In-situ observations of fracture in lean steels with different microstructures

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Objectives

Insight into the contribution of microstructure to fracture behavior

- ✓ **Evaluate plastic strain distribution on lean steels with different microstructures**
- ✓ **Monitor damage onset and crack propagation**

In-situ SEM tensile test & Digital Image Correlation (DIC)

Introduction

When designing lean steels, optimization of the microstructure is a must in order to improve mechanical performance. A better understanding of fracture micro-mechanisms related to microstructure distribution would favor the optimization of the alloying system and microstructure.

Steels obtained through PM present high amounts of porosity, which suppose propitious sites for crack nucleation when applying an external load. Pore morphology and distribution highly influence **mechanical properties**, since they determine local strain distribution. Besides, mechanical behavior is conditioned by the strength of the microconstituents , because it determines fracture path.

In-situ SEM tensile testing combined with **DIC** is being applied for cast and wrought steels in order to establish a relation between microstructure and fracture behavior. In PM, in-situ characterization can provide valuable information about the damage onset. In the present project, the possibility of using in-situ SEM with DIC in sintered steels is evaluated

Experimental Procedure

P&S steels modified with master alloy additions

Nominal composition: Fe-(1.8Cr)-0.5C-1MA* (wt.%)

Base powders: plain Fe- *grade ASC 100.29 Höganäs AB (Sweden)*
Cr-prealloyed Fe (Fe-1.8Cr)- *grade Astaloy CrA Höganäs AB (Sweden)*

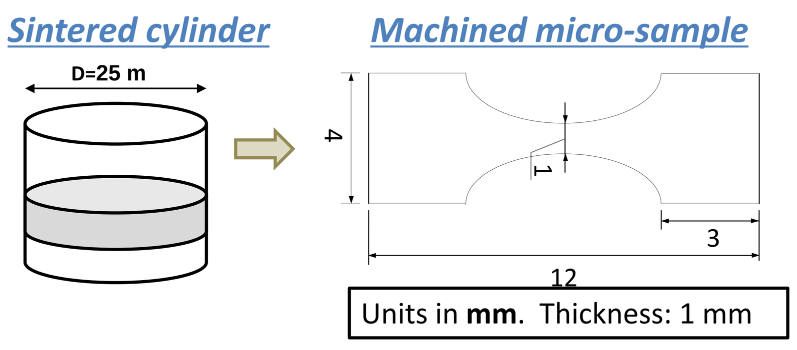
Melting point master alloy powders:

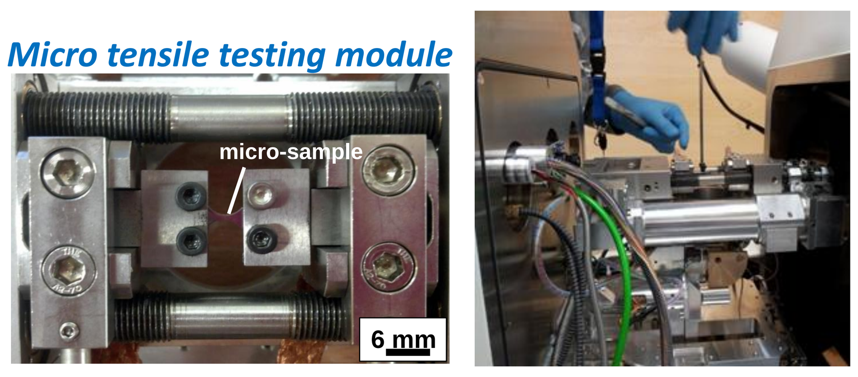
MA1 (**Cu-2.1Ni-1.2Si**, $T_{liquidus}$= 1091 ºC), sieved <45 µm
MA2 (**Ni-3.9Cu-11.6Si**, $T_{liquidus}$= 1127 ºC), sieved <45 µm

*MA: Master alloy –*liquid phase promoter to enhance densification and mechanical properties.*

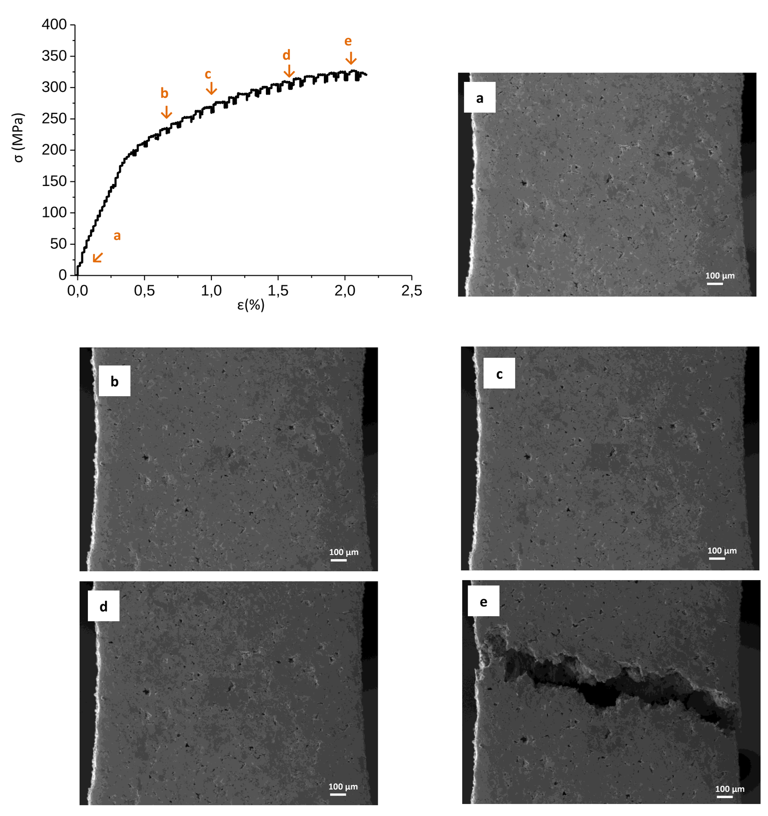
Material	Steel composition (wt.%)	Compaction	Sintering in 95%N_2-5%H_2	Cooling Rate
A	Fe-0.5C-1MA1	Uniaxial compaction 600 MPa	1120 ºC- 30’	~ 0.8 ºC/s
B	Fe-1.8Cr-0.5C-1MA1			
C	Fe-1.8Cr-0.5C-1MA2		1250 ºC- 30’	
D	Fe-1.8Cr-0.5C-1MA2		1250 ºC- 30’	~ 2.5 ºC/s

Assessments of strain, crack nucleation and propagation.



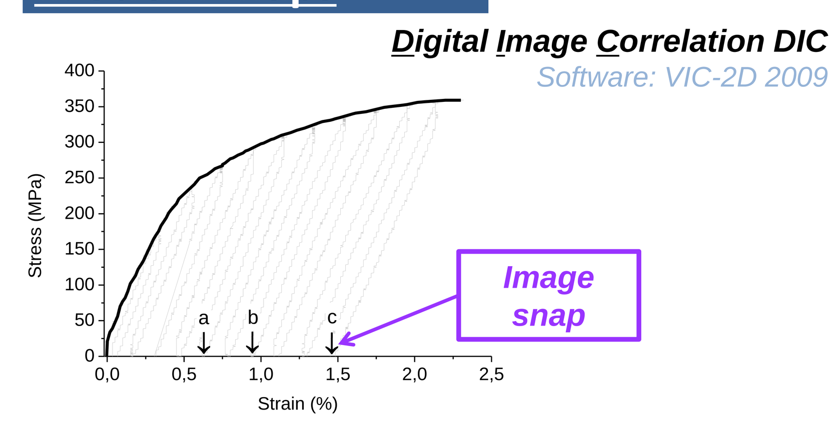


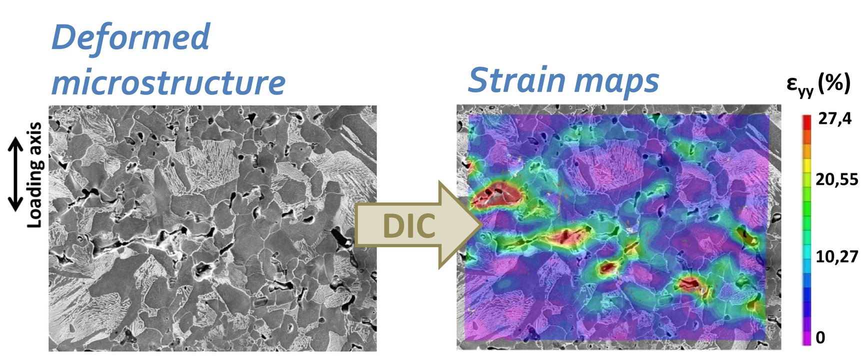
I. SEM In situ Testing



SEM In-situ testing: in-situ observation of fracture and further fractography

II. Strain Maps





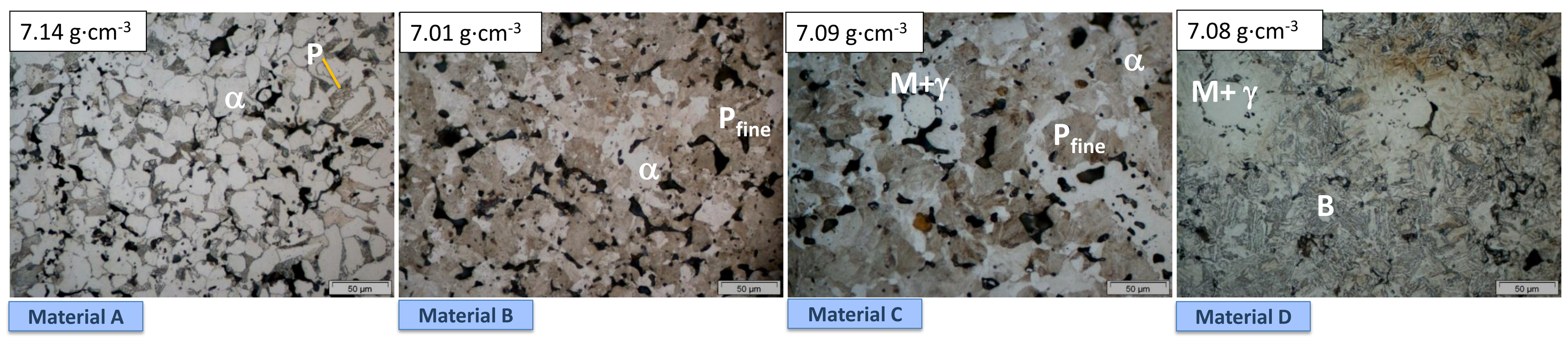
Strain maps: evolution of local plastic deformation during tensile testing

Conclusions

- **Strain localization** starts at big irregularly shaped pores and leads to the formation **strain bands**. A **network-like structure of deformation bands** linking porosity develops.
- **Sharp and elongated pores**, in perpendicular direction to the loading axis, induce the highest strain localization and are preferential areas for crack nucleation.
- **Soft phases** around these pores contribute to strain localization and crack initiation.
- Failure is first detected at soft phases (ferrite>pearlite>bainite>martensite) and **crack propagation** preferentially occurs along interphase boundaries between microconstituents.

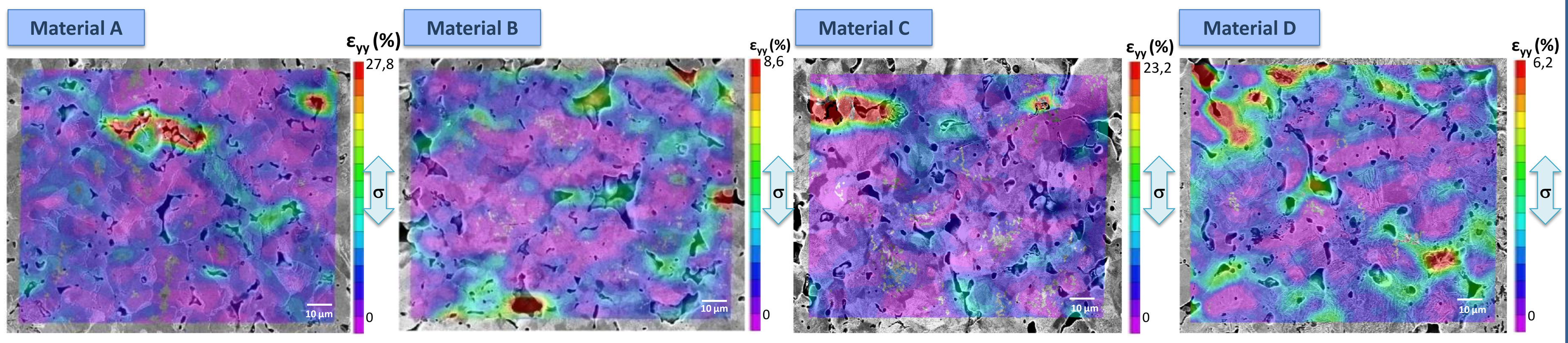
Results

Microstructure

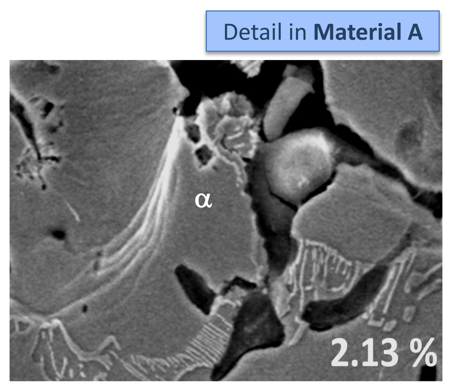


Material A	Material B	Material C	Material D
9.7% porosity	10.6% porosity	9.5% porosity	9.7% porosity
A_{pore}=95 µm², F_{shape}=0.55, F_{circle}=0.65	A_{pore}=138 µm², F_{shape}=0.56, F_{circle}=0.65	A_{pore}=101µm², F_{shape}=0.60, F_{circle}=0.73	A_{pore}=101 µm², F_{shape}=0.65, F_{circle}=0.71
Biggest pores: F_{shape}=0.59, F_{circle}=0.31	Biggest pores: F_{shape}=0.55, F_{circle}=0.29	Biggest pores: F_{shape}=0.52, F_{circle}=0.36	Biggest pores: F_{shape}=0.52, F_{circle}=0.28

DIC: plastic strain maps at maximum strain

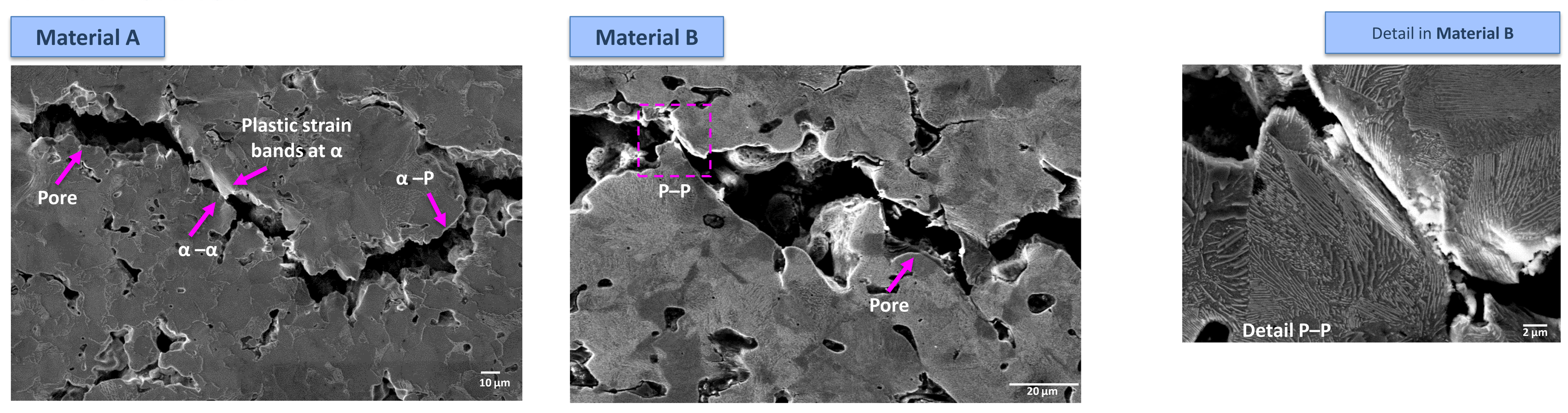


- ✓ Localization of plastic deformation around **big and irregular pores**, preferentially in perpendicular direction to loading
- ✓ Formation of strain bands liking porosity → interconnection of **adjacent pores**
- ✓ **Soft phases** (ferrite) around big pores increase localization of plastic strain: presence of plastic deformation bands

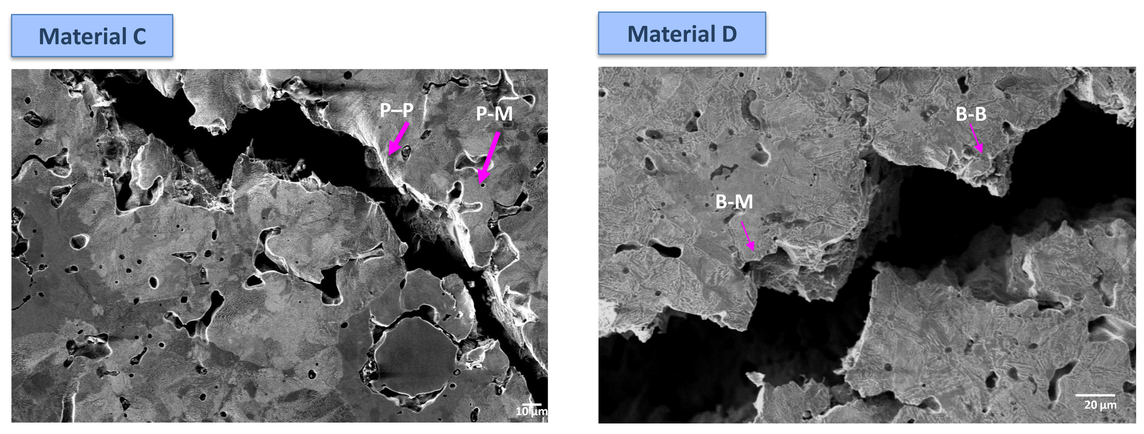


In-situ SEM tensile testing

FINAL CRACK



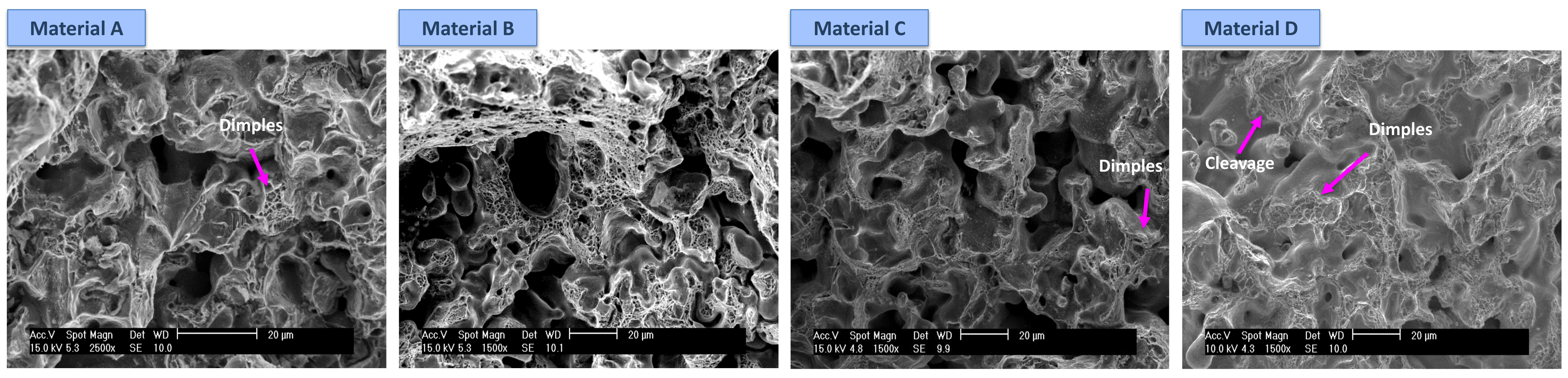
α: Ferrite, P: Pearlite, B: Bainite, M: Martensite



✓ Crack nucleation: **Bigger pores** (~ 400-700 µm²) and **soft phases**

✓ Propagation: Interconnection of **adjacent pores**, through **interphases between microconstituents**

Fractography



The observed micromechanisms of fracture confirms preferential crack path

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