

# Comparison of the mechanical properties of T91 steel from the MEGAPIE, LEXUR and TWIN-ASTIR irradiation programs

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# Outline

- ☐ Introduction - MYRRHA reactor
- ☐ MEGAPIE experiment
- ☐ LEXUR irradiation program
- ☐ TWIN-ASTIR irradiation program
- ☐ PIE
  - ✓ Tensile tests
  - ✓ Scanning electron microscopy

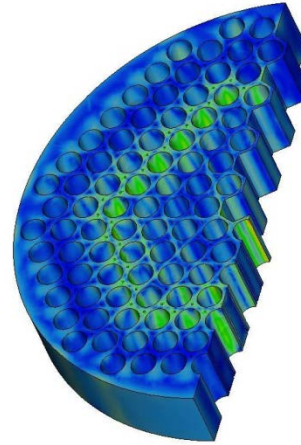
# Role of material research for development of MYRRHA

## Design tools:

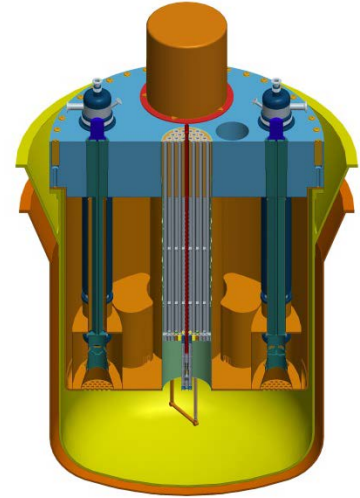
- ☐ Nuclear manufacturing codes: RCC-MRx, ...
- ☐ Fuel codes
- ☐ FE calculations



## Design



## Construction

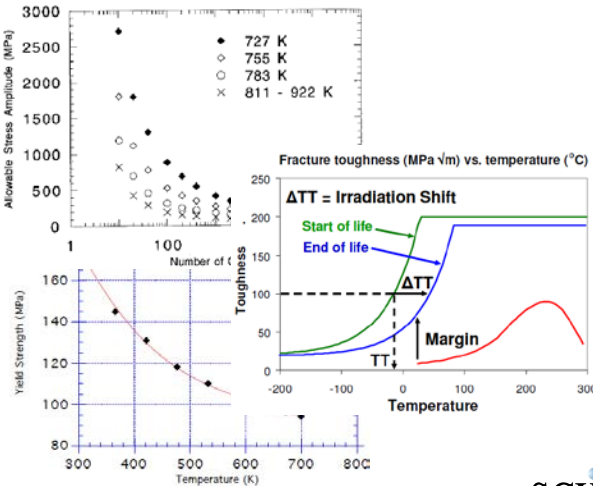


Approaches

## Required data for MYRRHA:

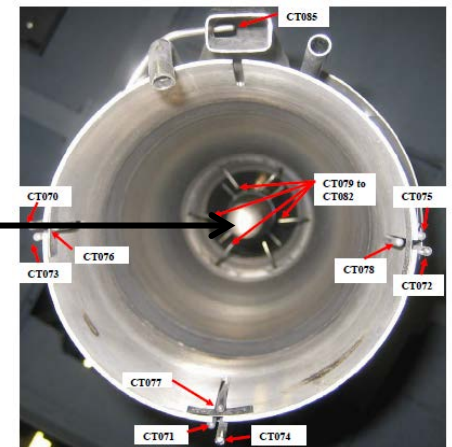
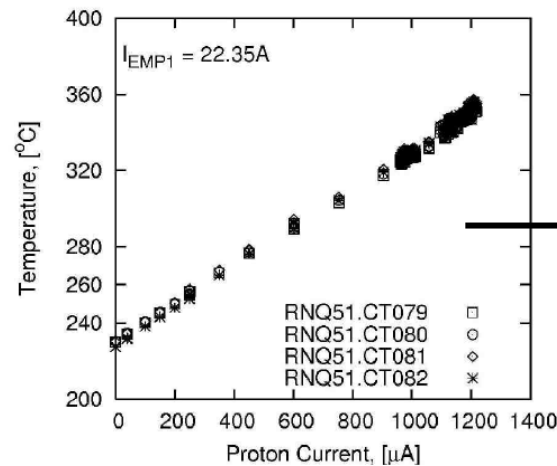
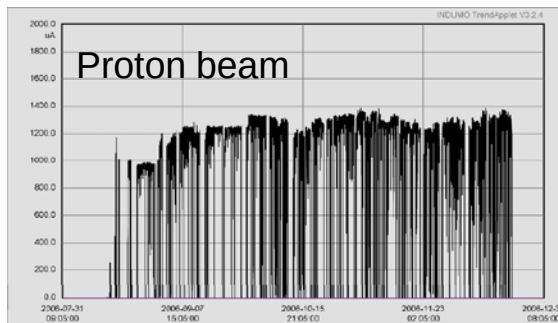
- ☐ Some basic characteristics of candidate materials (T91, SS 316L & 1.4970)
- ☐ Effects of LBE & irradiation on material properties
- ☐ Physical effects: Liquid metal embrittlement (LME), Liquid Metal Corrosion (LMC), SCC, etc.

Data



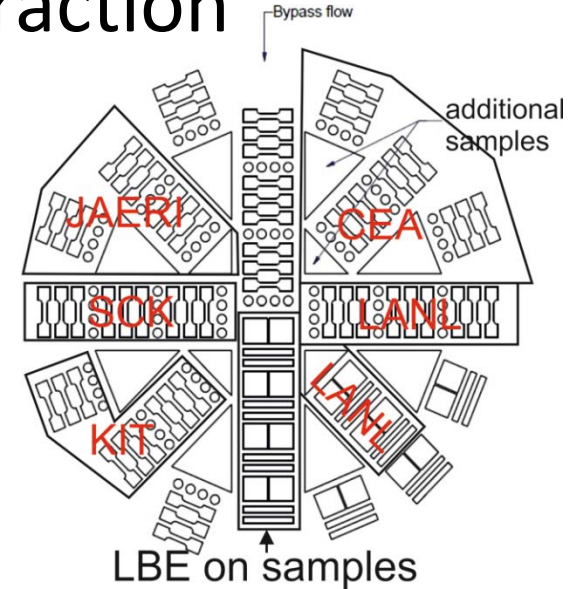
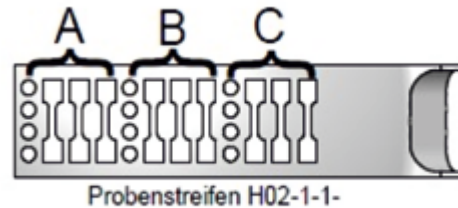
# MEGAPIE experiment

- ❑ Materials: T91, 316L
- ❑ Irradiation: High-E protons + spallation neutrons
- ❑ Dose: 0-7 dpa
- ❑ Environment: LBE
- ❑ Temperatures: 230-350°C
- ❑ Specimens extracted: Flat tensile, TEM discs, plates, bars

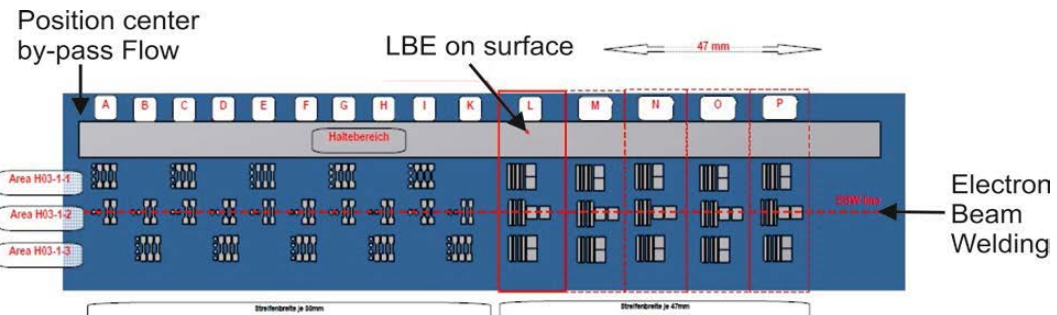


# MEGAPIE sample extraction

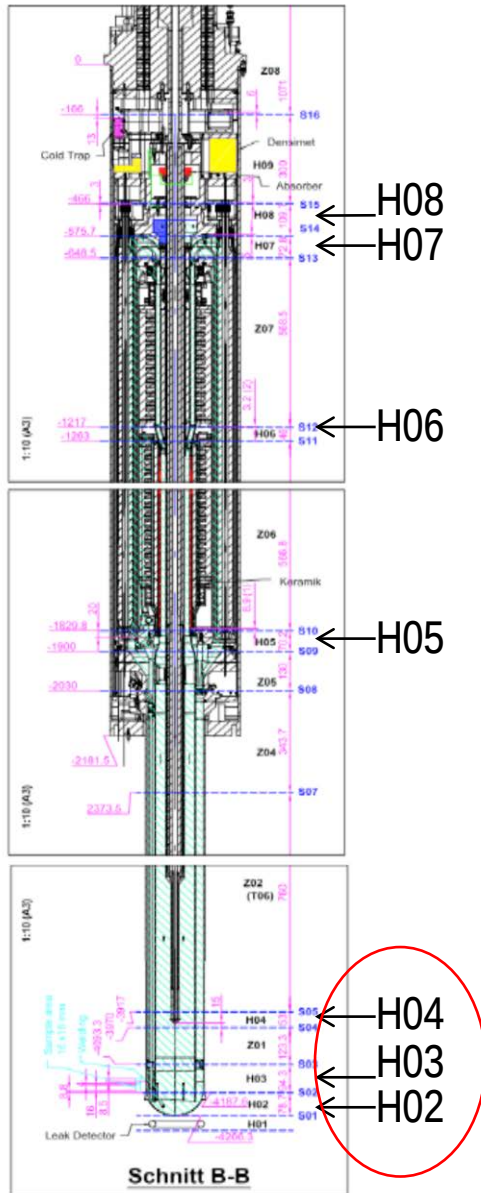
H02 - The Beam Entrance Window (Calotte)



H03 - lower liquid metal container (LLMC)



H04 - lower liquid metal container (LLMC)



## LEXUR II irradiation program

- ☐ Irradiation experiment in BOR-60 reactor (RIAR, Russia)
- ☐ Materials: T91, 316L, 15-15Ti, ODS (Pb)
- ☐ Doses: 6÷35 dpa
- ☐ Environment: LBE, Pb
- ☐ Temperatures: 350°C (LBE) & 550°C (Pb)
- ☐ Specimens: Round tensile, DCT, corrosion discs, pressurized tubes

## TWIN-ASTIR irradiation conditions

- ☐ Irradiation experiment in BR2 reactor
- ☐ Materials: T91, 316L, High Silicon Steels, welds
- ☐ Dose: 0, 1.25 and 2.5 dpa
- ☐ Environment: LBE & PWR water
- ☐ Temperatures: 300-320 °C & 350-370 °C & 460-490 °C
- ☐ Specimens: Round tensile, DCT, corrosion plates



# Tensile tests

## MEGAPIE

Temperatures: RT, 300 °C

Strain rate:  $5 \times 10^{-5}$  1/s

Environment: PbBi, ArH, Air

Oxygen:  $\sim 10^{-6}$  wt%

## LEXUR

Temperatures: RT, 350 °C

Strain rate:  $5 \times 10^{-5}$  1/s

Environment: PbBi, Air

Oxygen: saturated

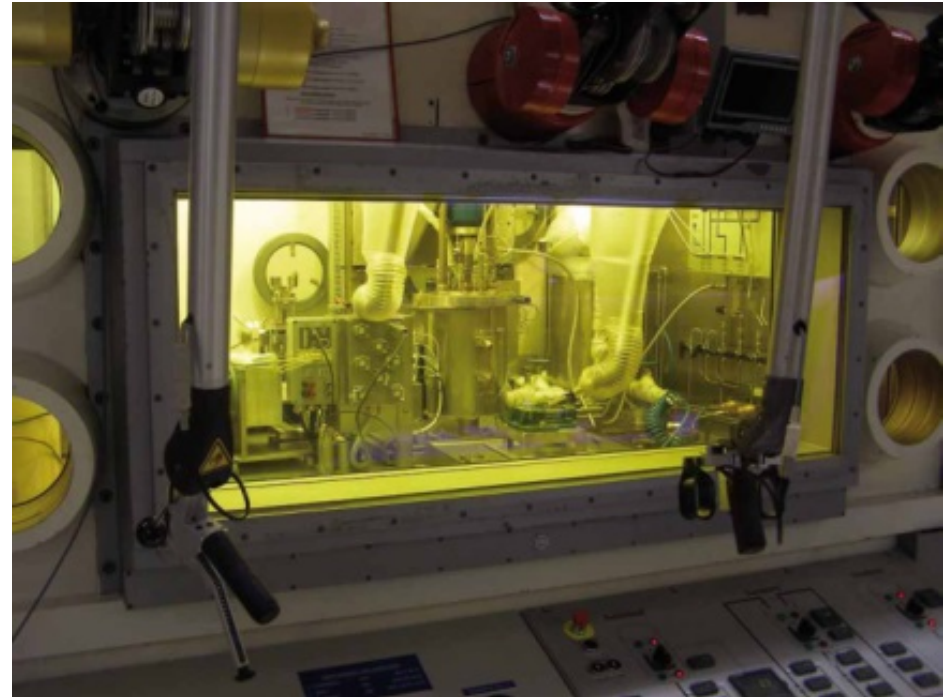
## TWIN-ASTIR

Temperatures: RT, 300 °C

Strain rate:  $5 \times 10^{-5}$  1/s

Environment: PbBi, ArH, Air

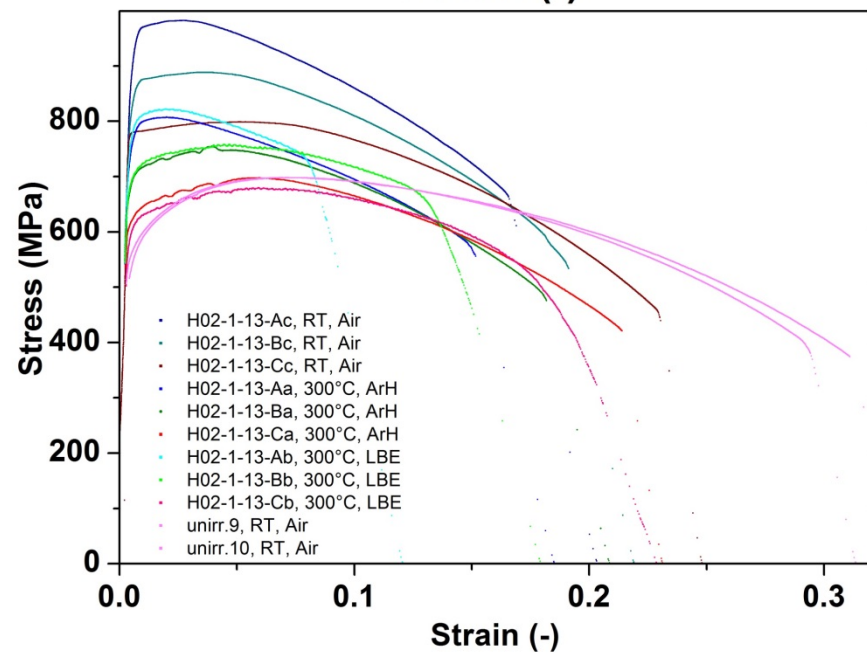
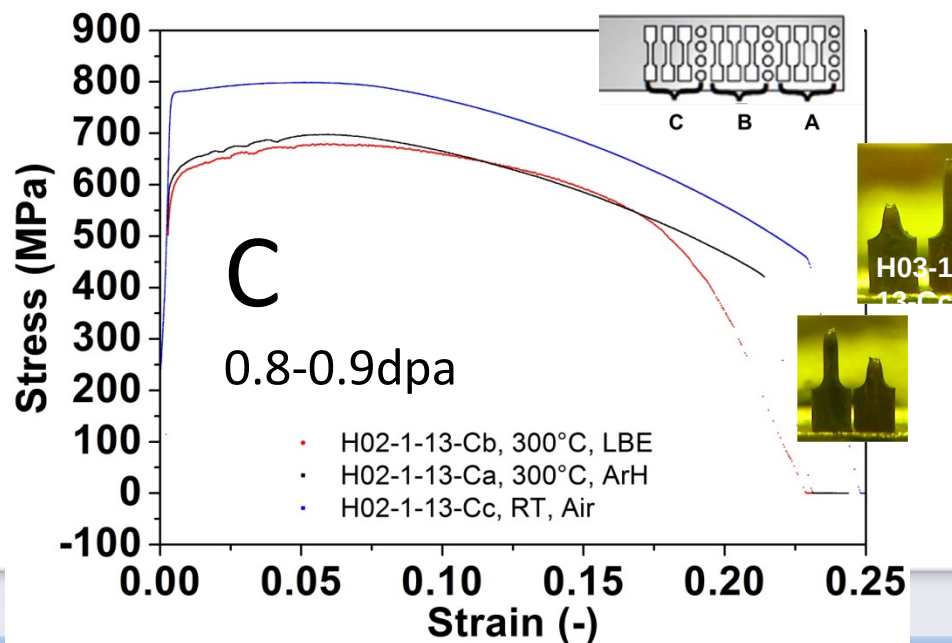
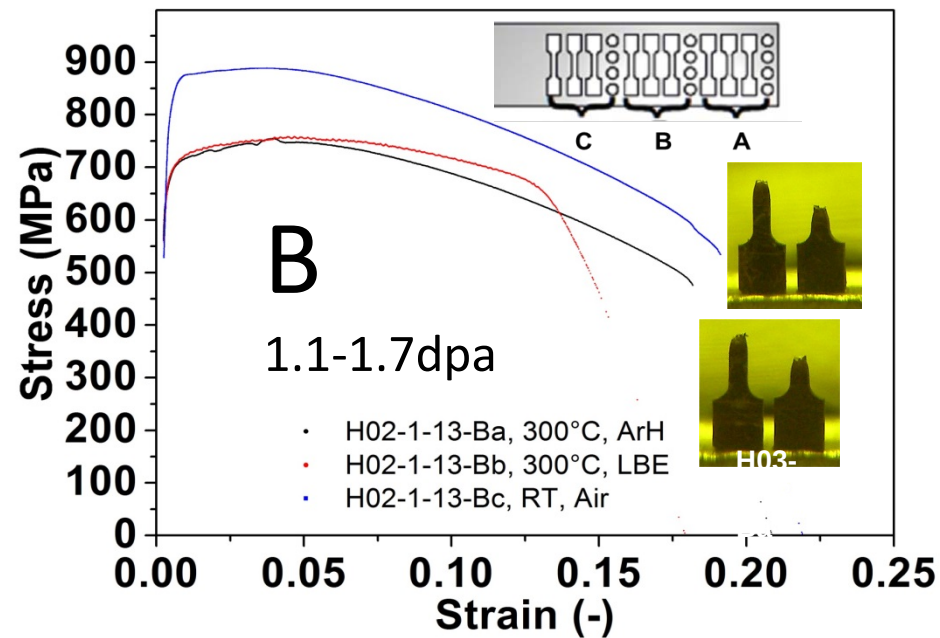
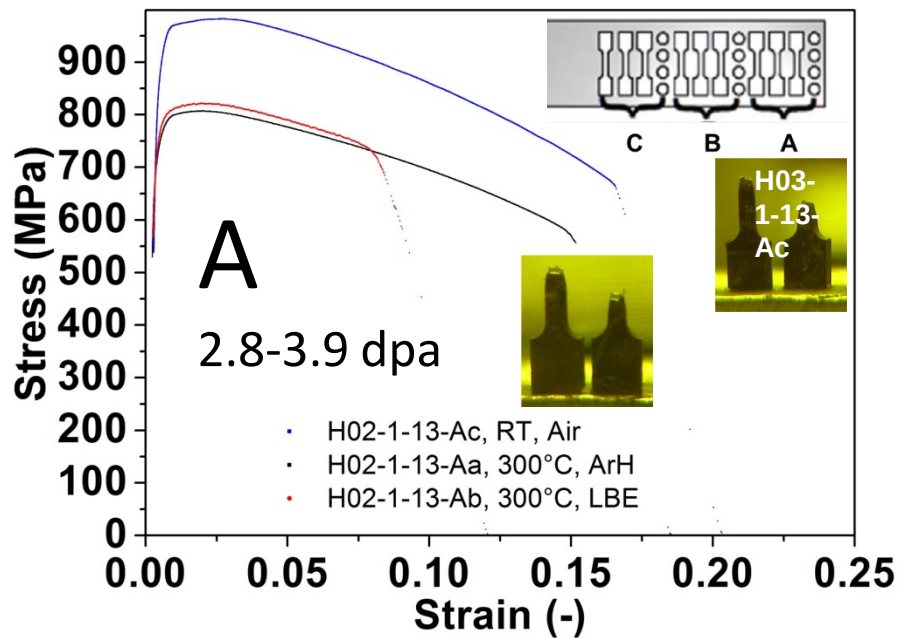
Oxygen: Oxygen:  $\sim 10^{-6}$  wt%



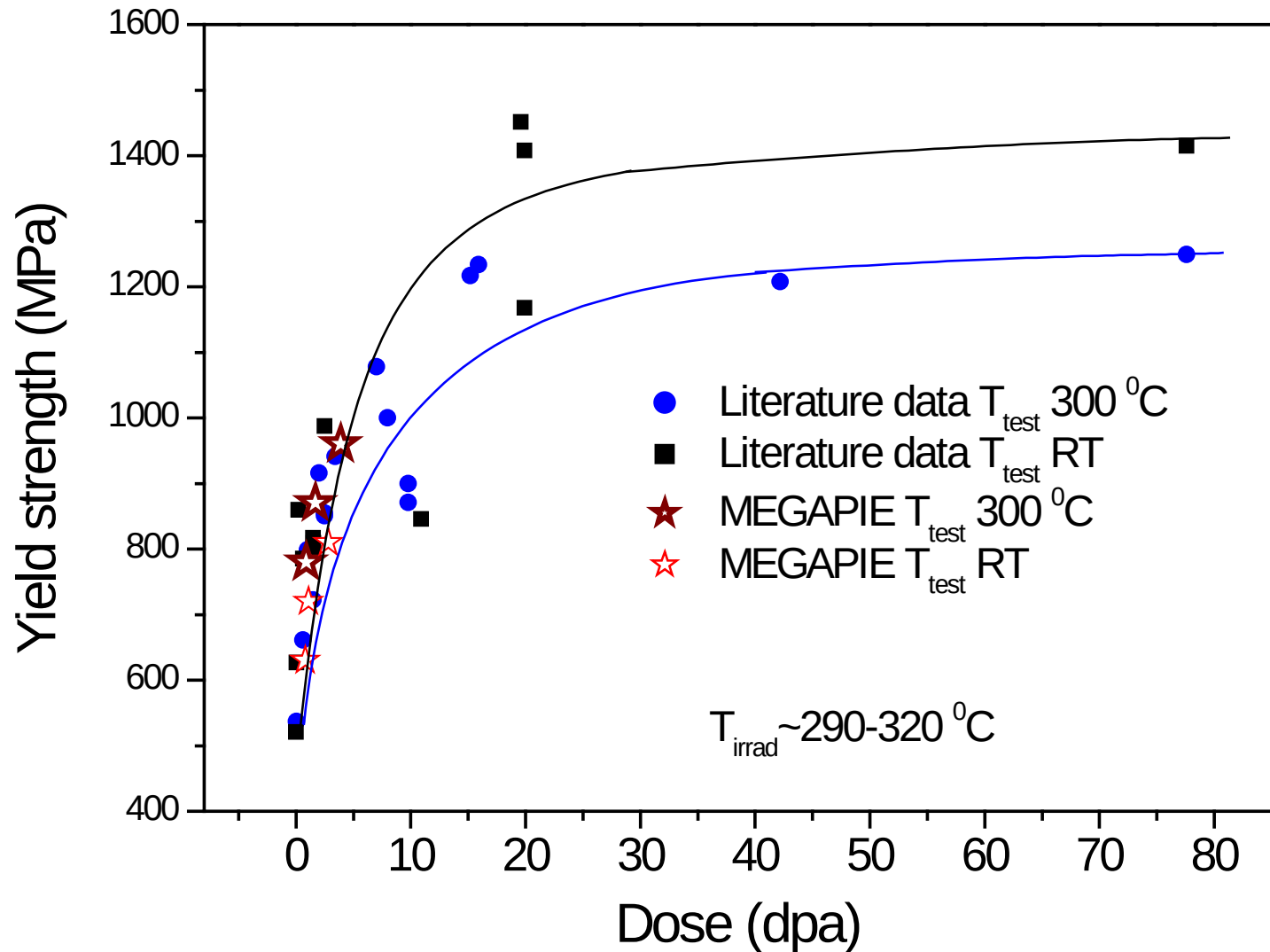
Limets 2, SCK•CEN



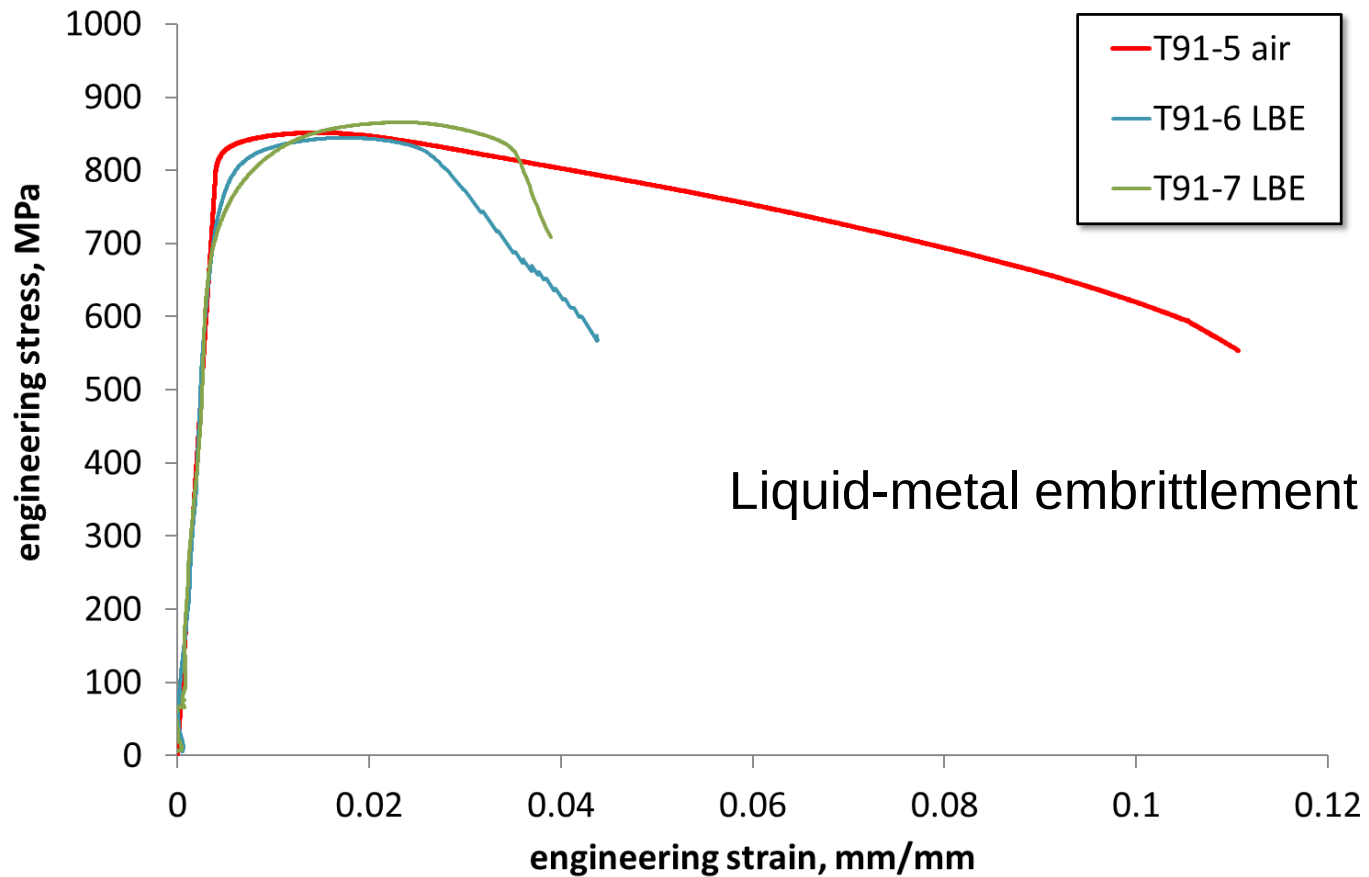
# Tensile tests T91



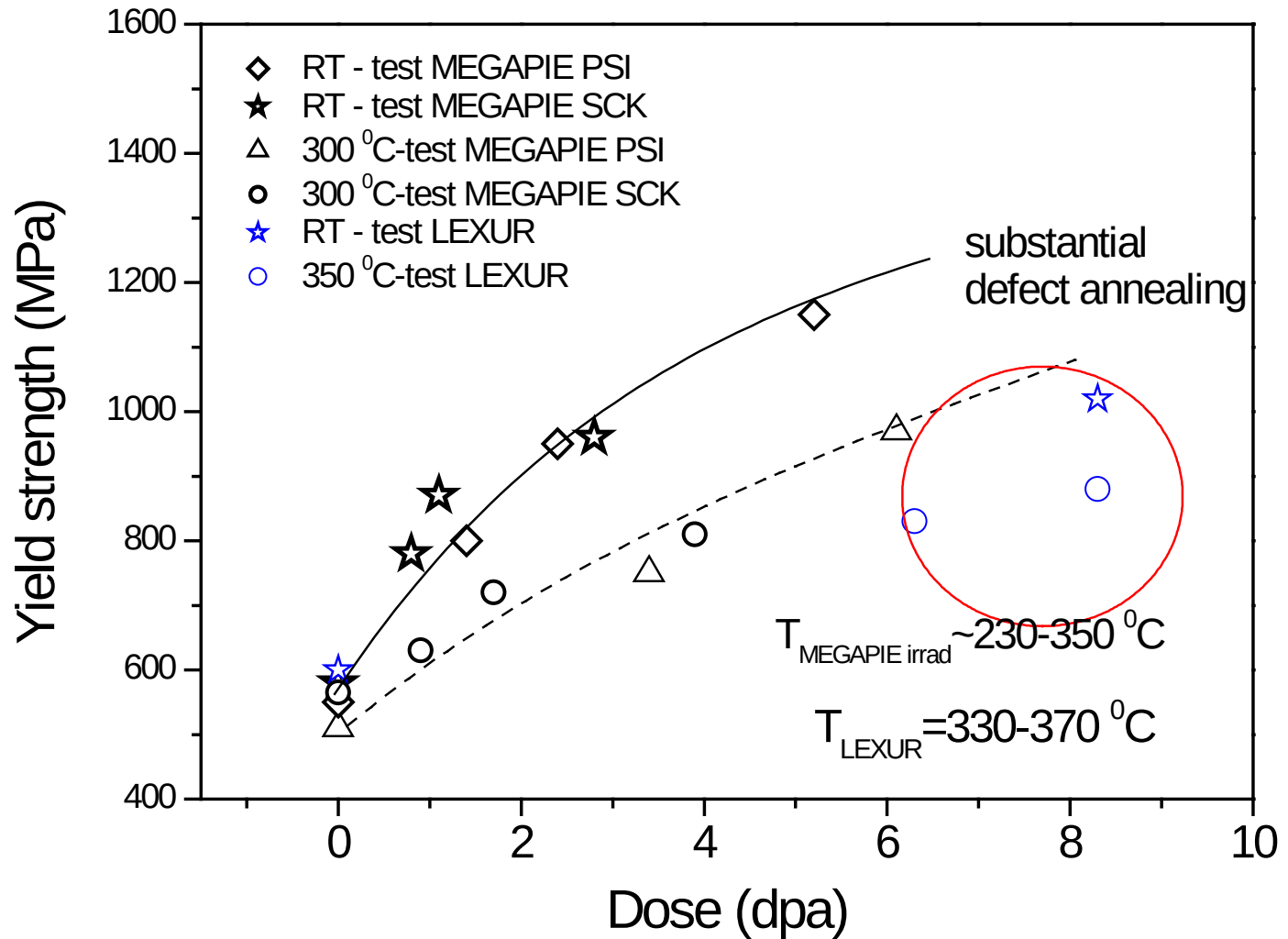
# Comparison with literature data



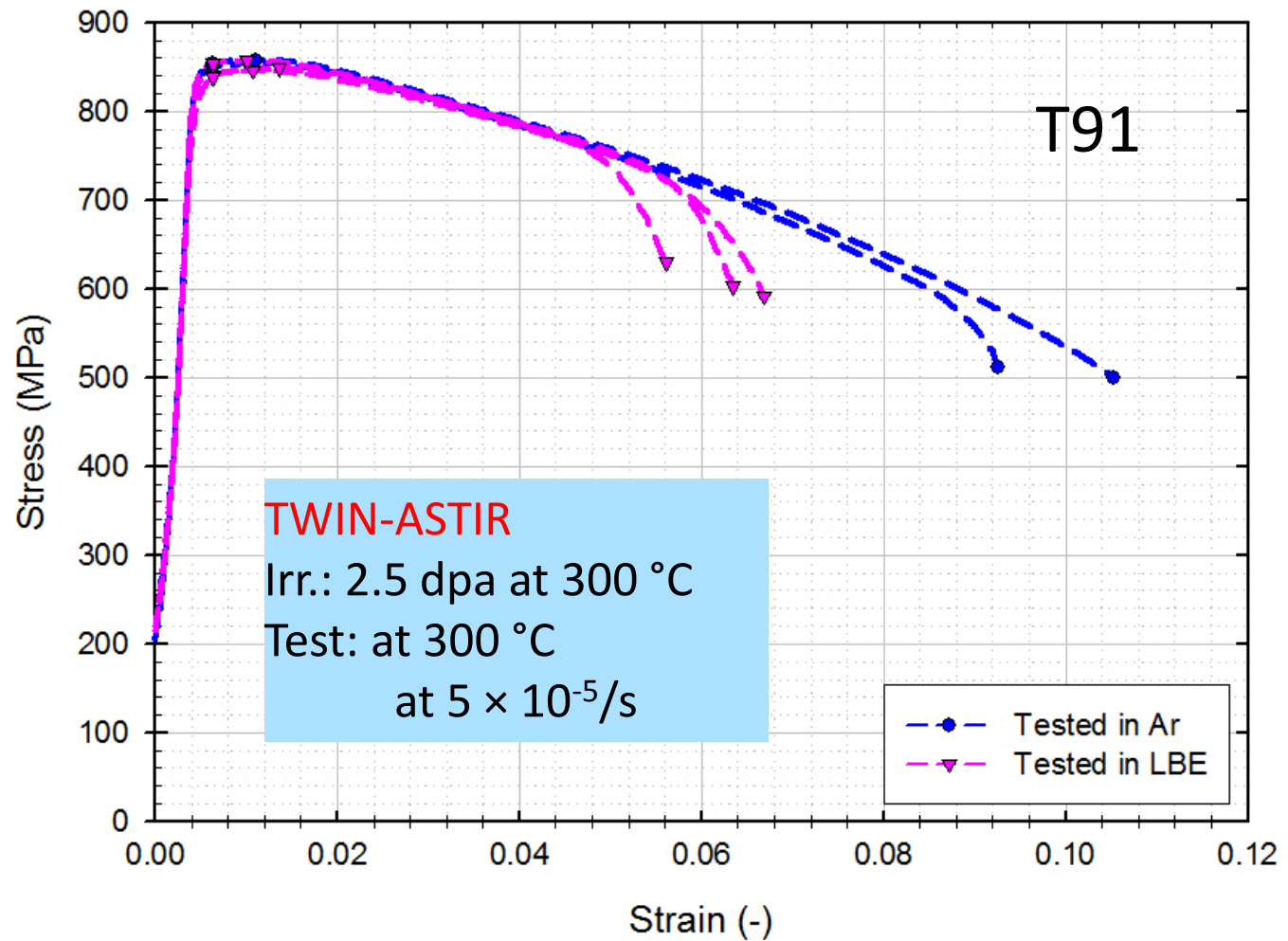
# LEXUR mechanical tests



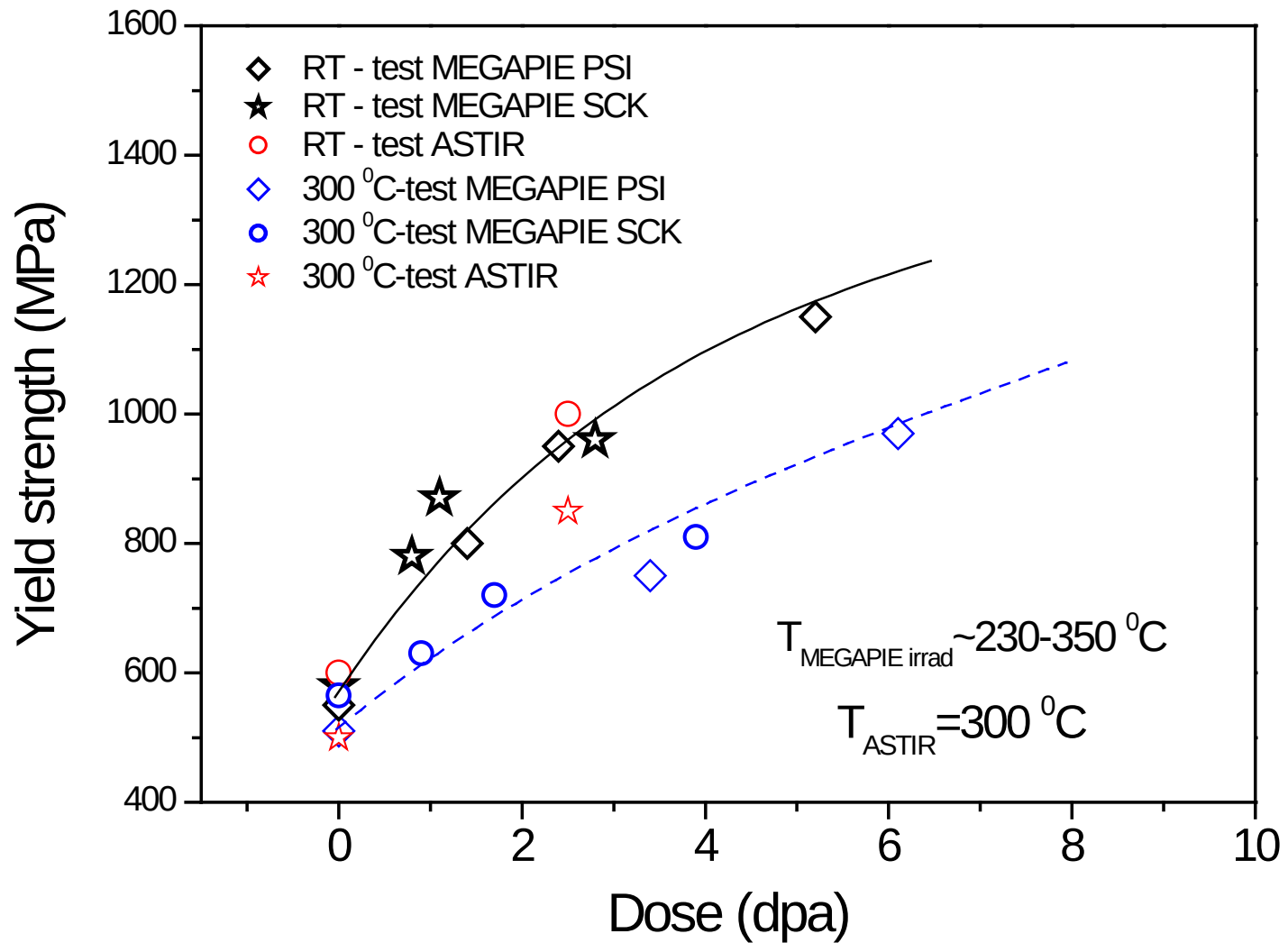
# LEXUR vs MEGAPIE

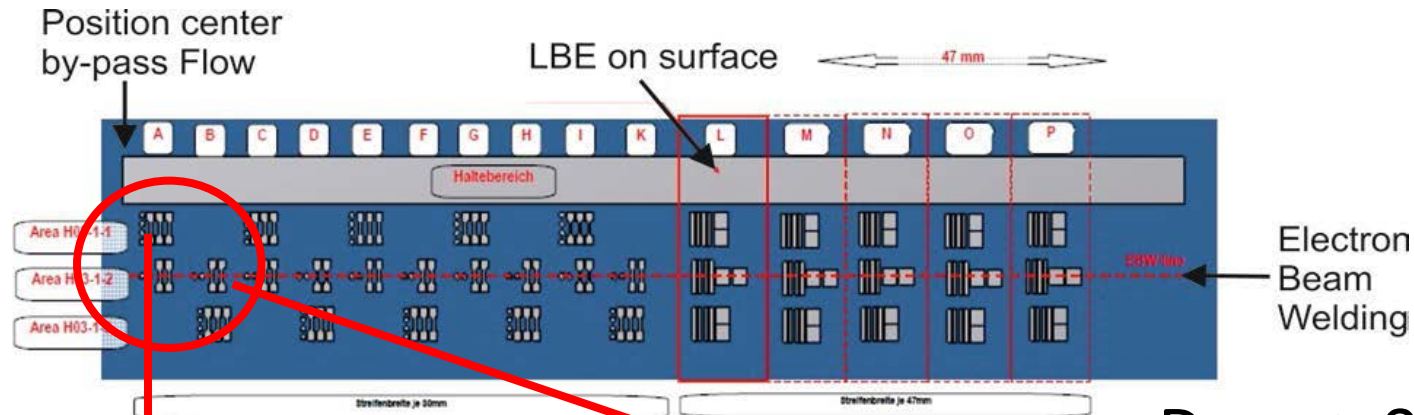


# TWIN-ASTIR mechanical tests

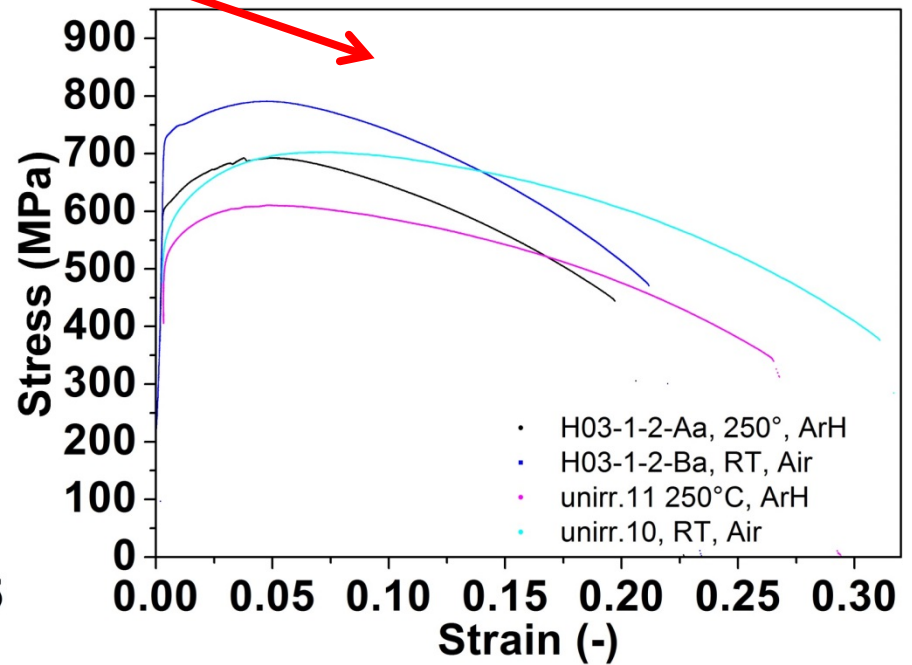
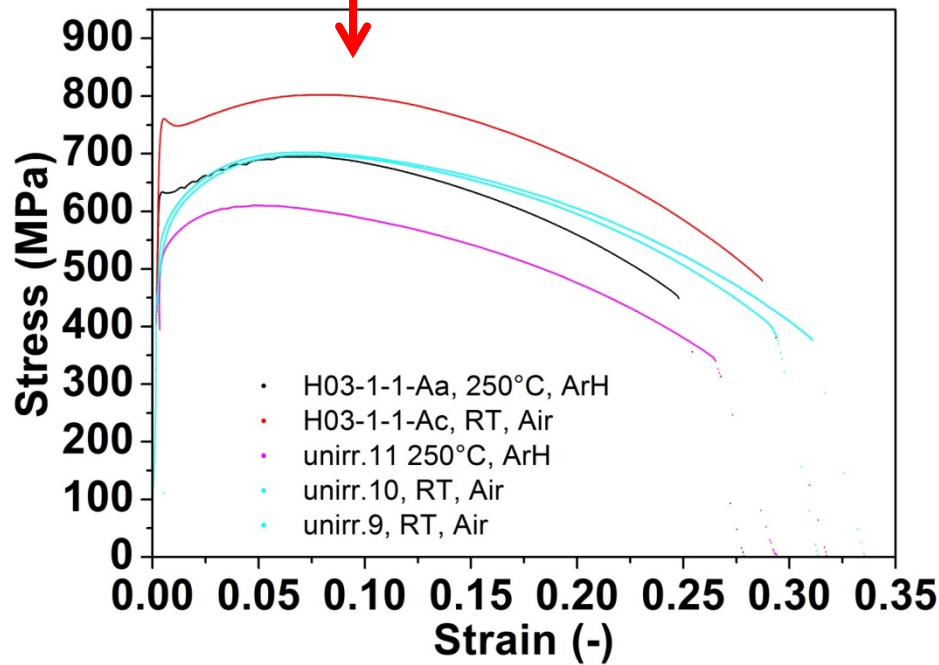


# Twin-ASTIR vs MEGAPIE





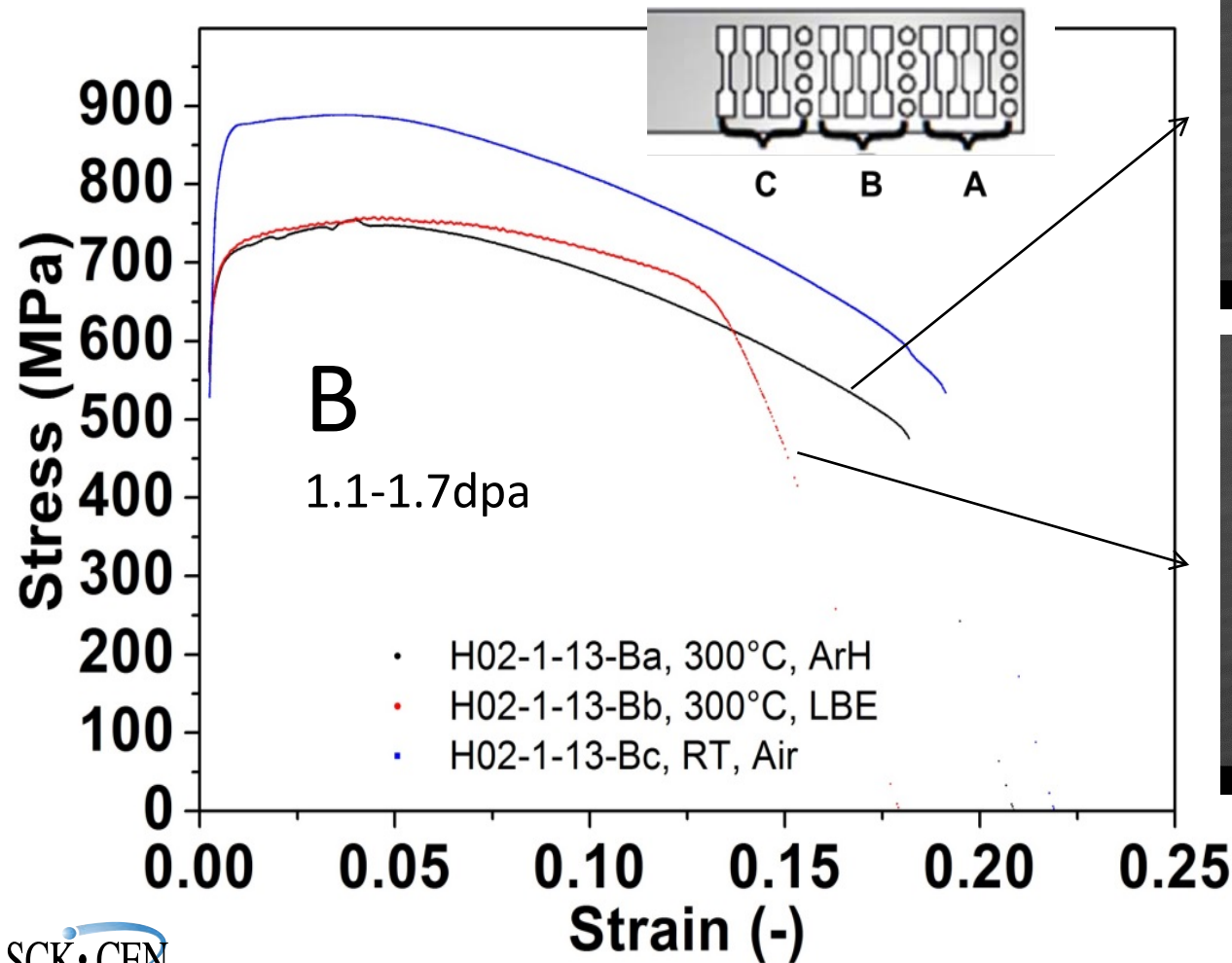
Dose  $\sim 0.7$  dpa



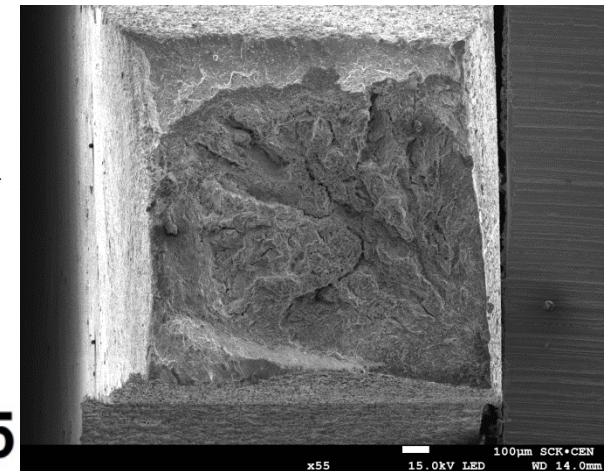
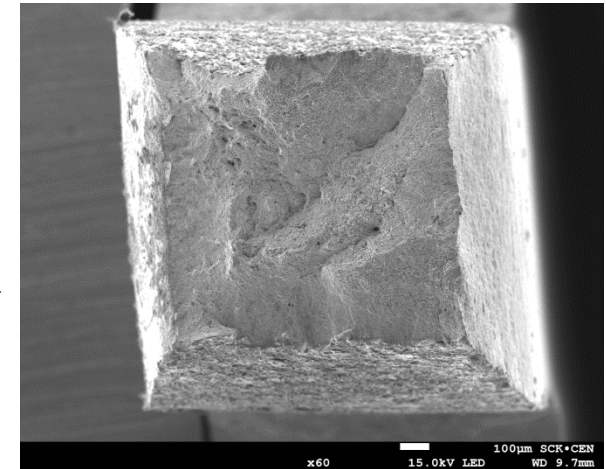
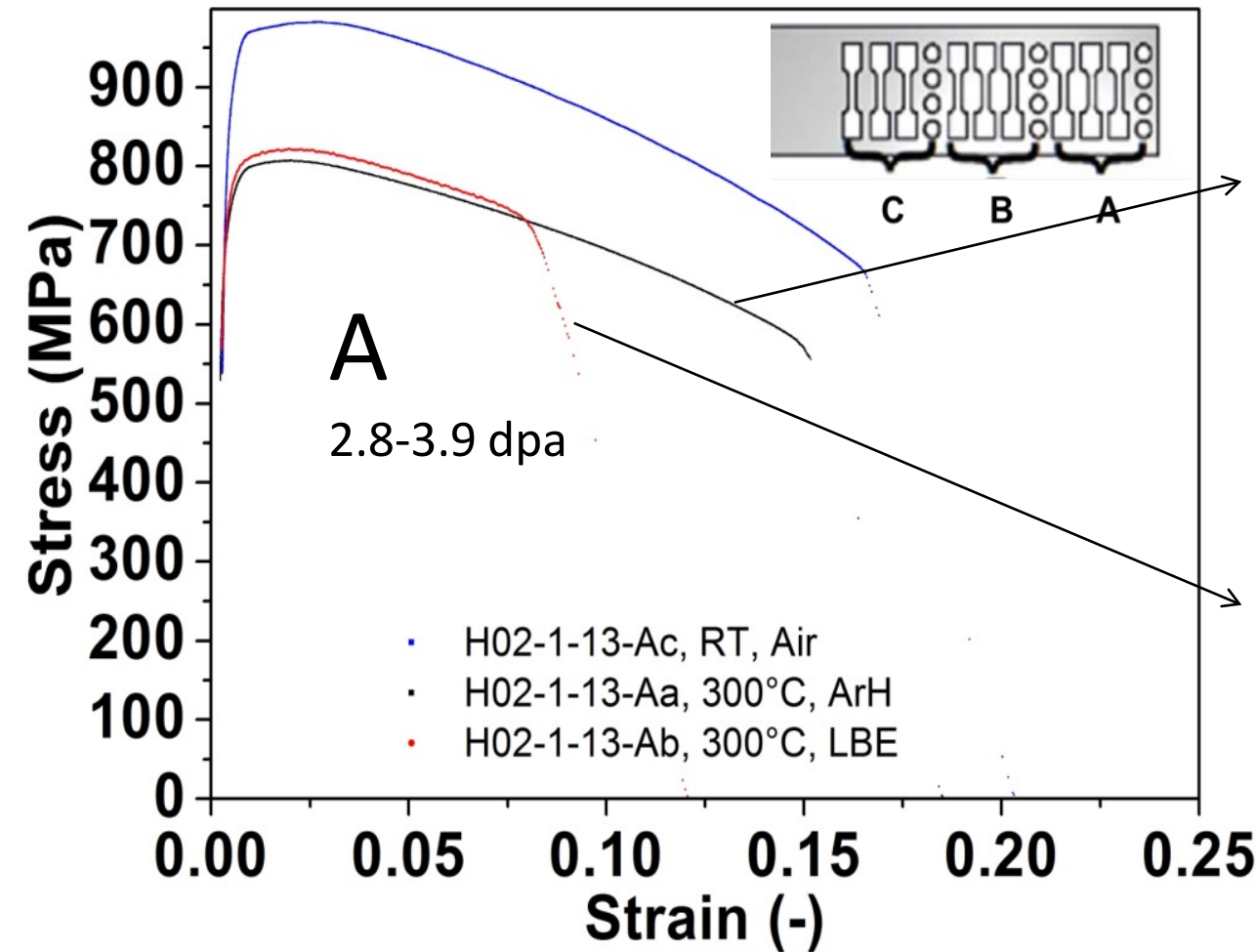
No effect of EBW



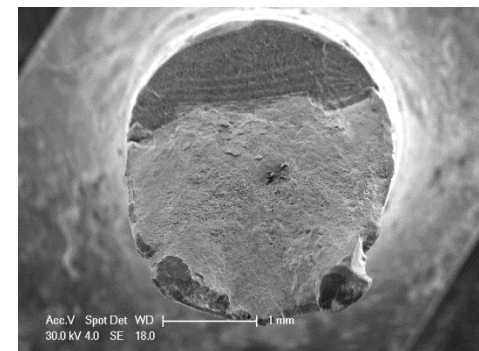
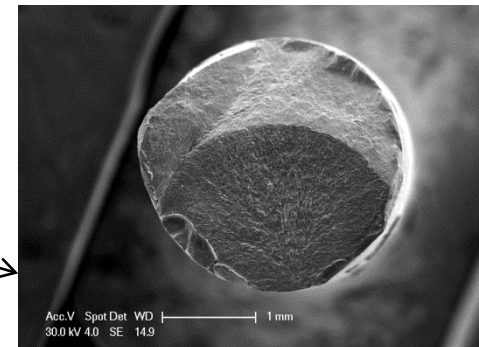
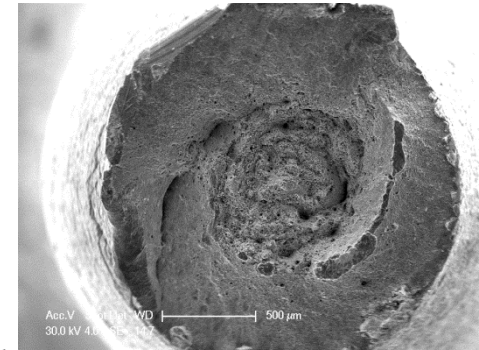
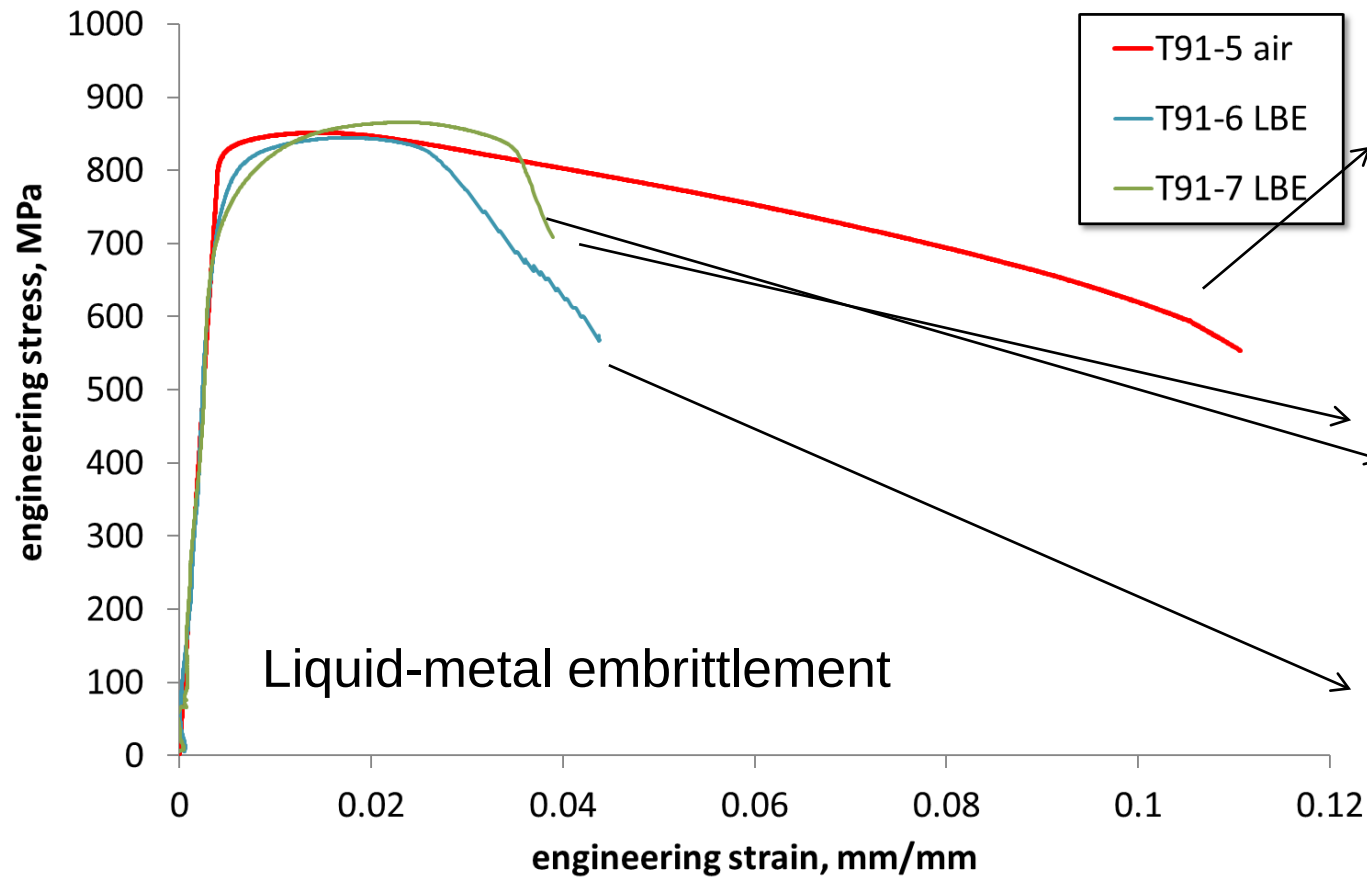
# SEM – fractured surface MEGAPIE



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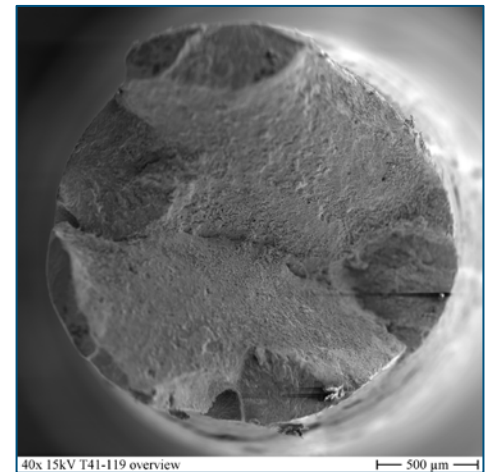
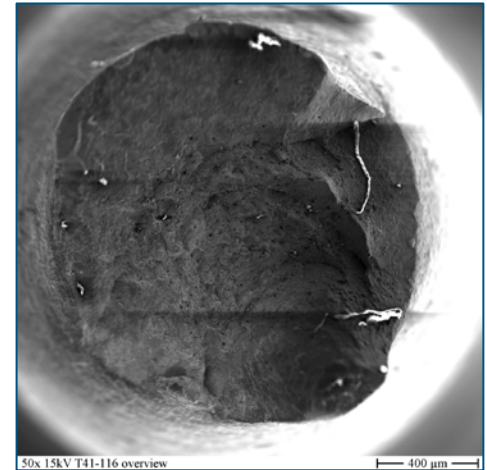
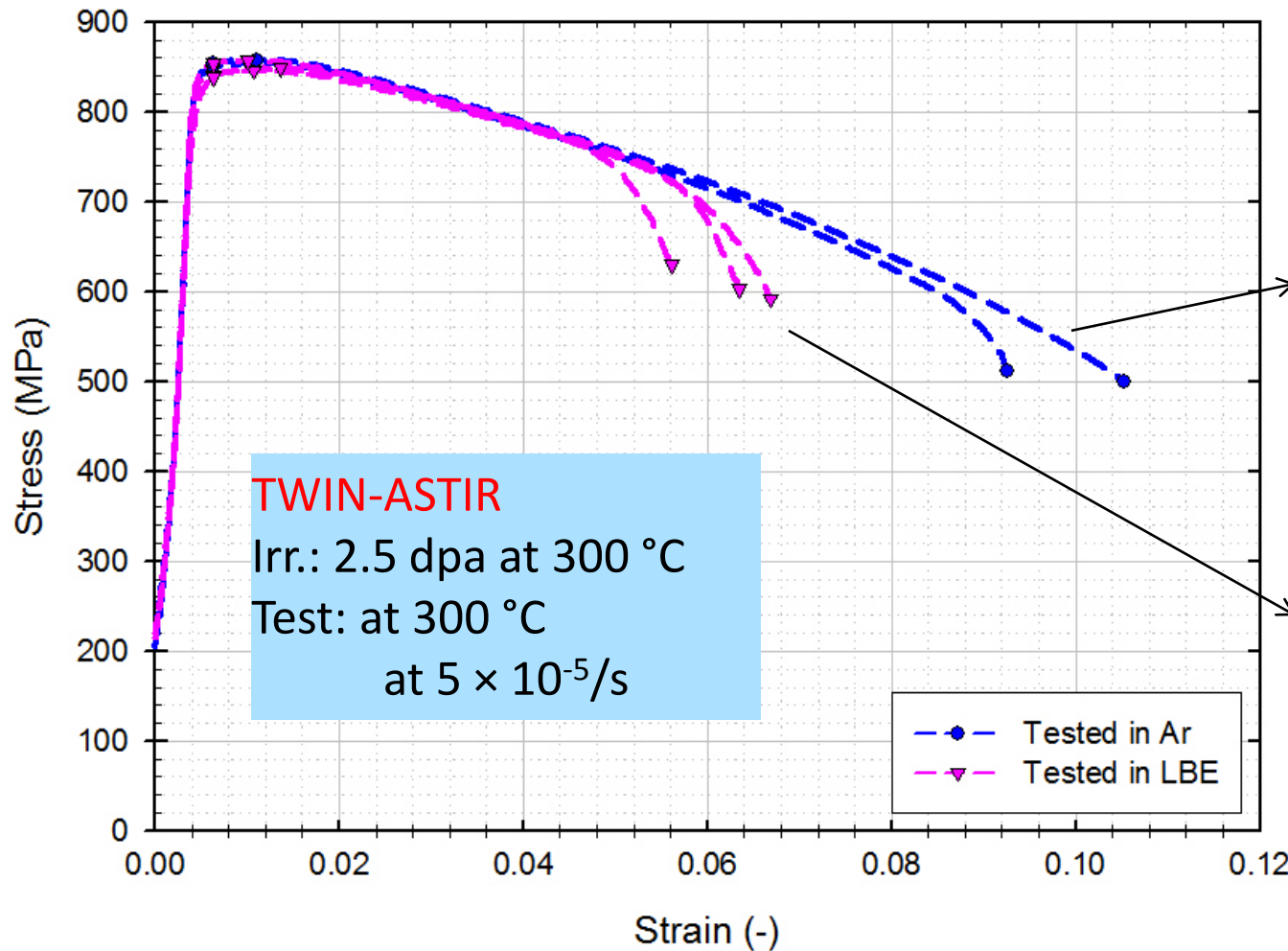


# SEM fractured surface -LEXUR



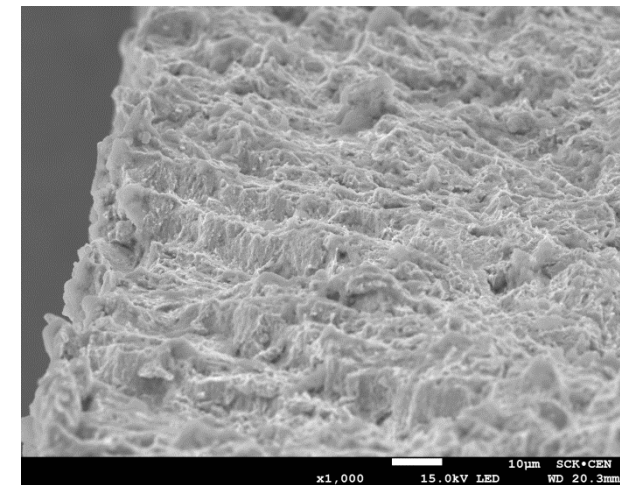
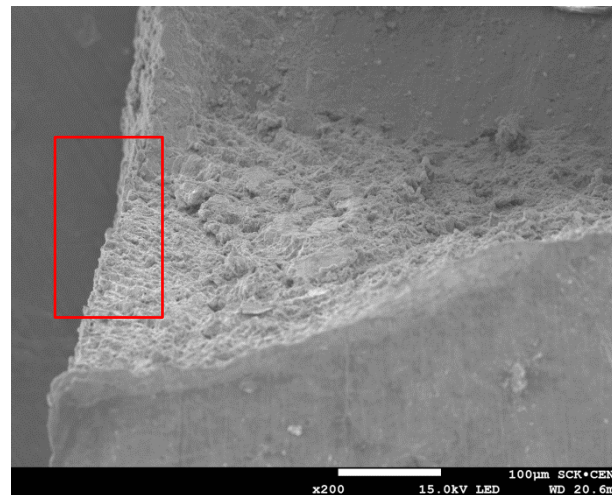
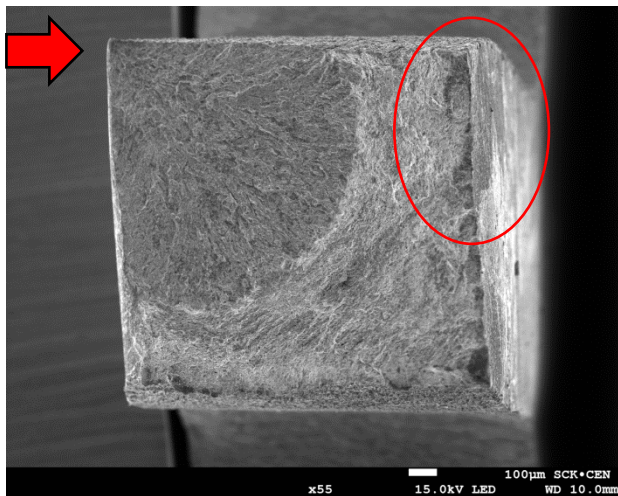
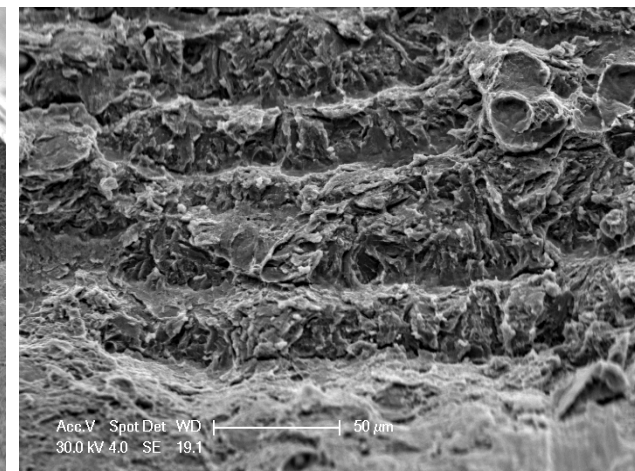
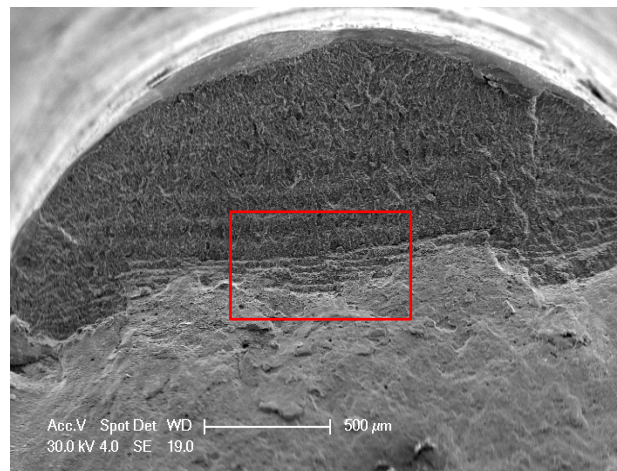
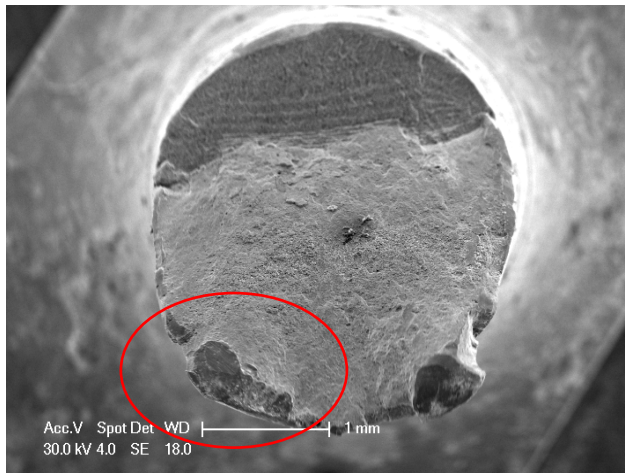


# TWIN-ASTIR mechanical tests



# Step-like surface

LEXUR



# Secondary surface cracks

MEGAPIE

# Conclusions

- ☐ Tensile properties consistently scale with respect of irradiation dose and test temperature. LM embrittlement is clearly observed.
- ☐ Yield strength values agree well with other measurements performed on the samples extracted from the target window, as well as to those obtained from LEXUR and TWIN ASTIR PIE.
- ☐ Consistent features associated with LM embrittlement are observed by SEM of the fractured surface.
- ☐ No particular effects are associated to spallation vs neutron irradiation conditions.
- ☐ No effects due to HAZ.
- ☐ TEM studies are under progress.

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