding

Complex thermal history

- Very high cooling rates
 - Build up of high internal stresses
 - ⇒ Cracks, Deformations
 - Thermal history may vary locally as a function of the position inside a part
 - ⇒ Microstructure may vary locally
 - ⇒ Mechanical properties may vary locally!

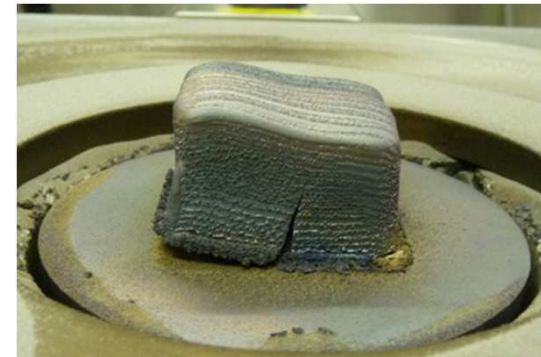
Ti6Al4V, LC
Local hardness



[Paydas et al. (2015)]

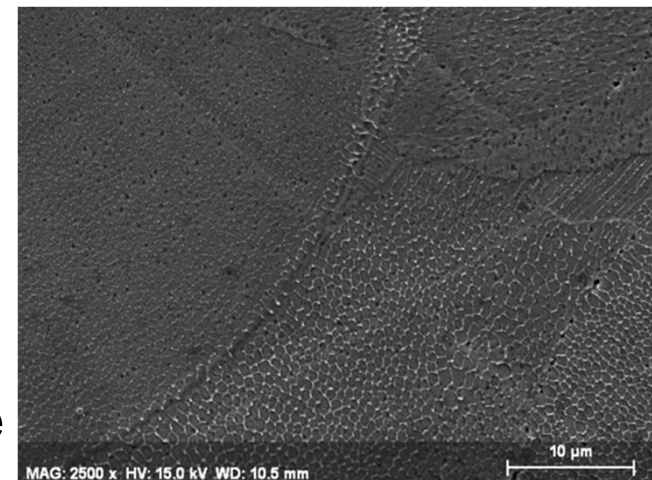
- Out-of-equilibrium microstructures
e.g. chemical segregation at a very local scale

Tool steel, LC

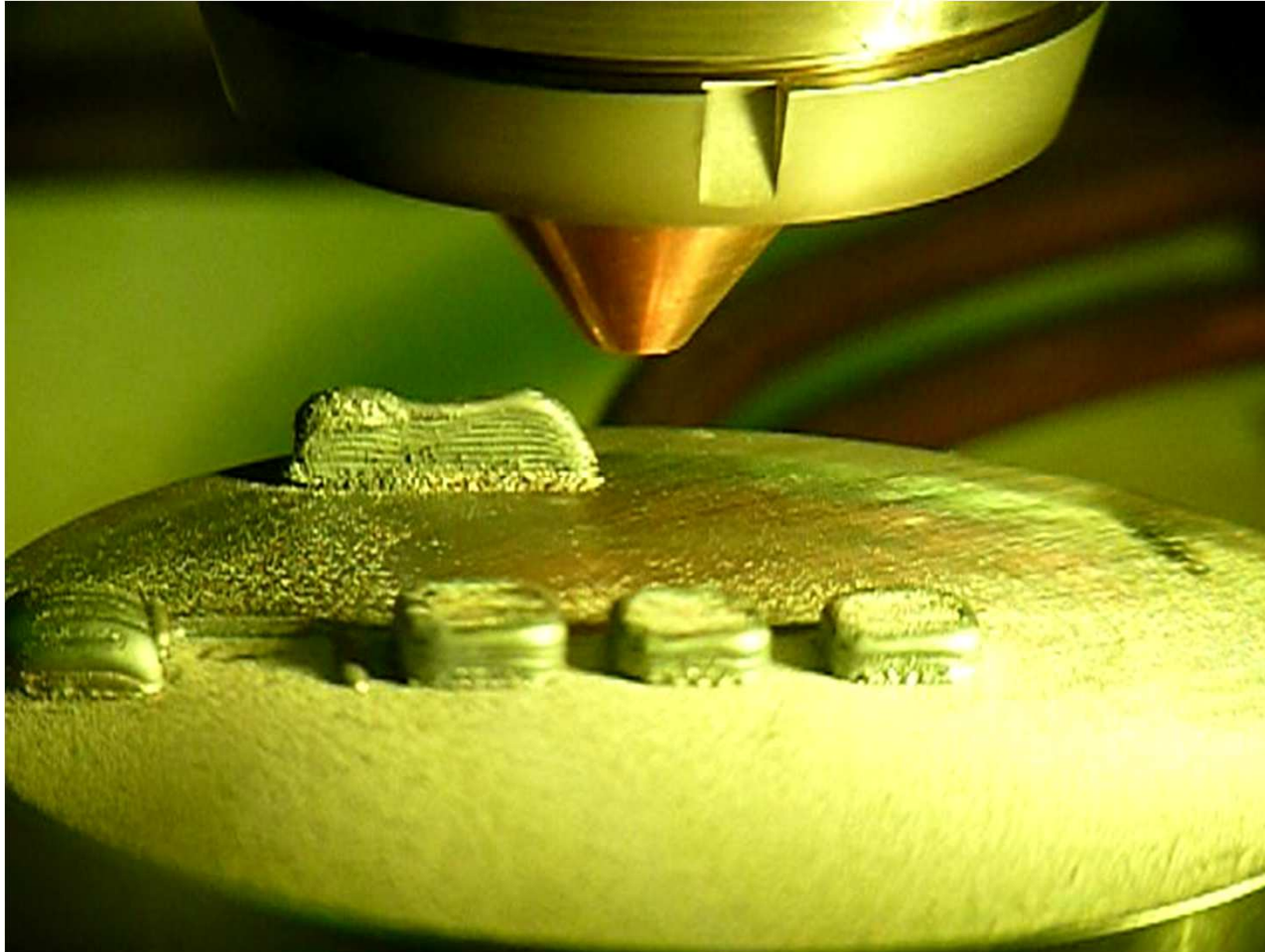


[N.Hashemi, ULg]

Microsegregation of Cr in
stainless steel, LBM



[Mertens et al., 2014]



Introduction (9)

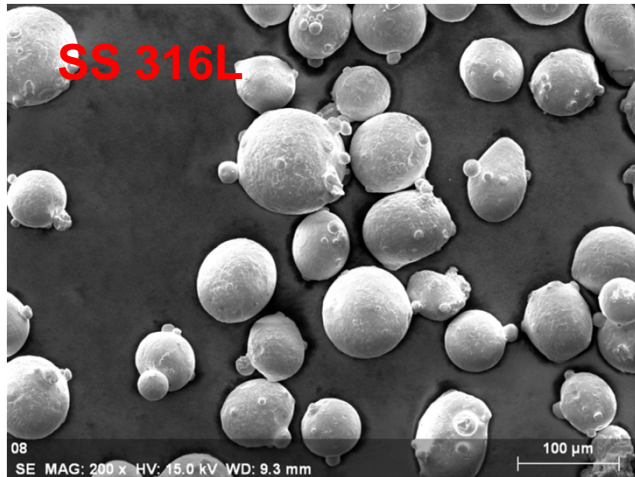
Objectives

- Investigating the processing of SS 316L matrix composites
 - With SiC particles
 - With WC particles
- Assessing the feasibility
- Requirements concerning the powders
- Stability of the reinforcement particles?
- Role of interfacial reactions, dissolution and secondary precipitation?

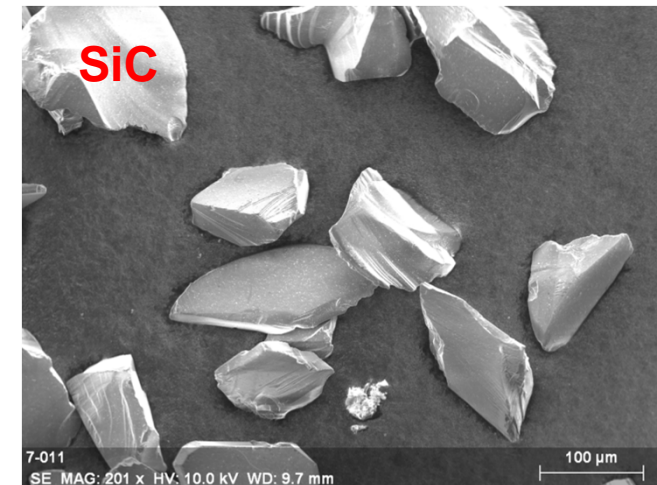
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Experimental procedure (1)



7 - 12 %



Thin coatings

OR

- SS 316L as substrate
- Irepa Laser Cladding System
 - Laser power = 500 – 680 W
 - Travel speed = 270 – 190 mm/s,
 - Layer thickness = 700 μm

16 – 47 %



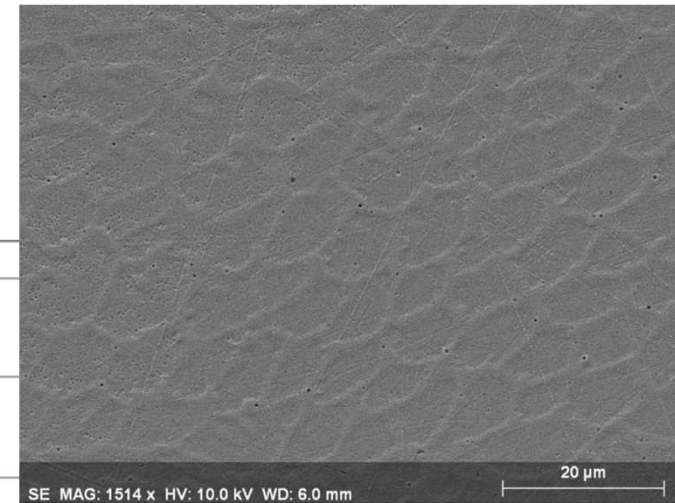
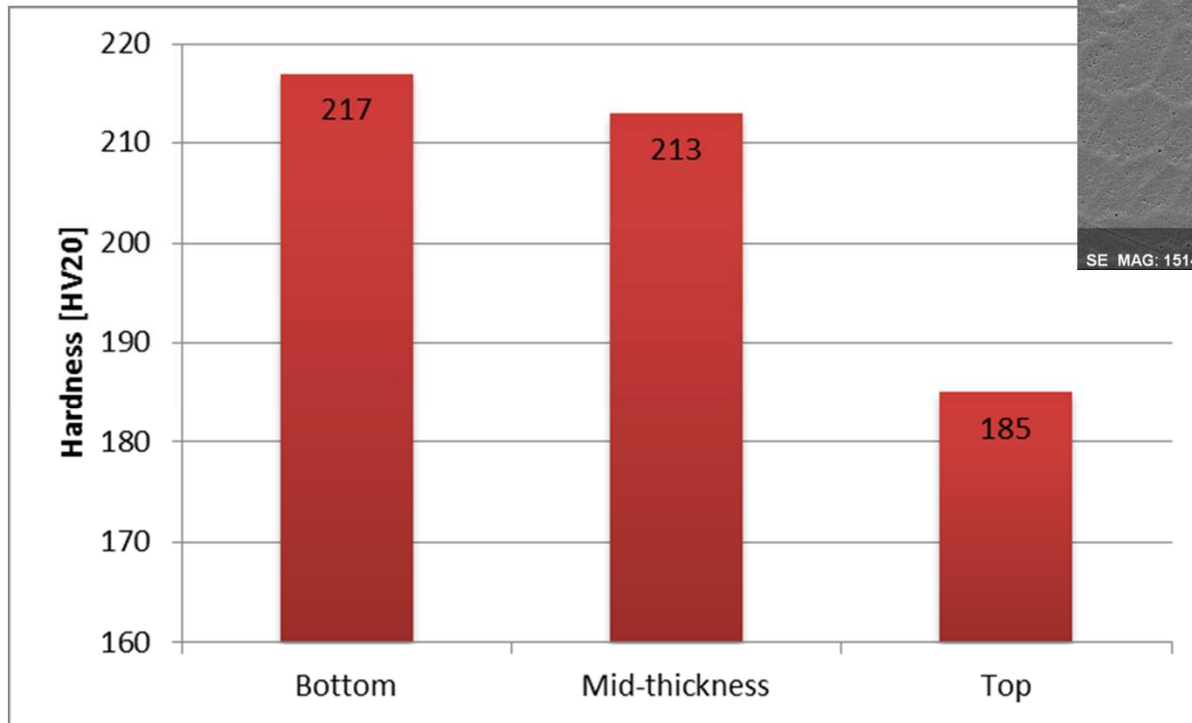
Thick (15 layers) deposits

Experimental procedure (2)

- Microstructural observations were carried out by SEM, after etching with aqua regia (i.e. 55% HCl + 20% HNO₃ + 25% methanol)
- 20 kg Vickers hardness tests were used to assess local variations in microstructure and properties

Results and discussion (1)

Reference SS 316L deposits

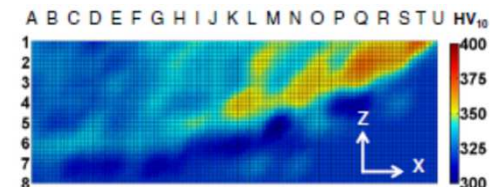


[Mertens et al., 2017]

- Typical fine cellular microstructure ~10μm
- Hardness varies as a function of position, in correlation with local variations of the thermal history

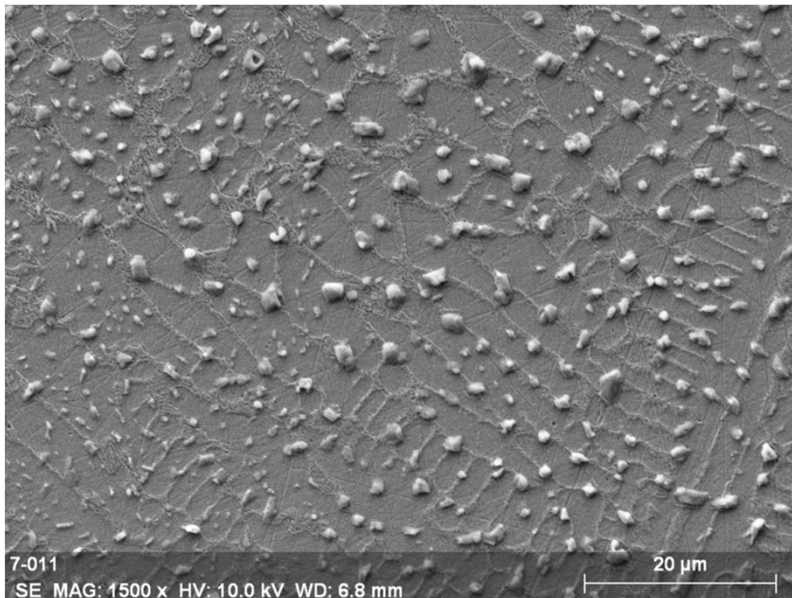
Heat accumulates during deposition, leading to some microstructural coarsening and loss in hardness

[Paydas et al., 2015]

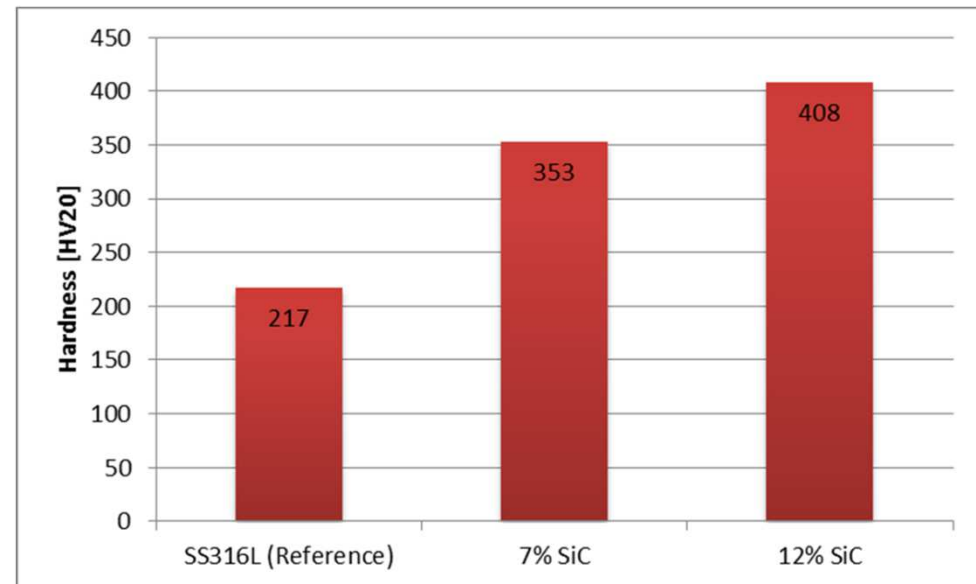


Results and discussion (2)

SS316L + SiC



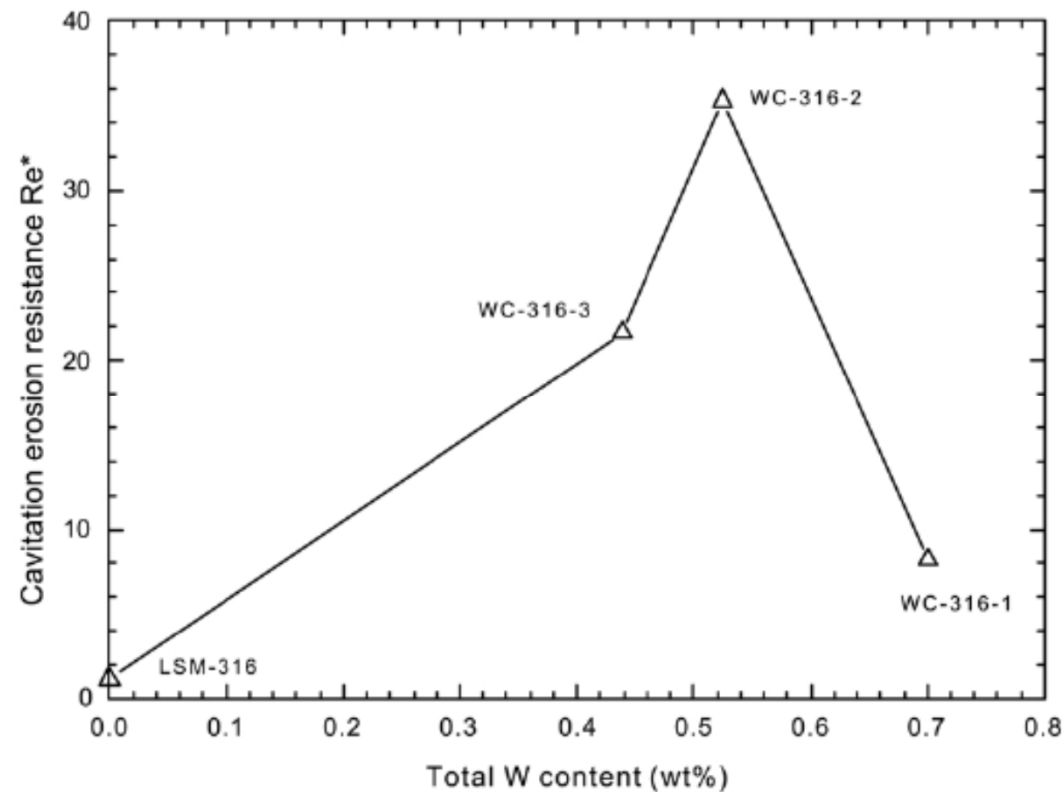
- **Extensive dissolution of SiC during laser cladding**
- Interdendritic spacing $\sim 3\text{-}4\ \mu\text{m}$
⇒ Microstructural refinement



Hardness increases with SiC content

Improving the cavitation erosion resistance

SS 316 + WC

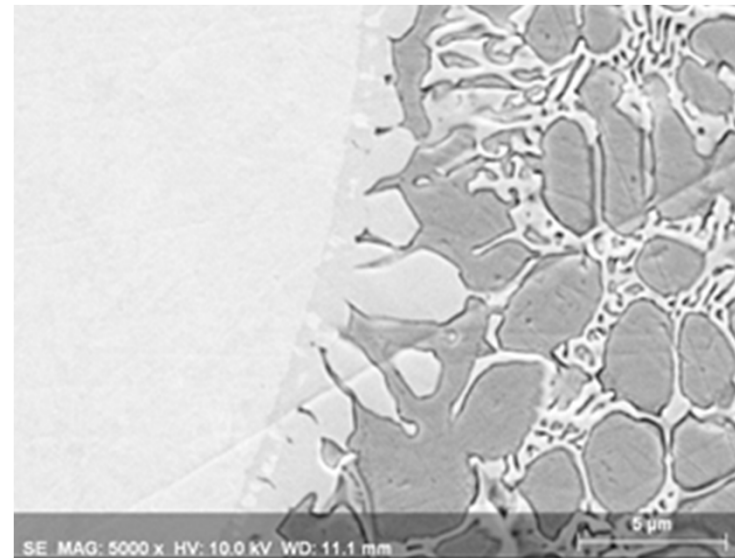
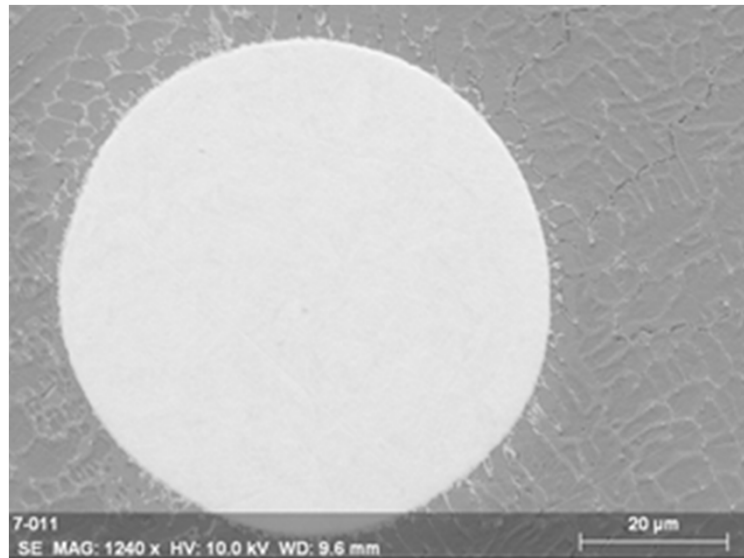


- Optimised cavitation erosion resistance is obtained after complete dissolution of WC particles and reprecipitation of an extremely fine structure

[Lo et al, 2003]

Results and discussion (3)

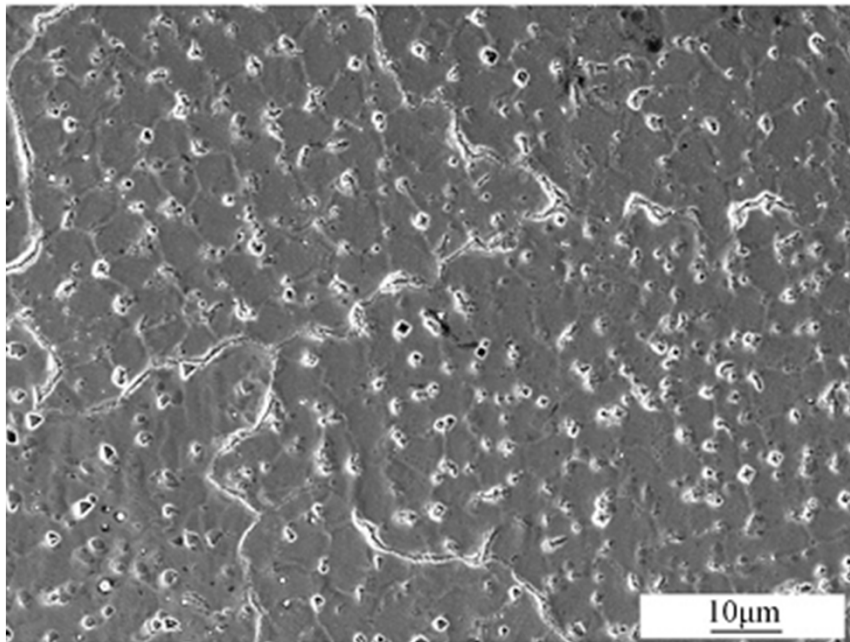
SS 316L + WC



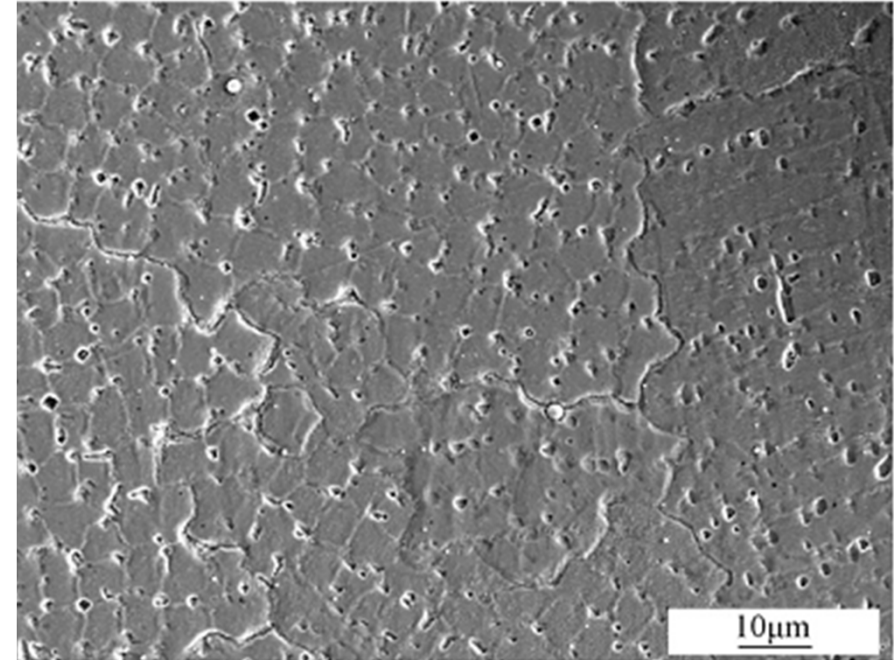
- Partial dissolution of WC
 - **Secondary precipitation** of WC, W_2C and other carbides ($M_{23}C_6$, M_7C_3 or M_6C) in a fine lamellar structure
 - Interdendritic spacing: 2-4 μm
- Microstructural refinement**

Addition of particles for microstructural refinement

NiCoCrAlY + nano CeO₂



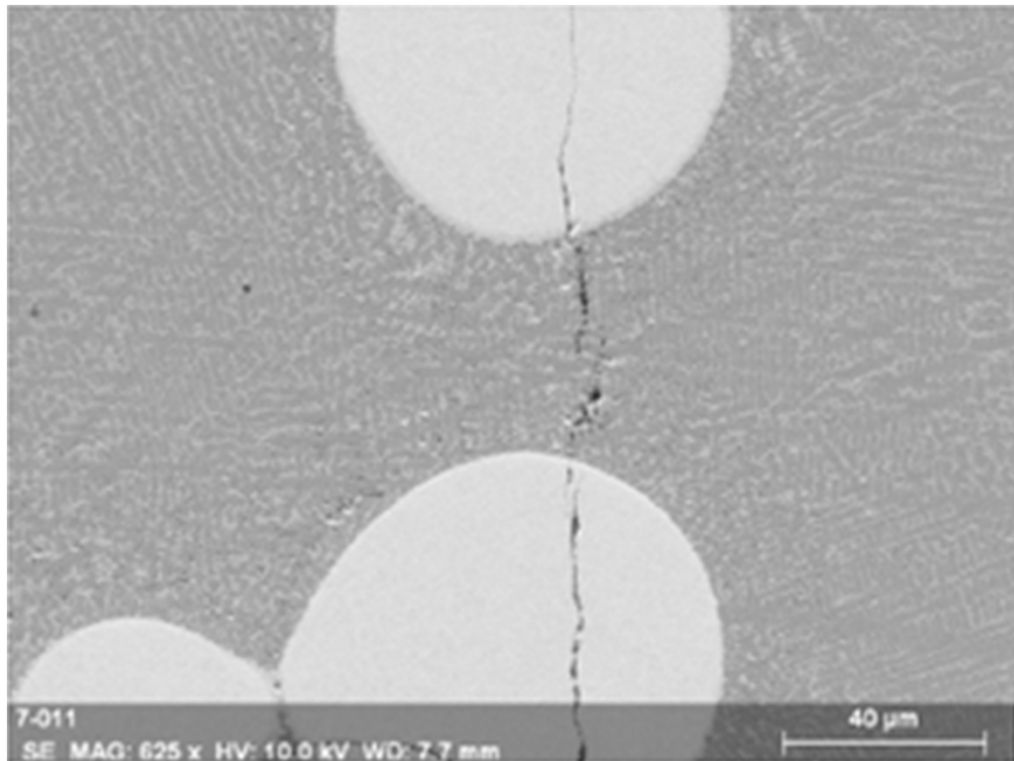
⇒ Microstructural refinement



[Wang et al., 2010]

Results and discussion (4)

SS 316L + WC

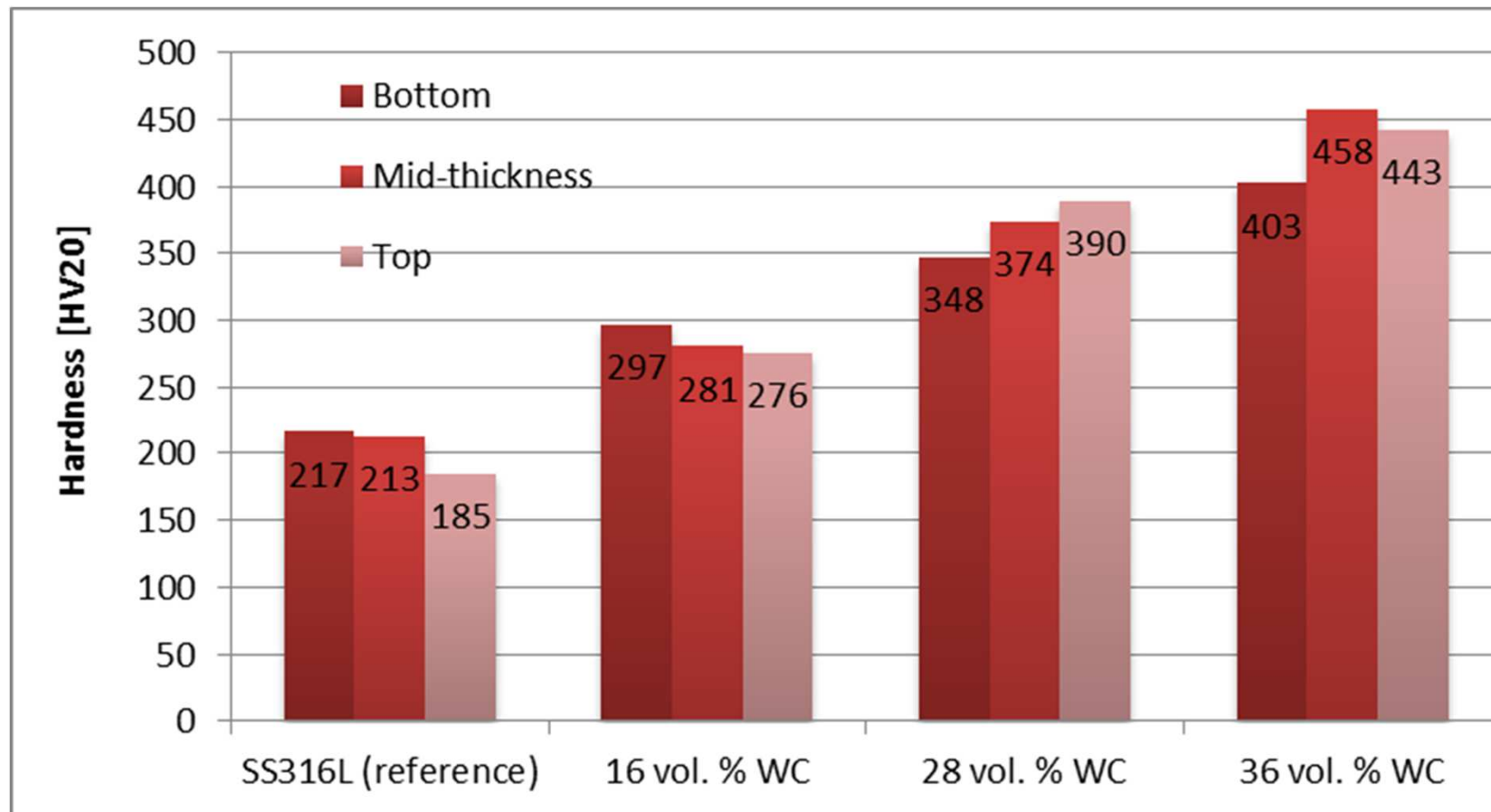


- **Cracks** occur at high WC content (>36%)
- Sometimes linking two or more adjacent particles
- Due to thermal mismatches between WC and matrix

[Mertens et al., 2017]

Results and discussion (5)

SS 316L + WC

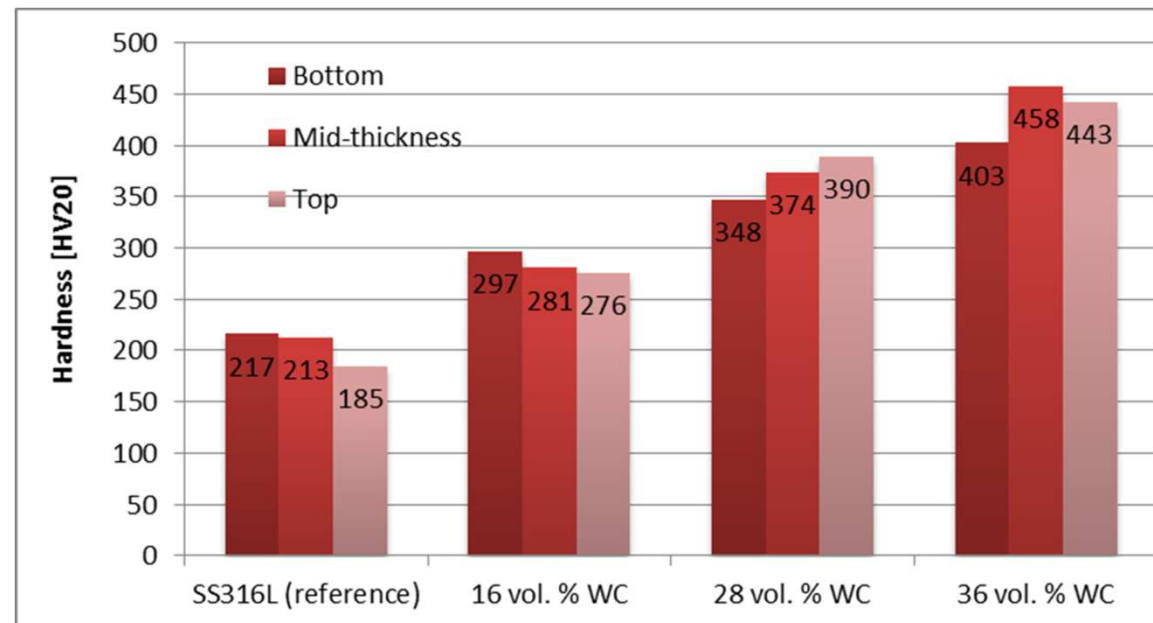


Hardness presents a complex variation pattern as a function of both position and WC content

Results and discussion (6)

SS 316L + WC

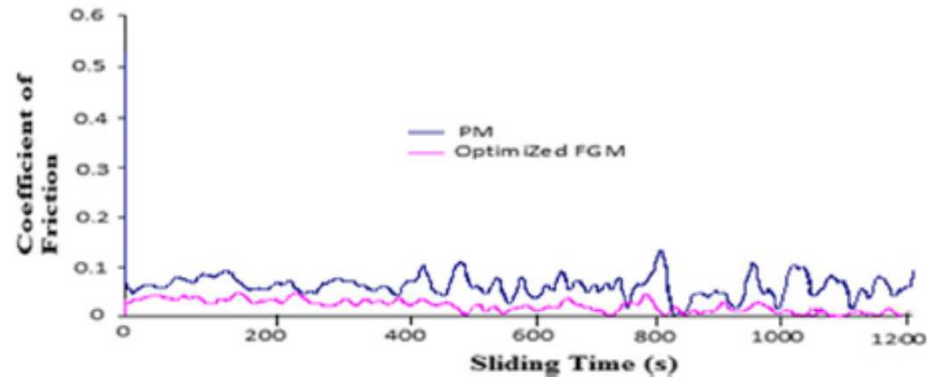
- Hardness presents a **complex variation** pattern as a function of both position and WC content
- Combined effect of **particles, precipitates and solid solution strengthening**
- Higher laser absorptivity of WC compared to SS 316L
⇒ **WC content influences the local thermal history**



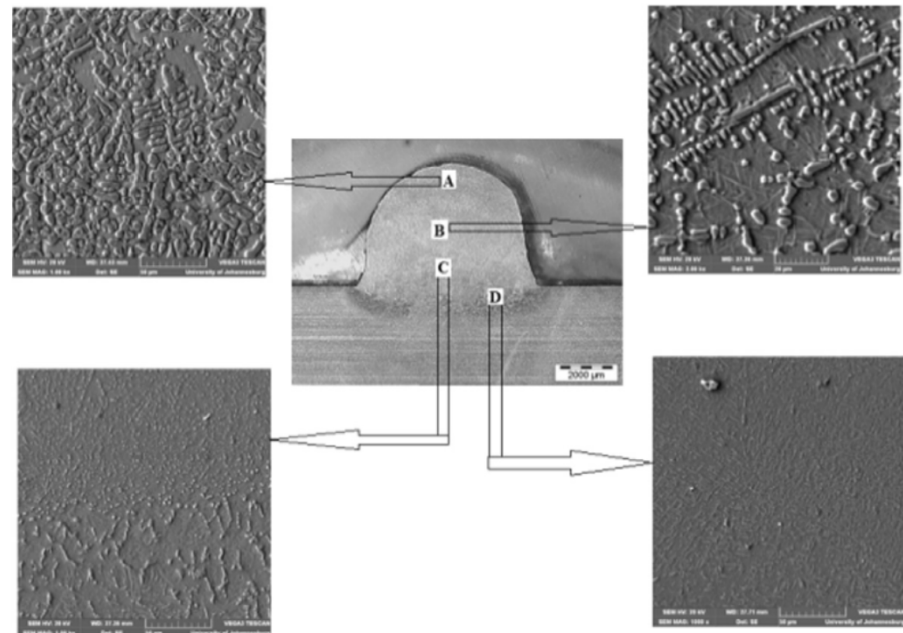
[Mertens et al., 2017]

Heat balance during the processing of FGMs

Graded Ti6Al4V + TiC



FGMs Ti6Al4V + TiC is have a better wear behaviour when the processing parameters are varied as a function of the TiC volume fraction



Concluding remarks (1)

- Sound composite coatings were made by laser cladding Stainless Steel 316L + SiC or WC particles
- Extensive dissolution of SiC vs partial dissolution of WC
- Hardness of both types of composite coatings was significantly enhanced in comparison with reference SS 316L coating, due to strengthening by the surviving particles, but also by secondary precipitates and solid solution
- High WC contents led to cracking of the WC particles due to thermal stresses arising between the particles and the matrix

Concluding remarks (2)

- Laser Cladding is a powerful technique for the production of Metal Matrix Composites and Functionally Graded Materials (FGMs)
- Thermal history is complex and may vary locally as a function of position inside a part.
 - ⇒ Microstructure may vary locally
 - ⇒ Mechanical properties may vary locally
- The volume fraction of reinforcement particles is an important parameter that controls the microstructure directly (chemistry) and indirectly (i.e. by influencing the thermal history)

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All publications from ULg can be obtained from: <http://orbi.ulg.ac.be/>

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Thank you for your attention!