PAUL SCHERRER INSTITUT

Microstructure and mechanical properties of tungsten at elevated temperatures

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outline

1. Motivation
2. Experimental
3. Results
4. Summary

ADVANTAGES:

- ***highest melting point***
- ***high neutron yield***
- ***high thermal conductivity***
- ***good high temperature strength***

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DISADVANTAGES:

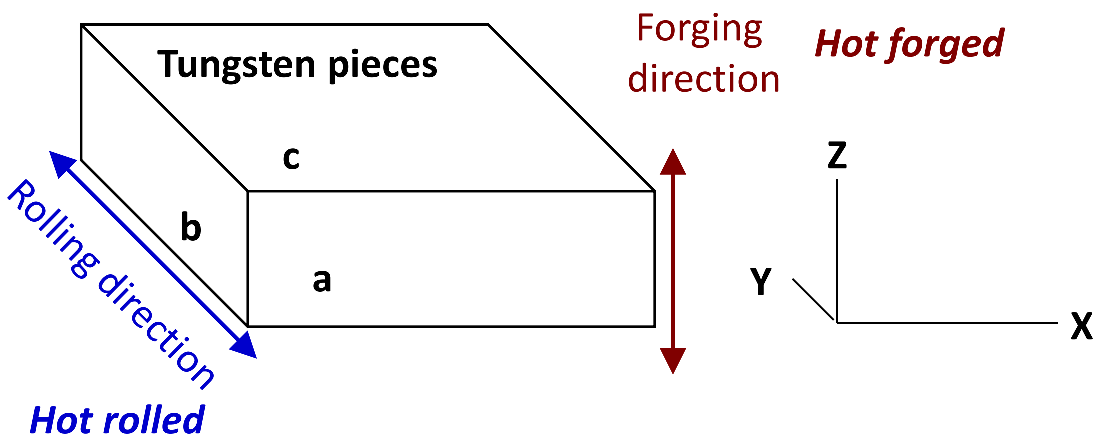
- ***high hardness***
- ***<u>inherent low fracture toughness</u>***
- ***<u>high DBTT</u>***

…………

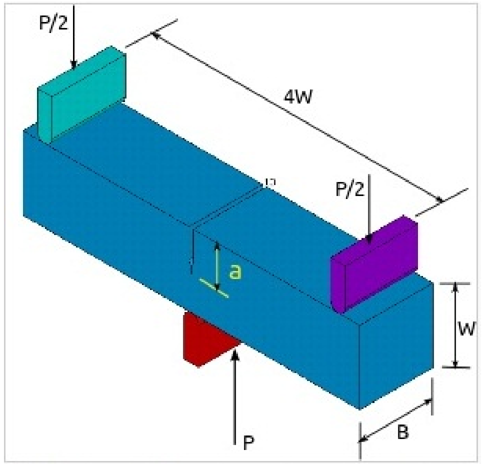
Tensile and fracture mechanical properties of hot rolled and forged tungsten are expected to exhibit strong anisotropy due to

- *effect of surface roughness*
- *different grain shape*
- *different orientations with respect to the rolling and forging direction*

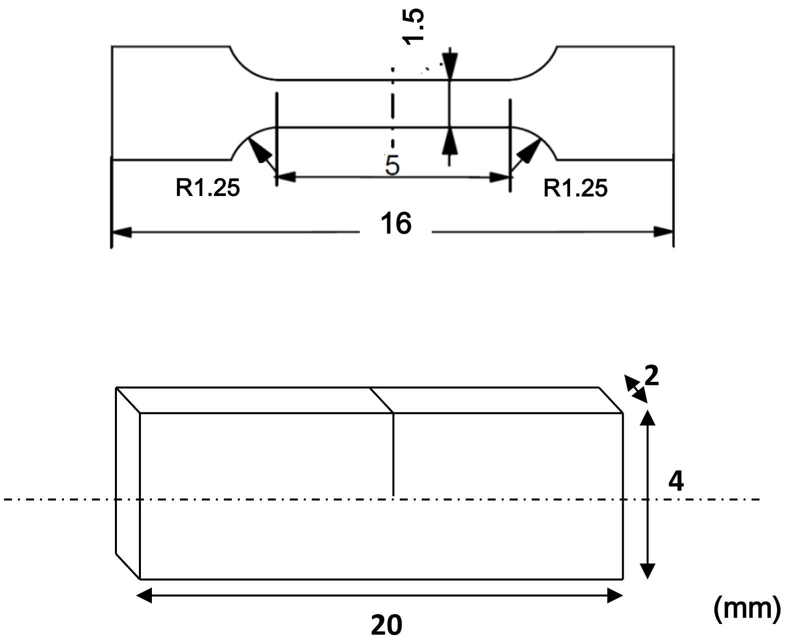
Understanding of fracture and tensile behaviors of tungsten by investigation of microstructure (grain size, texture etc.)



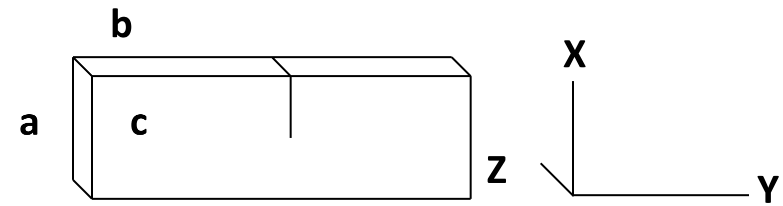
3PB test



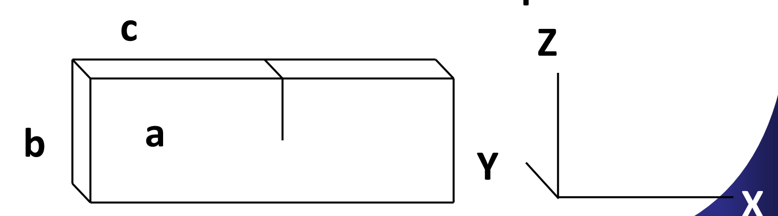
Specimens dimension



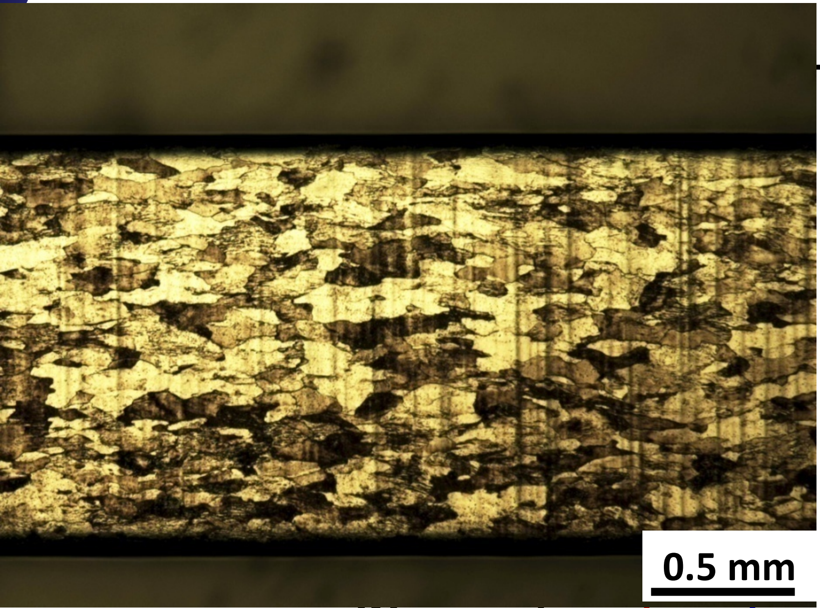
- HR- X- direction-bend sample

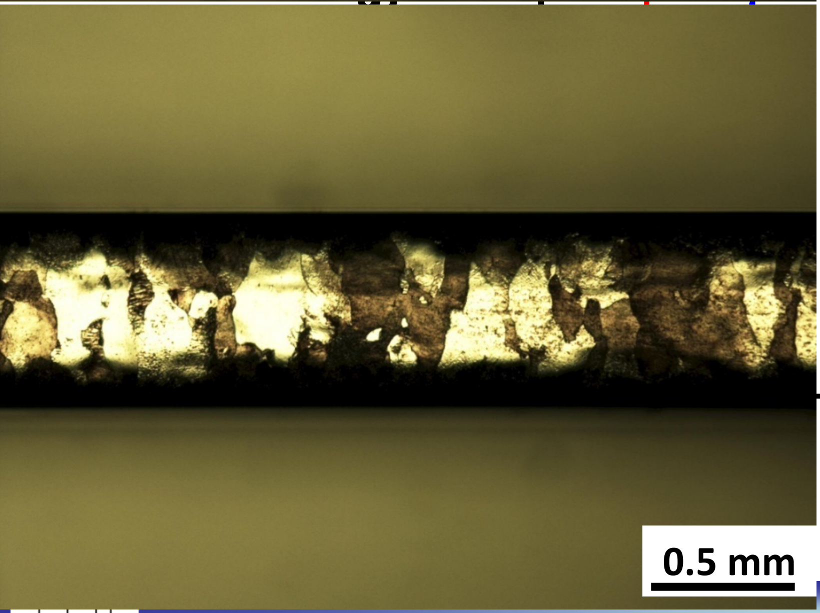


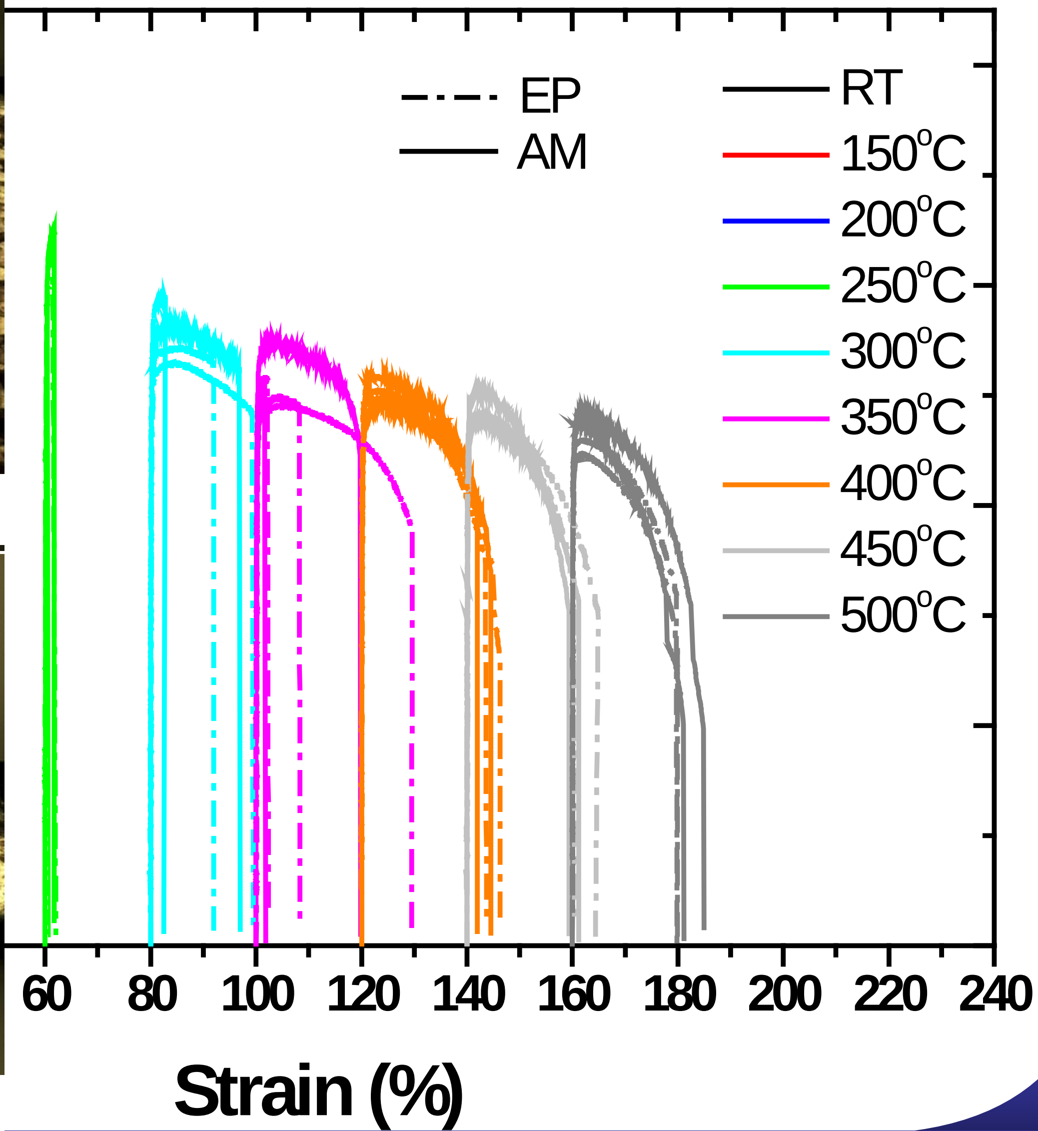
- HR- Z- direction-bend sample



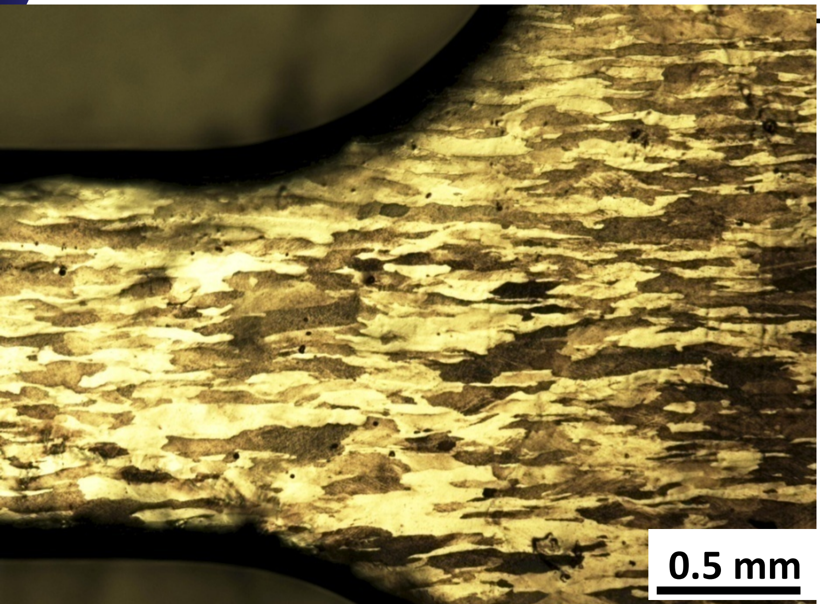
- ***Hot rolled-X direction***

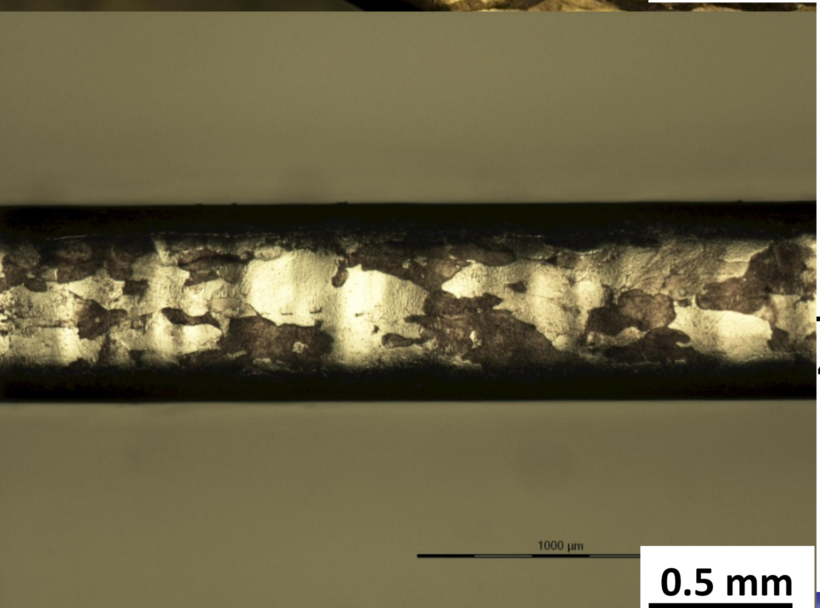


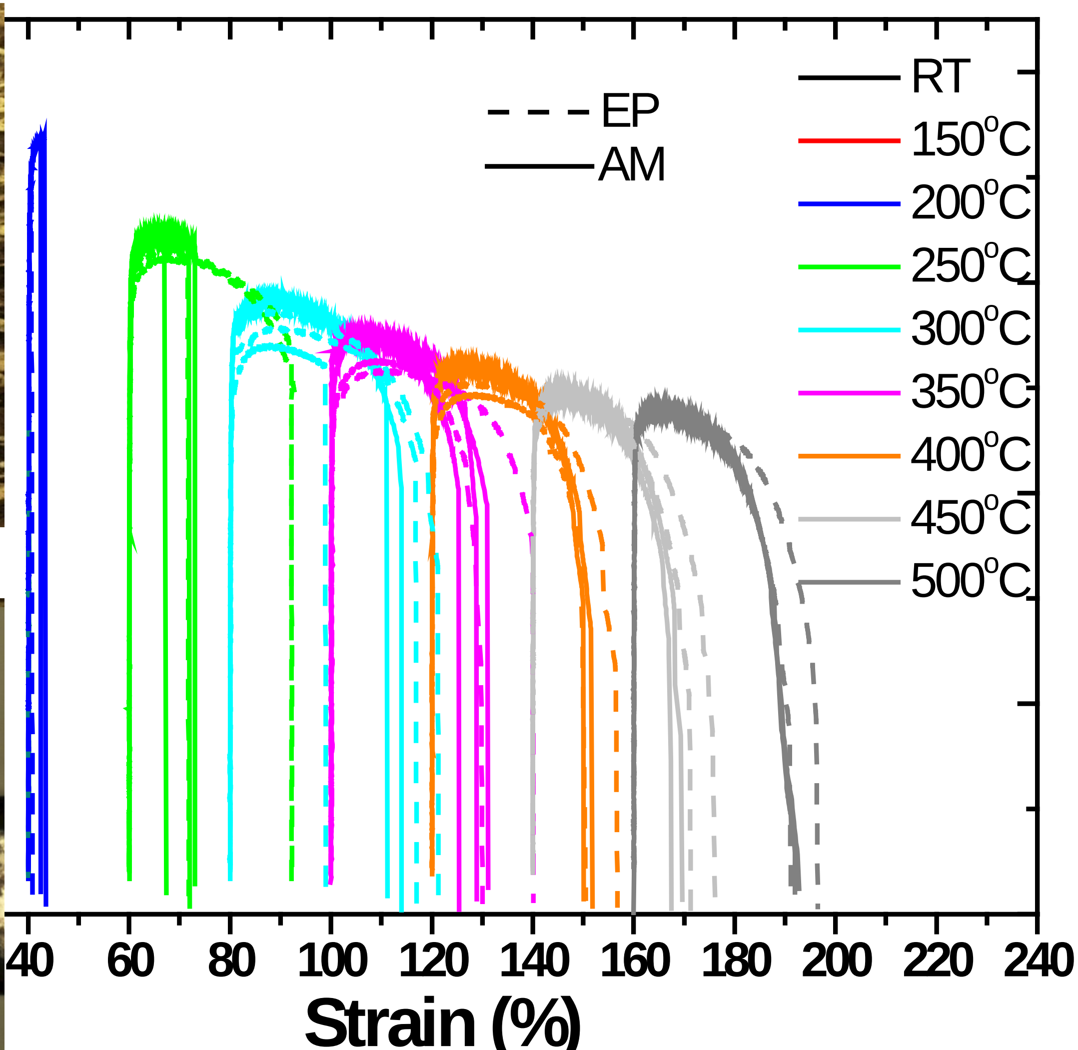




◻ *Hot rolled-Y direction*

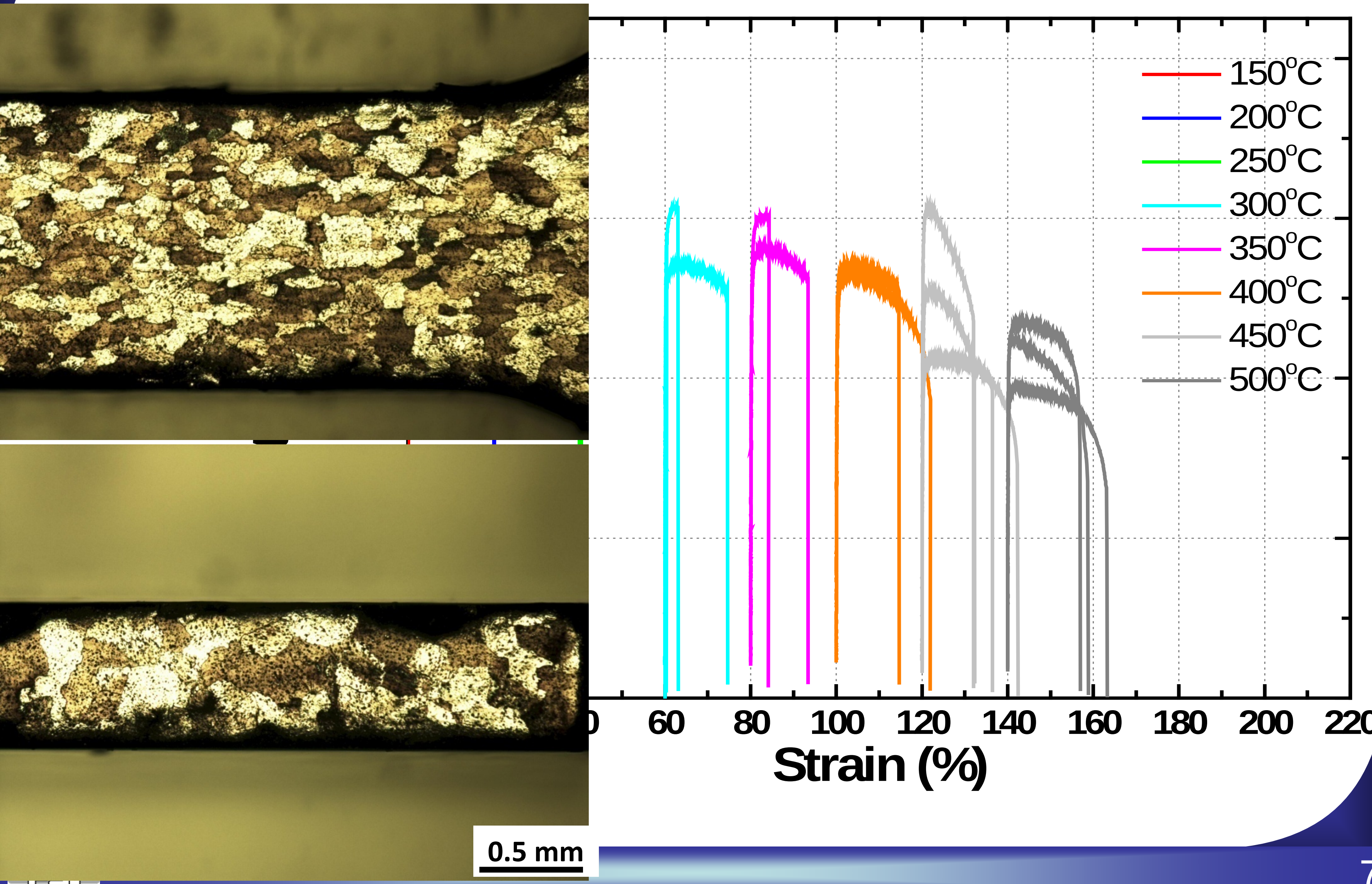




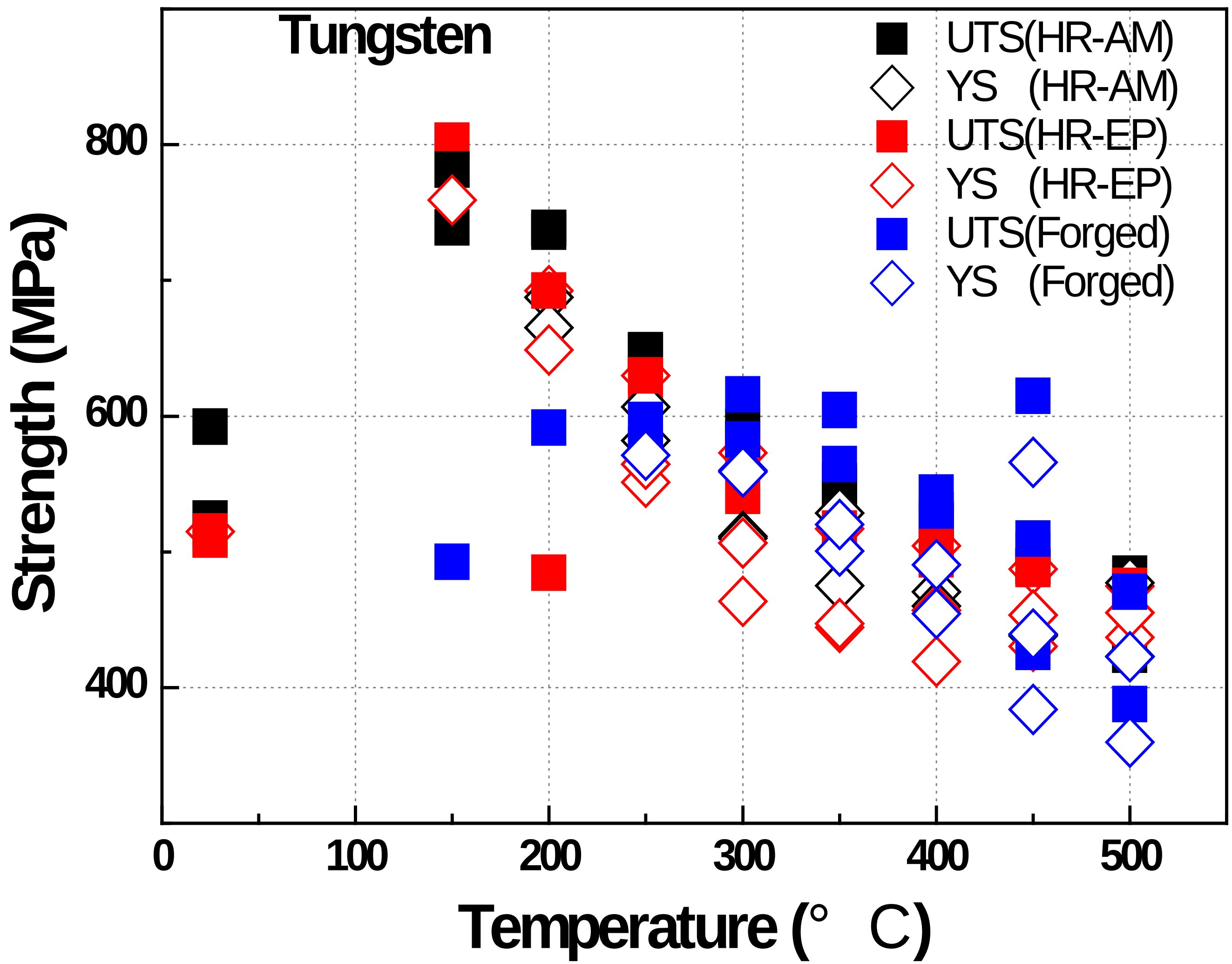


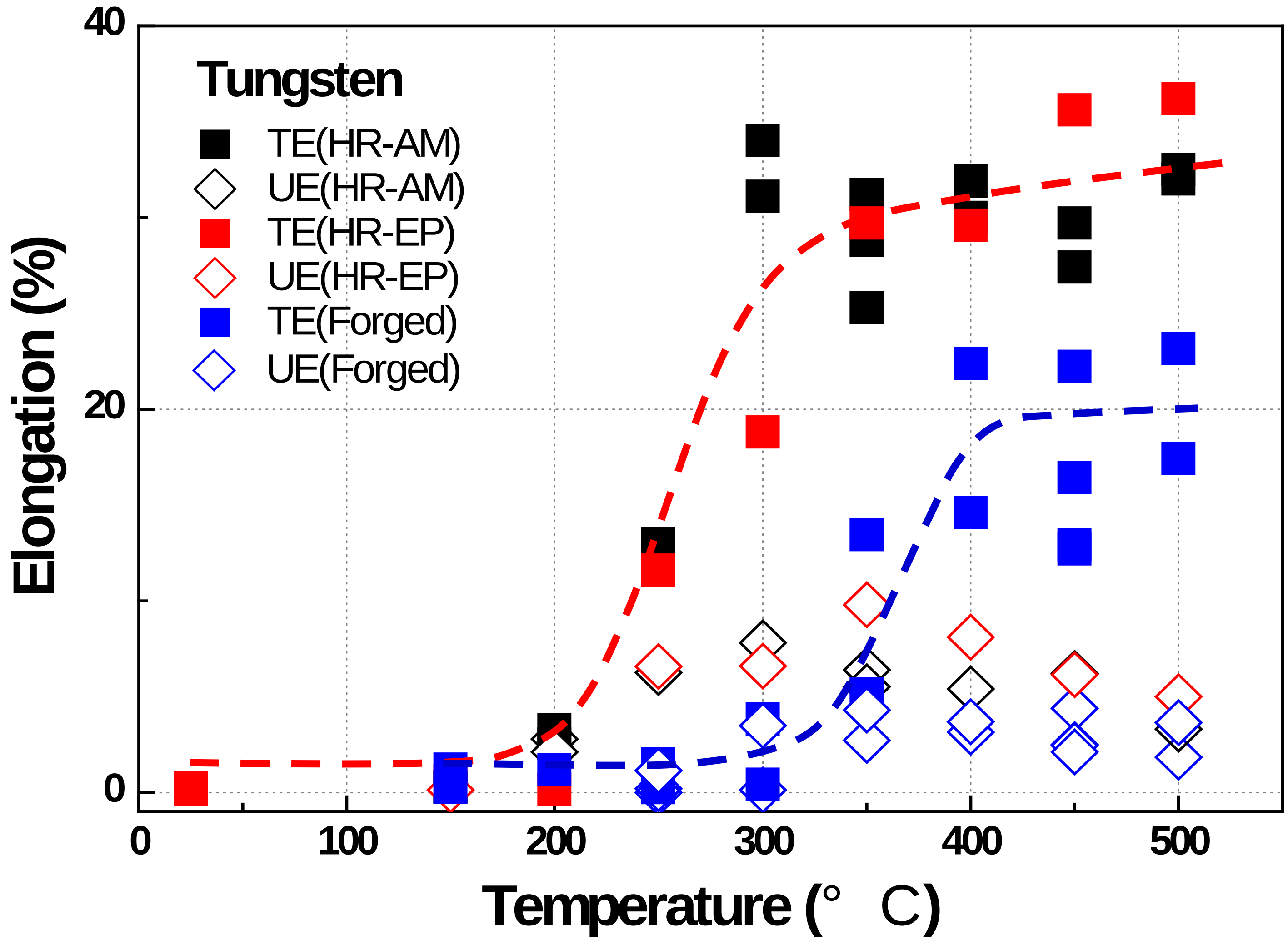
■ **Electropolishing of HR tungsten did not show any improvement in tensile properties**

- ***Hot forged-X direction***



3. Results: *tensile test*

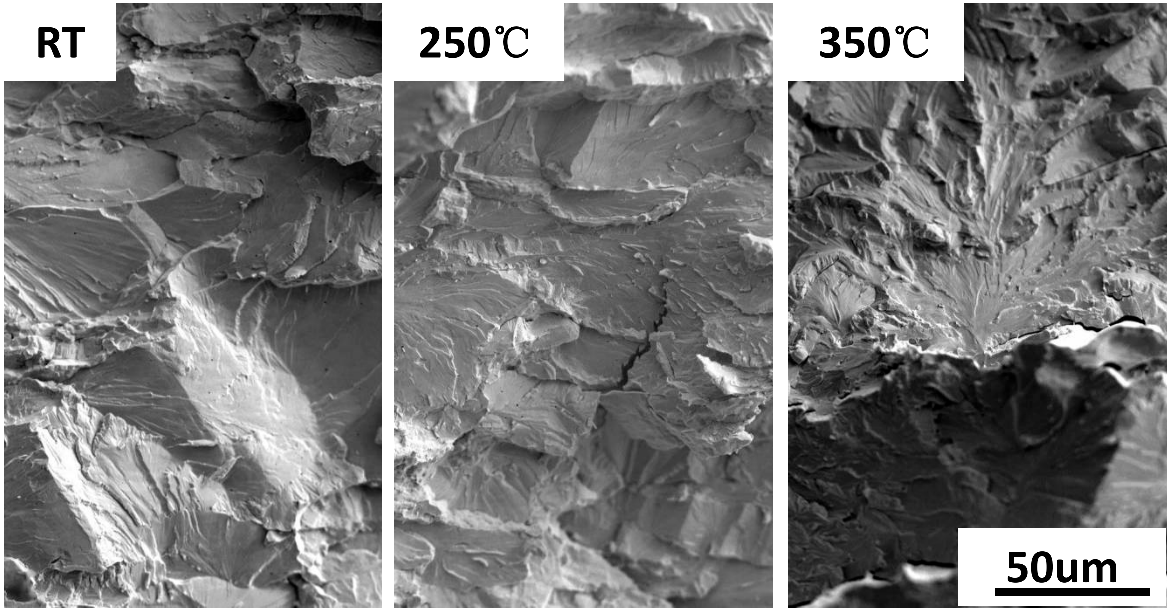




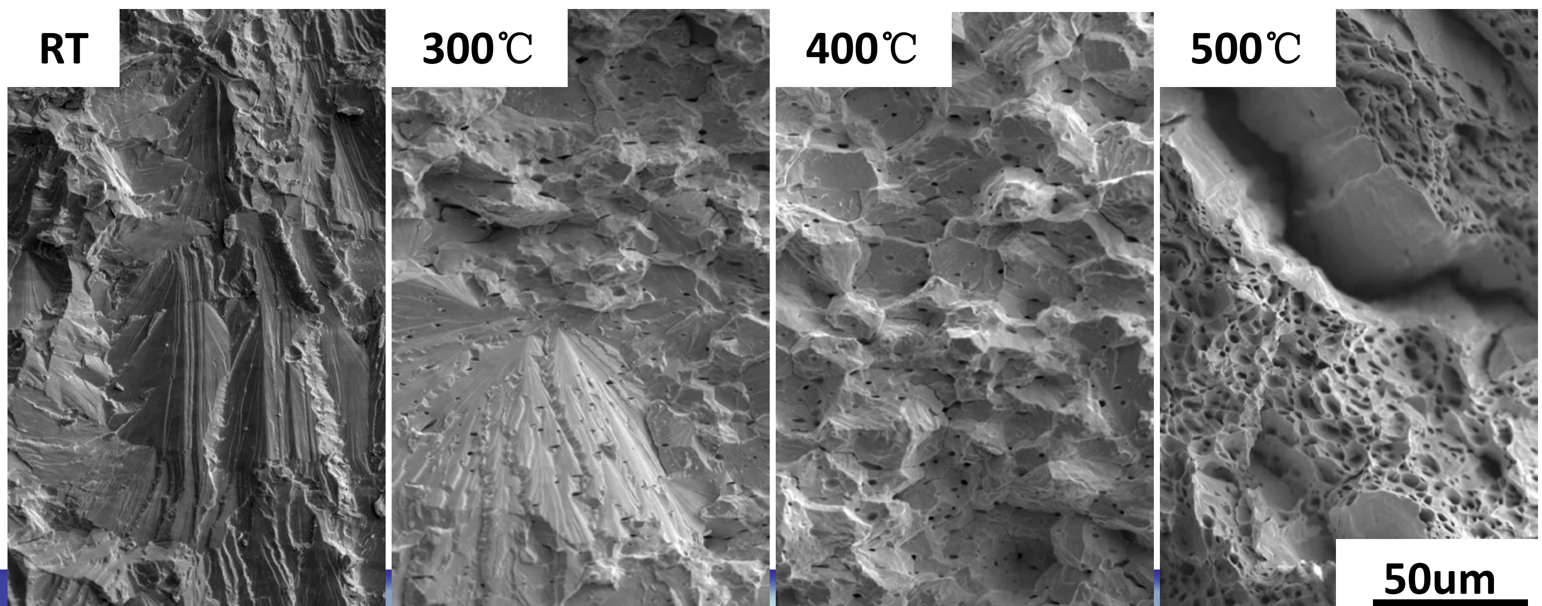
■ The DBTT measured from HF tungsten is significantly higher than HR material (~360 ℃ vs. ~260 ℃)

3. Results: *fracture morphology observation*

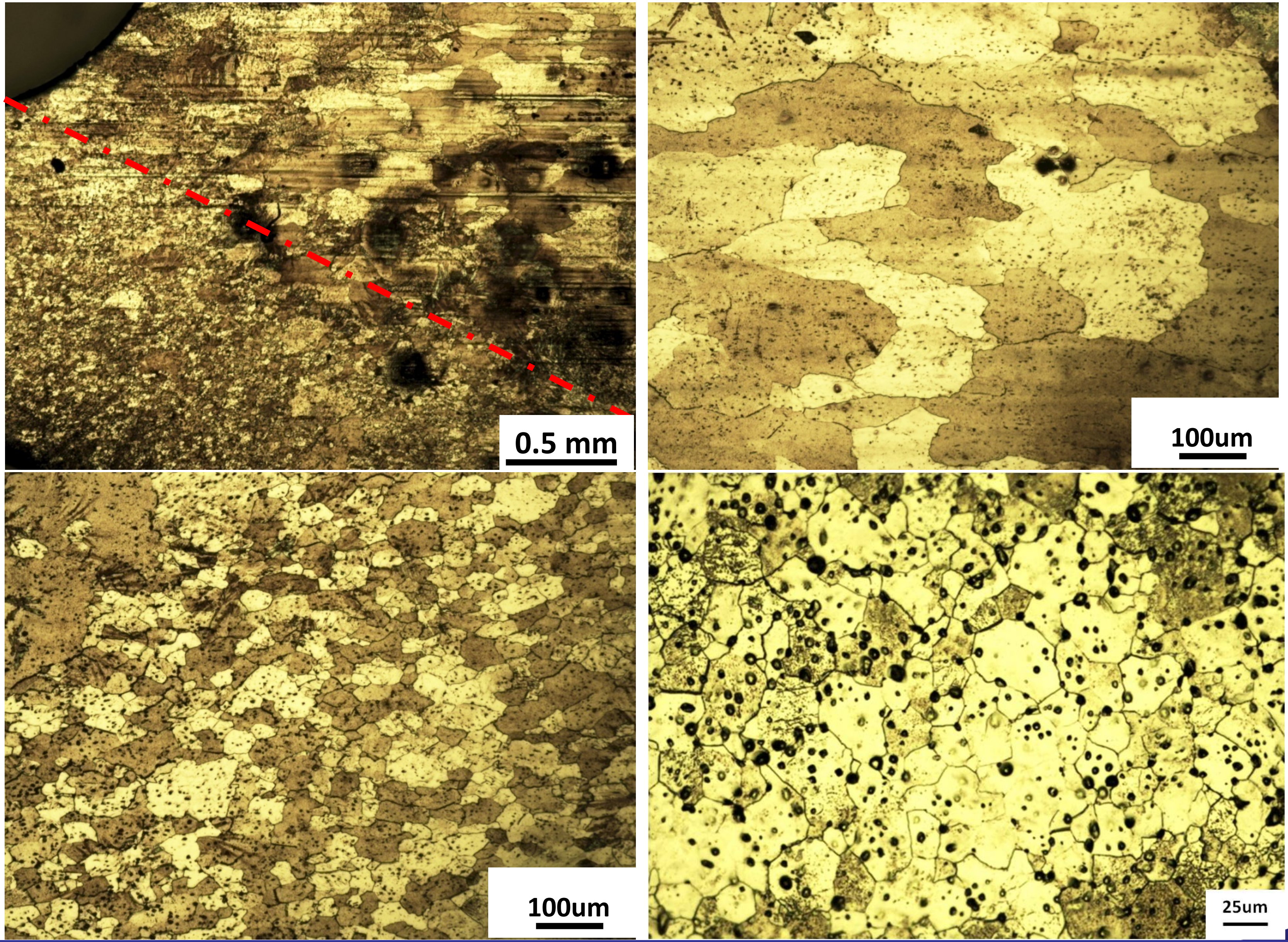
- ***Hot rolled***



- ***Hot forged***

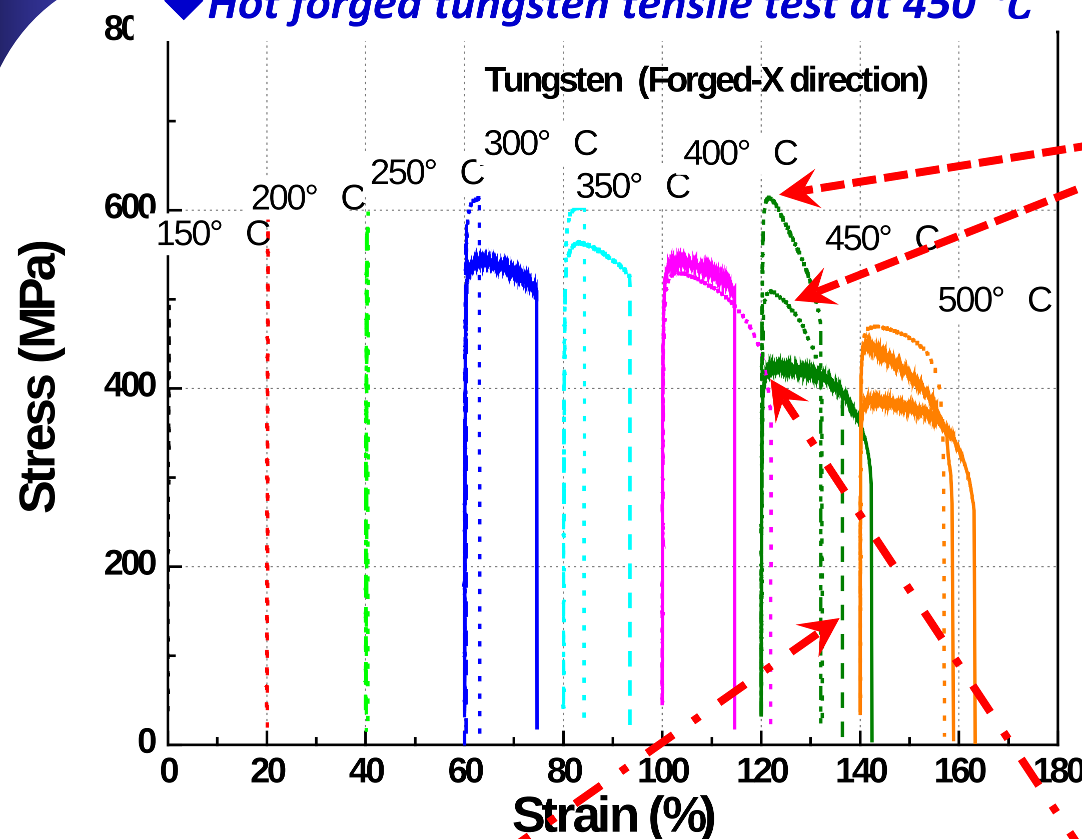


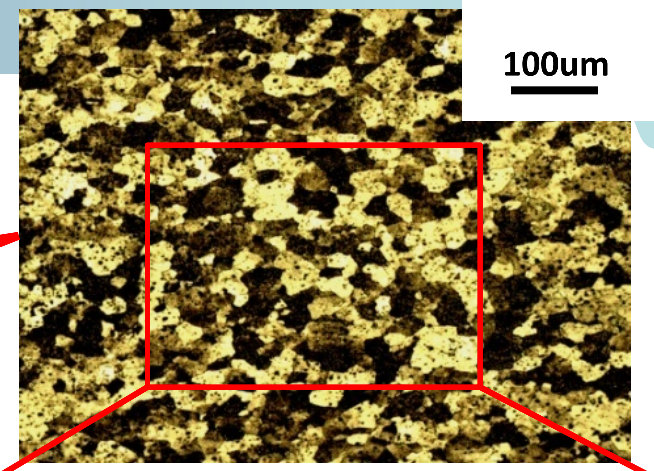
- ***Hot forged-X direction***

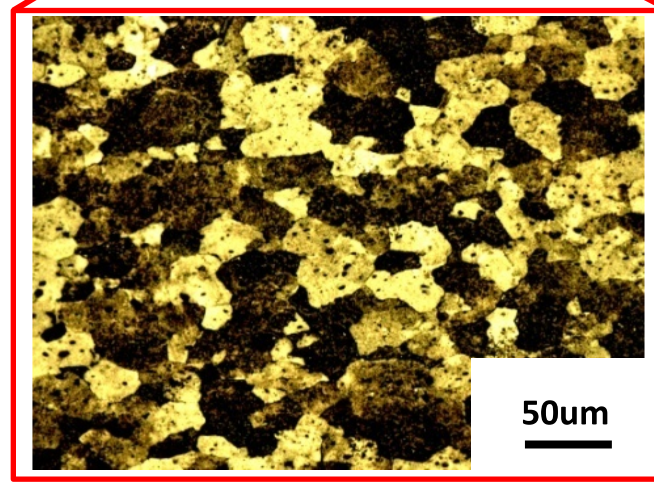


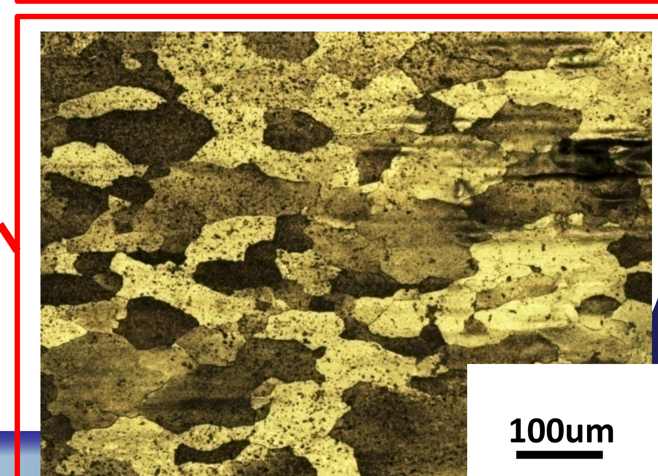
3. Results: microstructure observation

◆Hot forged tungsten tensile test at 450 ℃



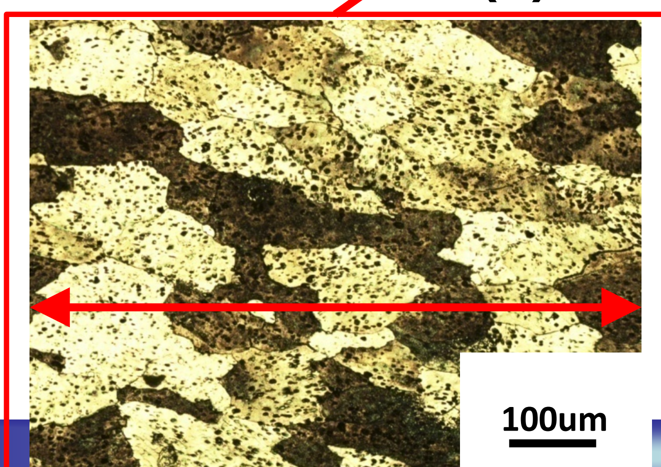


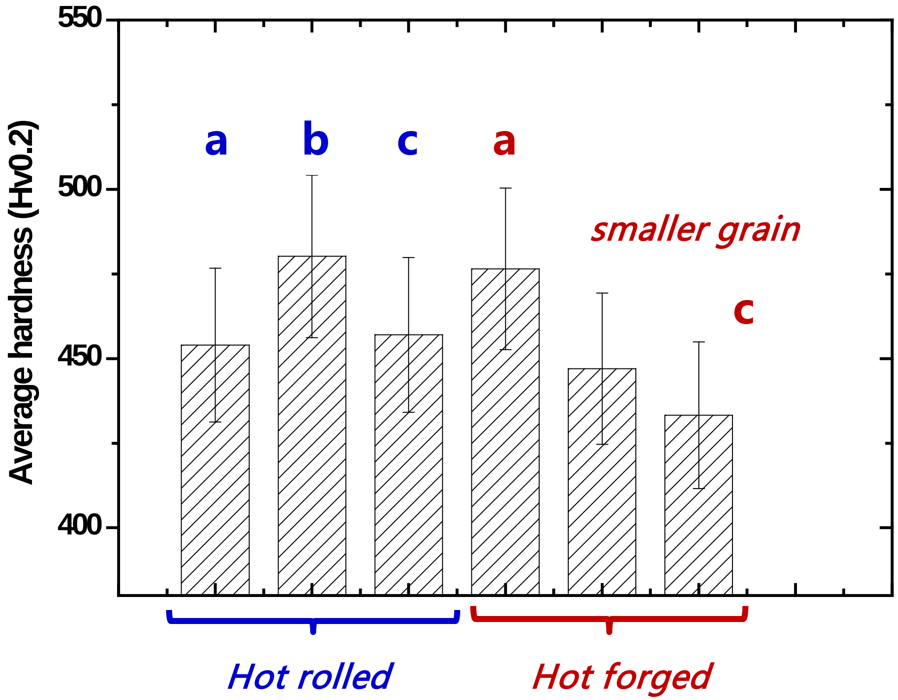


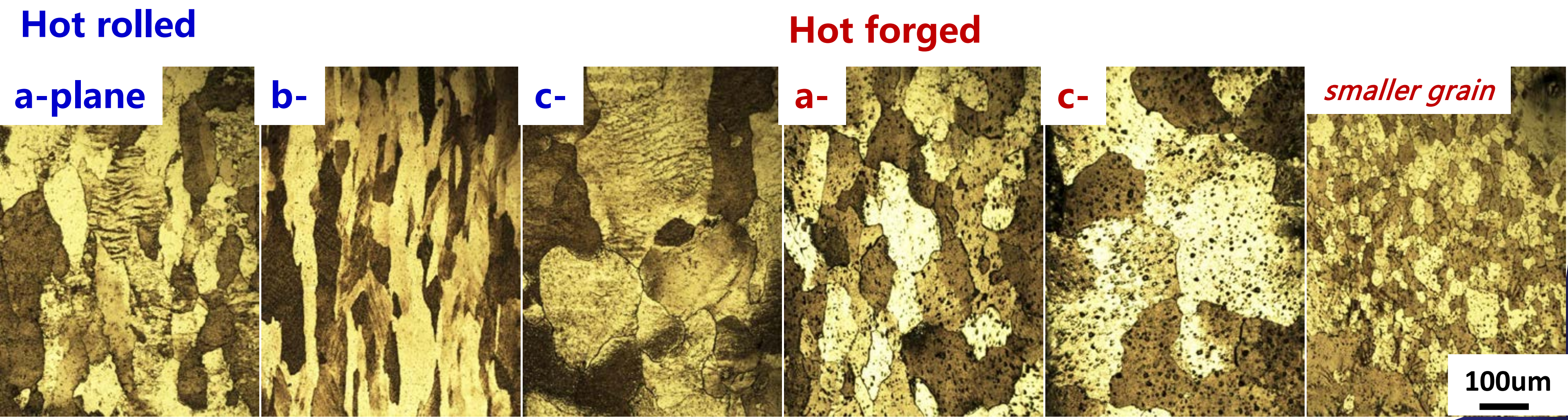


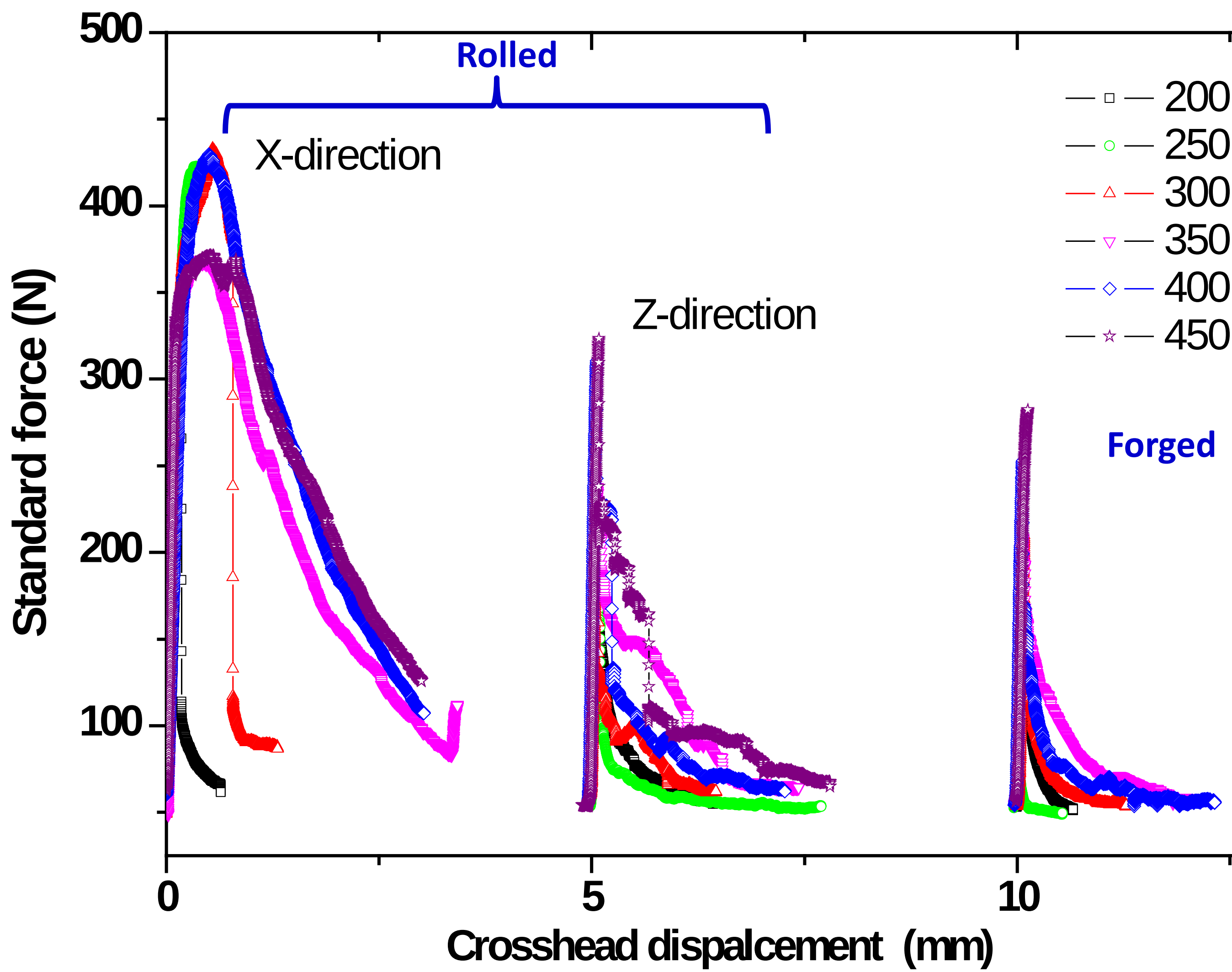
Different grain directions

Tensile sample direction

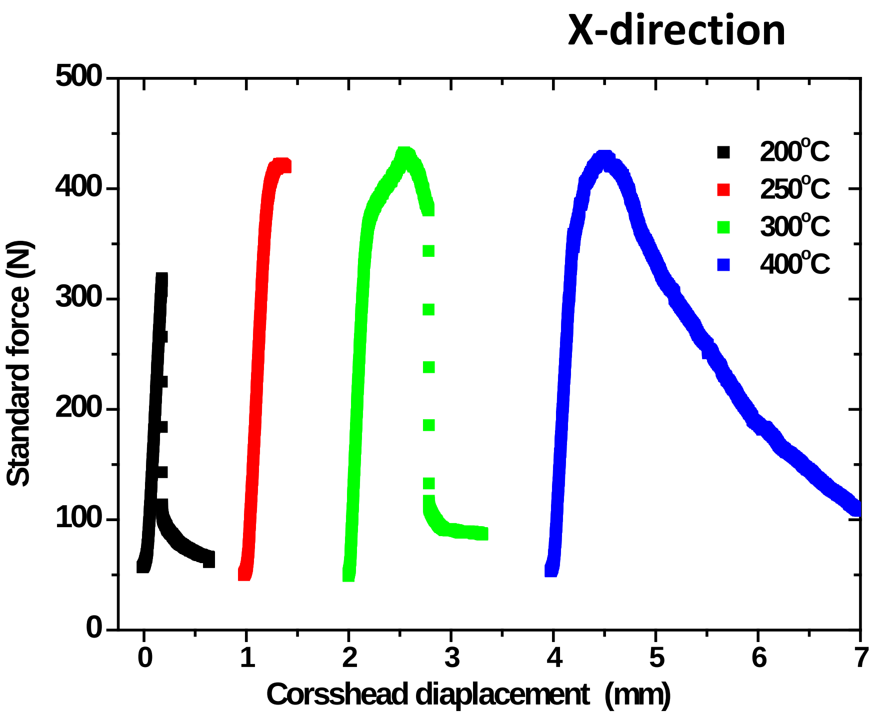


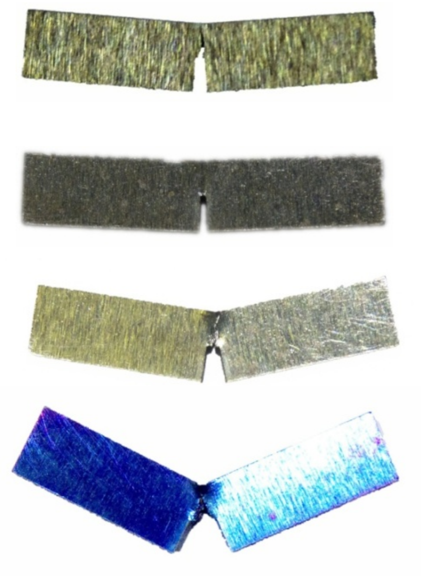

550
500
450
400
Average hardness (Hv0.2)
a
b
c
a
smaller grain
c
Hot rolled
Hot forged


Hot rolled
Hot forged
a-plane
b-
c-
a-
c-
smaller grain
100um

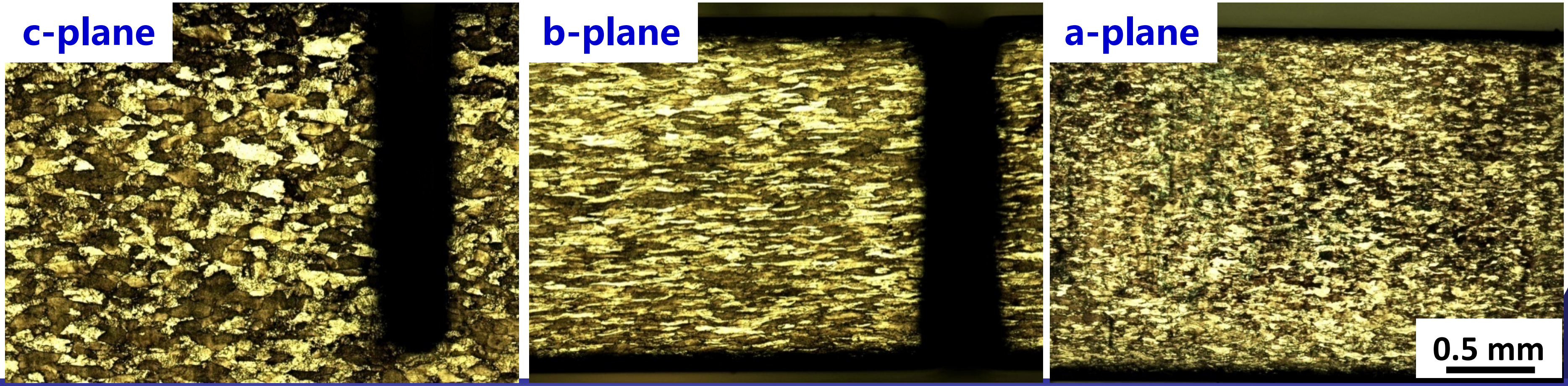


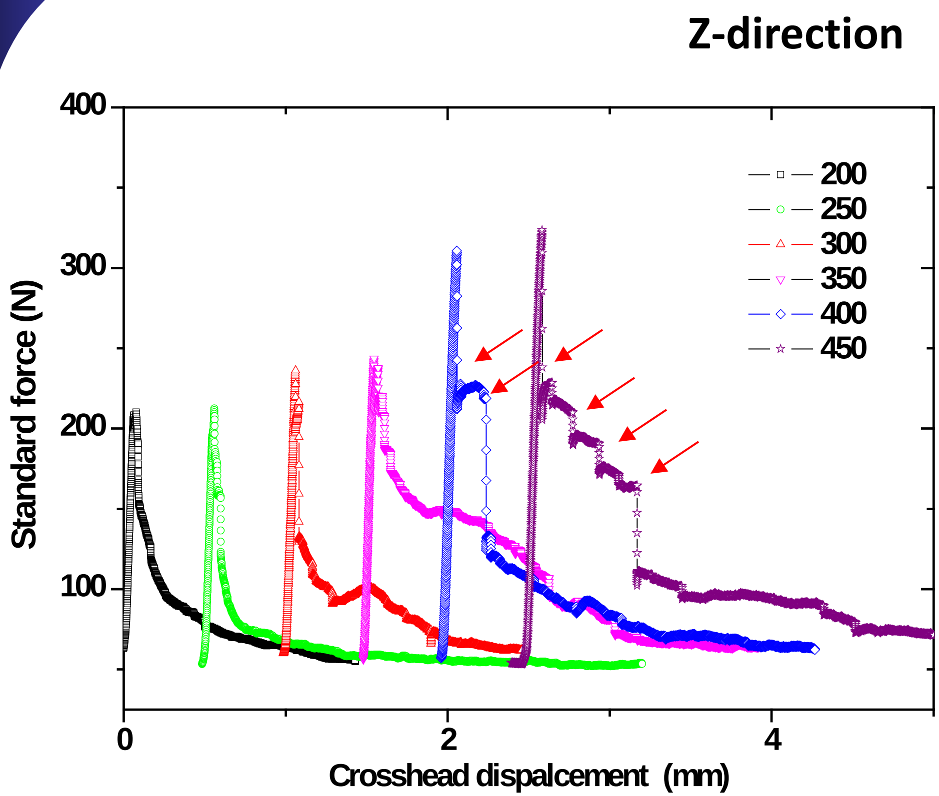
Rolled
X-direction
Z-direction
Forged
200
250
300
350
400
450
Standard force (N)
Crosshead dispalcement (mm)
0
5
10
100
200
300
400
500

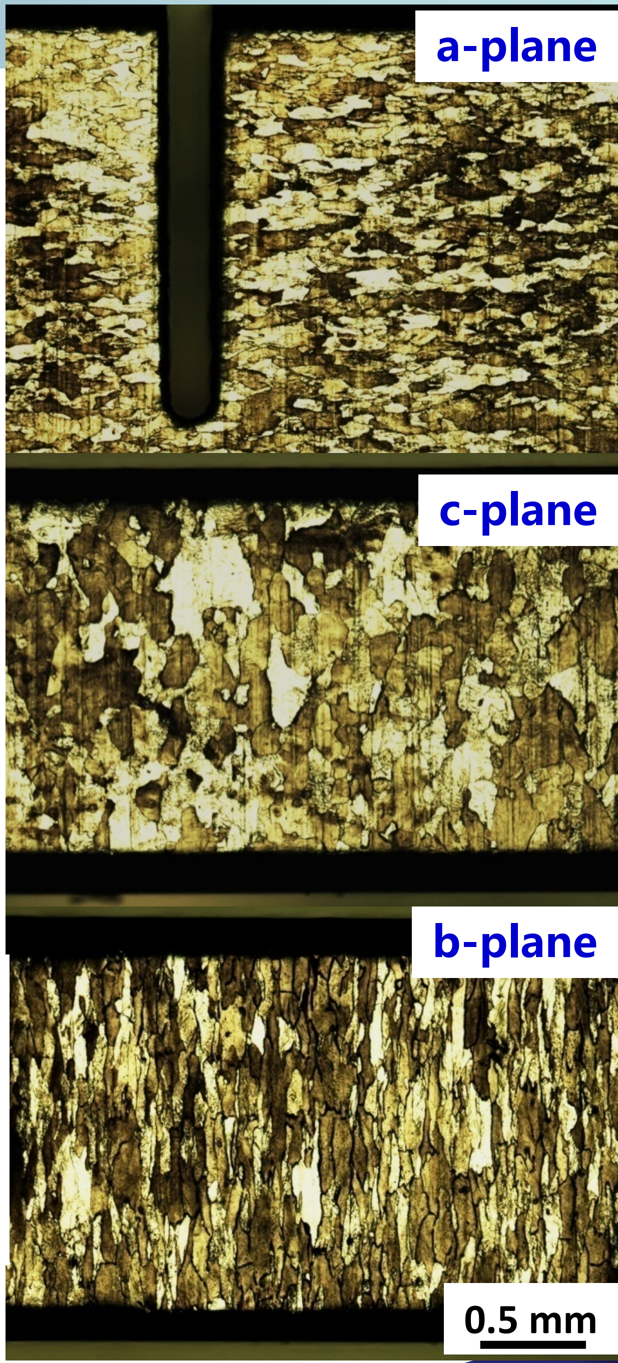




- brittle fracture below 250 ℃

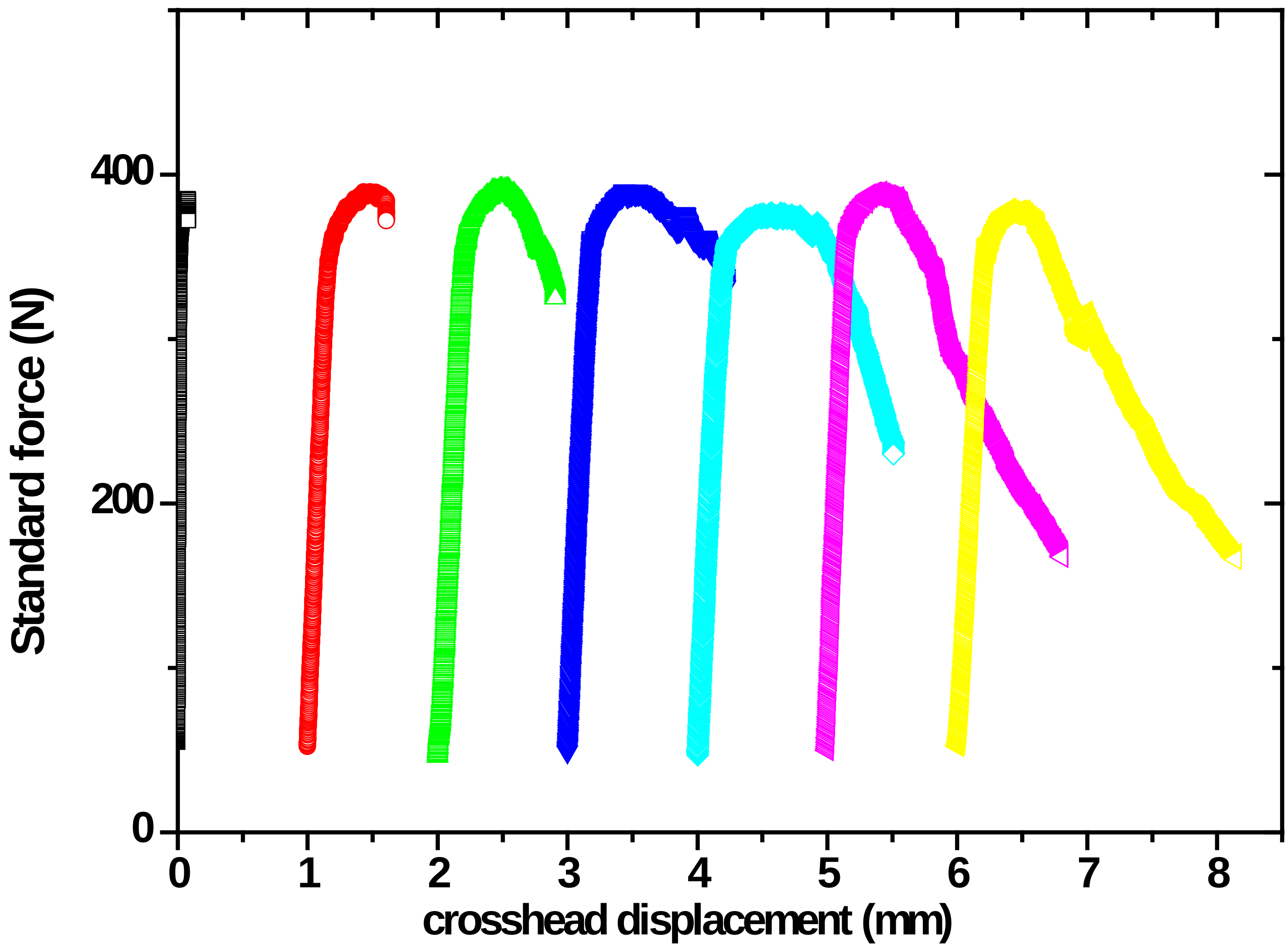


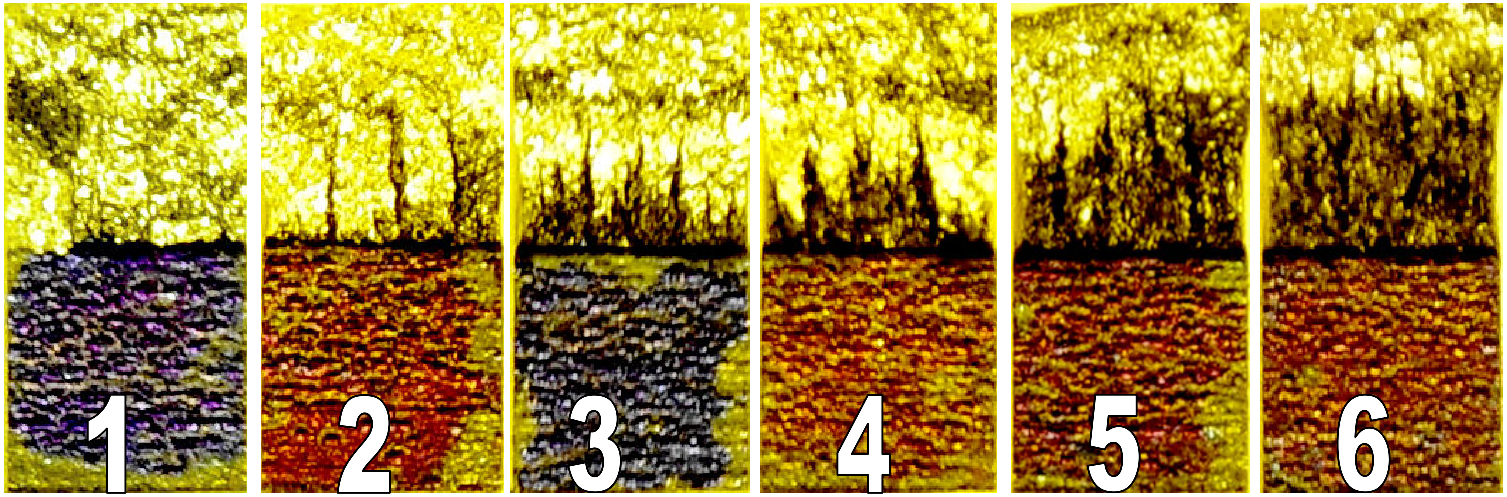




- **stable crack growth below 300 ℃**
- **plastic yielding prior to stable crack growth at high T**

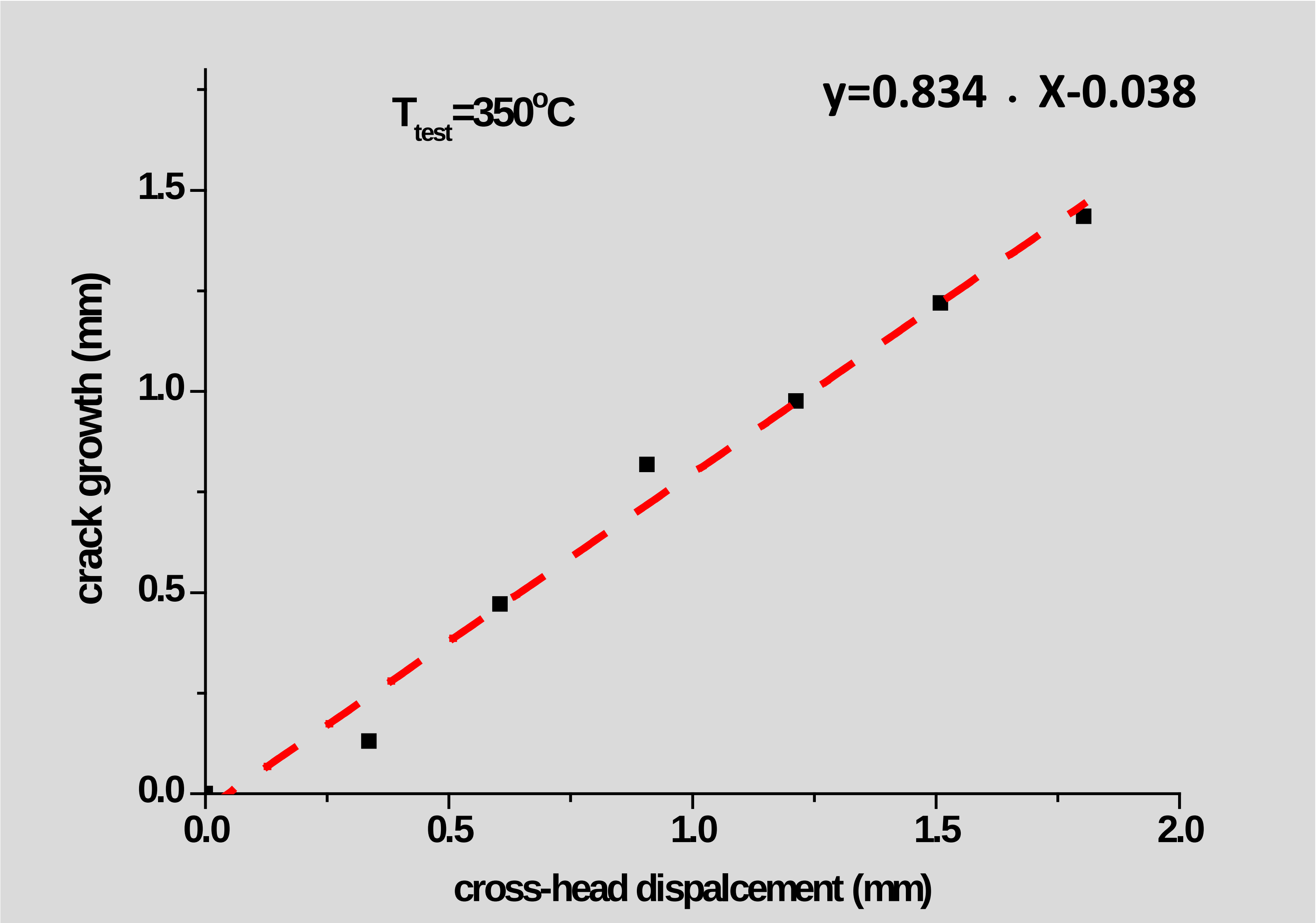
◆Crack growth in HR sample-350℃





Sample	1	2	3	4	5	6
Cross-head **(mm)**	**0.336**	**0.605**	**0.907**	**1.213**	**1.509**	**1.804**
Δa **(mm)**	**0.13**	**0.47**	**0.82**	**0.98**	**1.22**	**1.44**

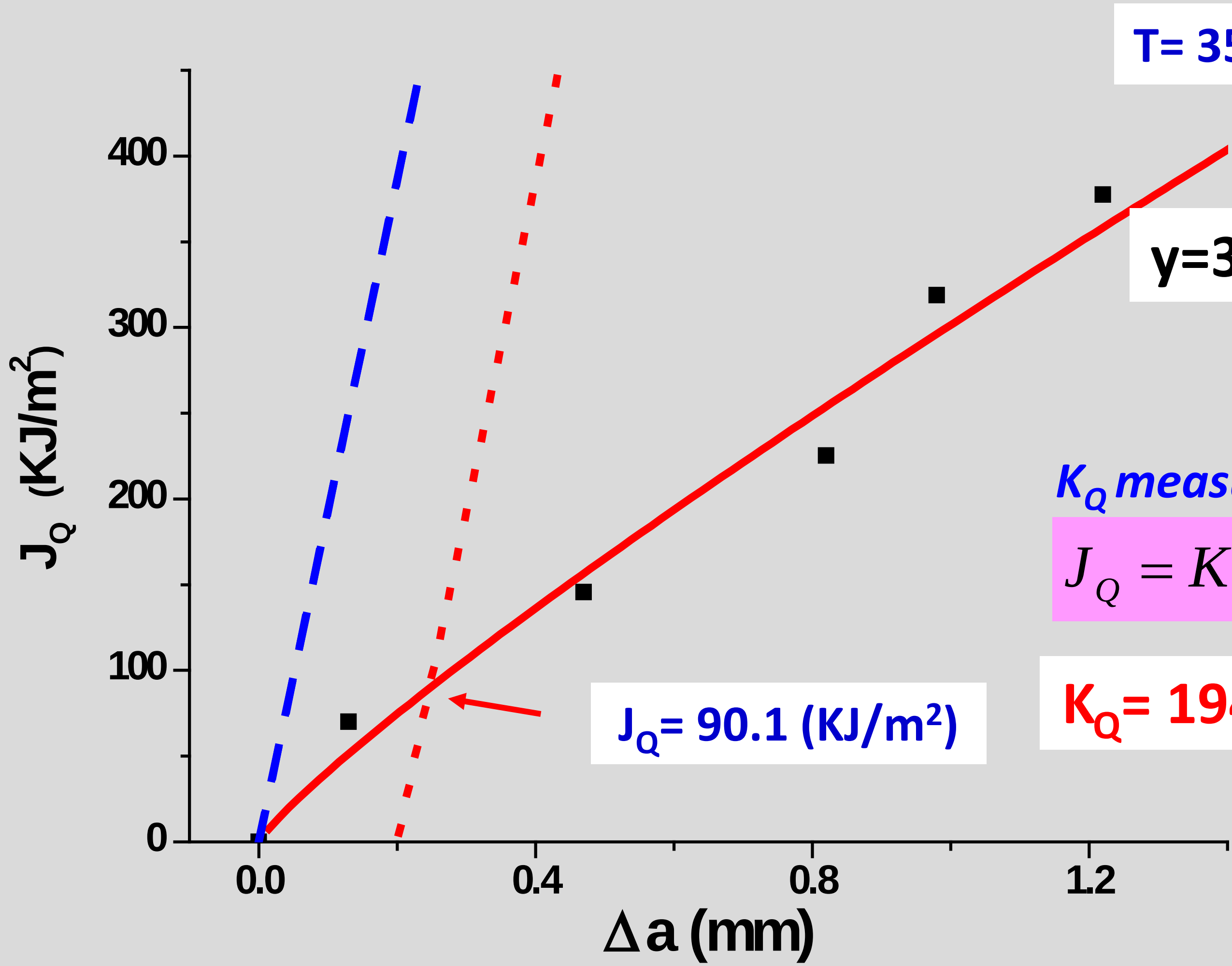
3. Results: *3PB test- crack growth- Rolled tungsten-Y*



$J = M \sigma_y \Delta a$

$\sigma_y = (\sigma_{YS} + \sigma_{TS})/2$; σ_{YS} : yield strength; σ_{TS}: ultimate tensile strength;

M=4 to diminish the specimen size effect



K_Q measurement

$$J_Q = K_Q^{\ 2} \big/ E(1-\gamma^2)$$

K_Q= 194.0 (Mpa*m$^{1/2}$)

◆*Surface roughness effect is limited*

◆*Strong influence of the anisotropic microstructure on the fracture toughness and DBTT.*

◆*Surface roughness effect is limited*

◆*The hardness of both rolled and forged sample are almost the same, only some difference in different directions due to different thermal mechanical treatments.*

◆*3PB test –intergranular fracture is dominant.*

Thank you for your attention!

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J_Q definition

- Definition of construction line
- $J = M\sigma y\Delta a$

  $\sigma y = (\sigma YS + \sigma TS)/2$

  σYS : yield strength

  σTS: ultimate tensile strength
- M=4 to diminish the specimen size effect

  [S.Jitsukawa, J.Nucl.Mater.233-237(1996)152]

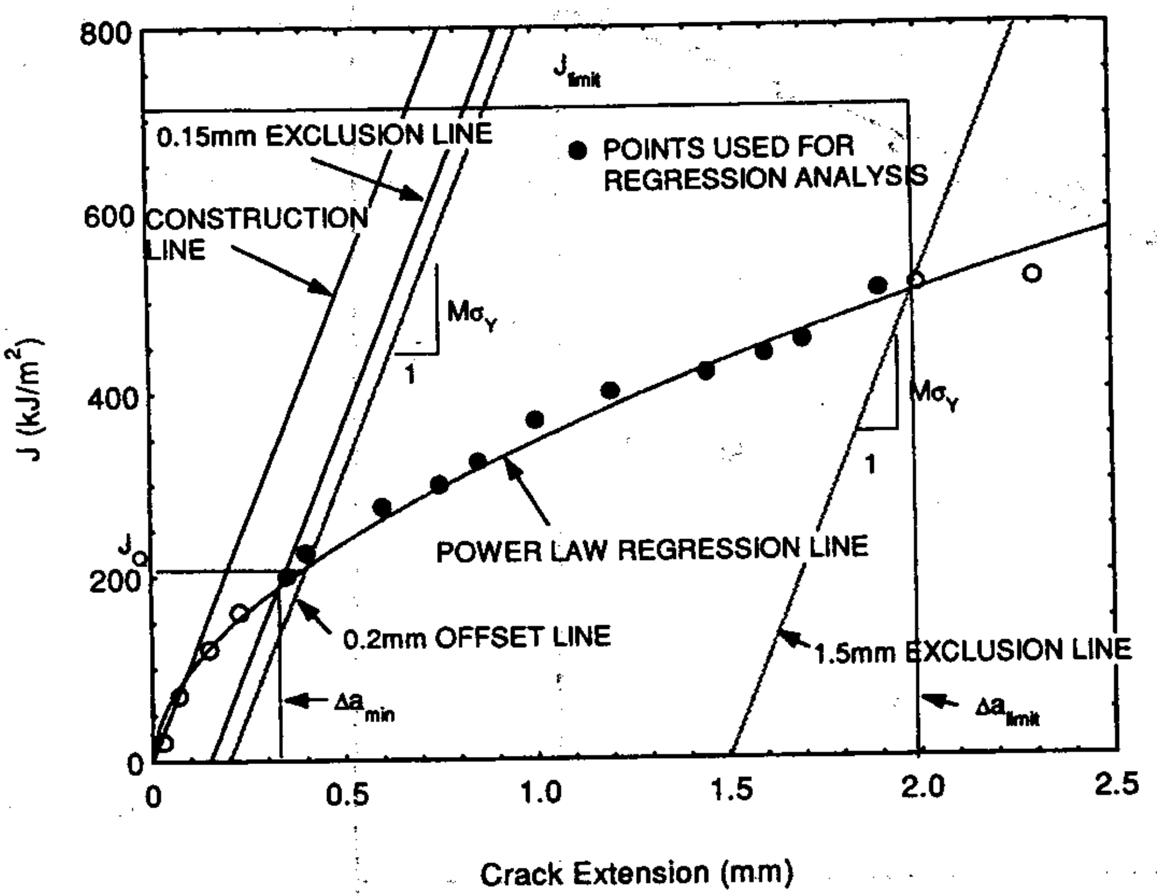
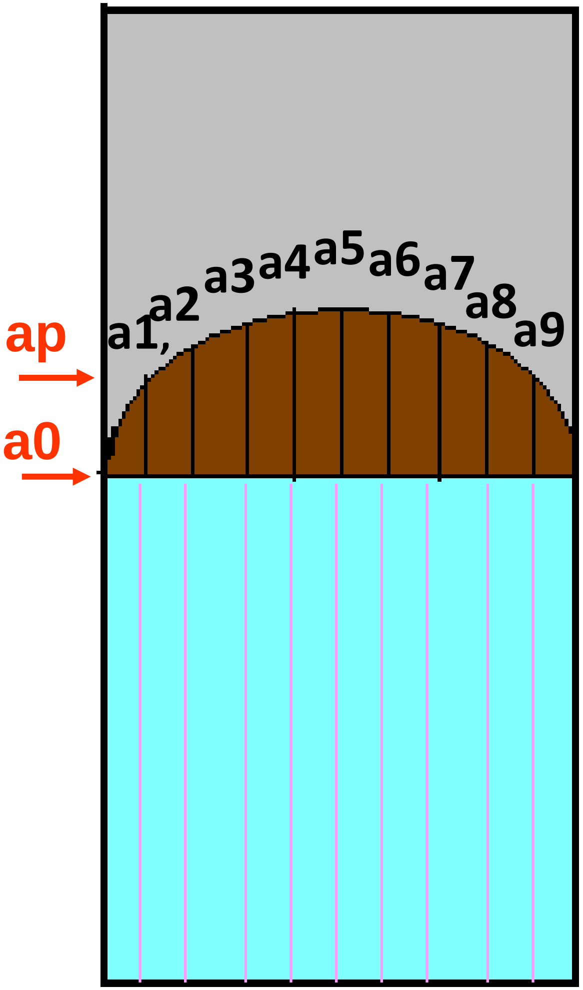


FIG. A9.1 Definition of Construction Lines for Data Qualification

Definitions of original crack a_0 and physical crack a_p

- Hinting at 300ºC for 0.5h, break in air
- Nine equally spaced points centered about the specimen centerline and extending to 0.005W from the surface.
  $a_p = ½ (½(a_1+a_9)+a_2+a_3+a_4+a_5+a_6+a_7+a_8)$.
- None of the nine measurement of a_0 and a_p may differ by more than 5% form the average.
- None of the nine measurements of crack extension Δa_i ($\Delta a_i = a_p - a_0$) shall be less than 50% of the average crack extension Δa.



K_Q measurement

In brittle case , the fracture of toughness can be directly calculated by:

$$K_Q = [P_Q S / BM^{3/2}] f(a/W)$$

where:

$$f(a/W) = \frac{3(a/W)^{1/2}[1.99-(a/W)(1-a/W)\times(2.15-3.93(a/W)+2.7(a/W)^2)]}{2(1+2a/W)(1-a/W)^{3/2}}$$

$$J_Q = K_Q{}^2 \Big/ E(1-\gamma^2)$$