Fatigue behaviour of rolled and forged tungsten

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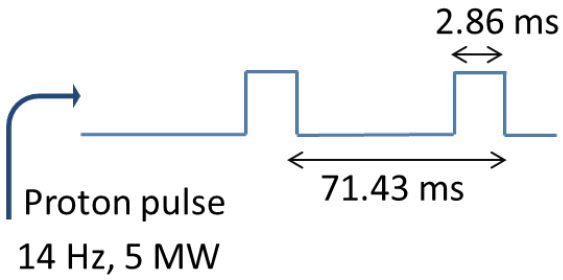
Objectives

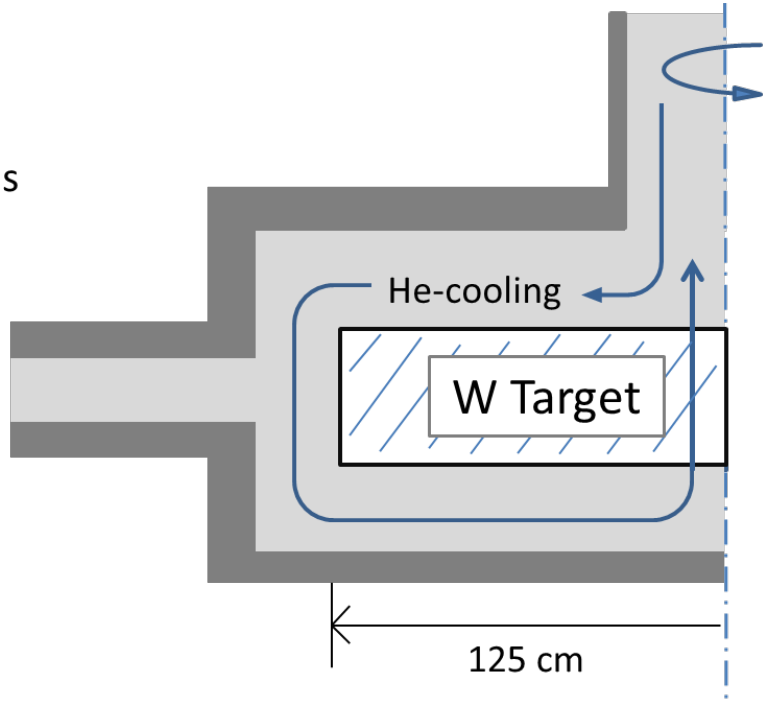
Understanding the fatigue behaviour of pure tungsten, which is essential for the design of the ESS spallation target.

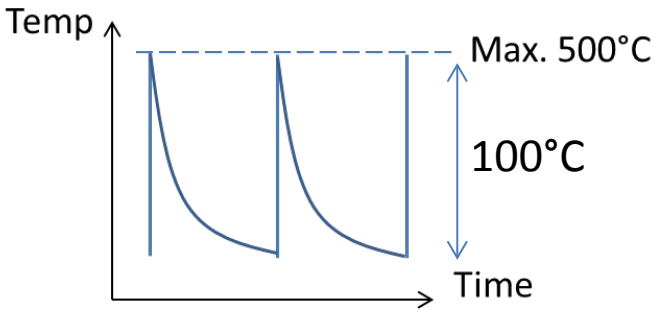
- Conducting fatigue and tensile tests at 25°, 300° and 500°C
- Comparing the fatigue limits of rolled and forged specimens
- Examining the importance of surface quality

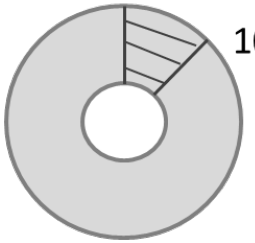
ESS Spallation Target

Life expectancy: 5 years - 4 x 10^7 cycles





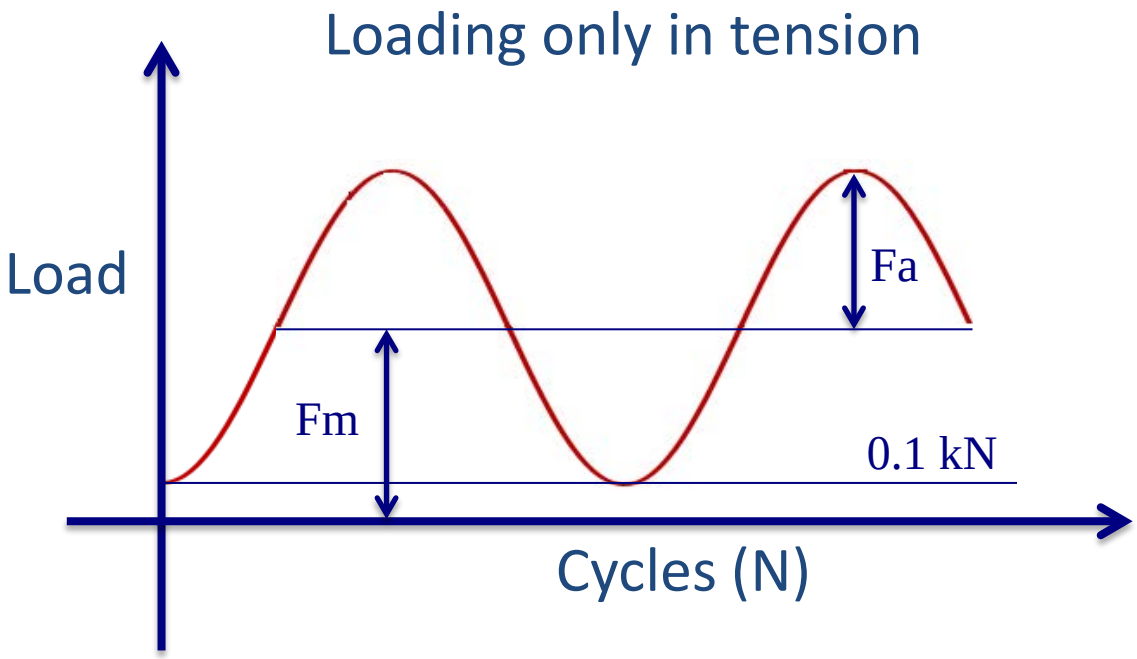




Tungsten target is heated during Spallation:

- Temperature peaks of >500°C
- Thermal Fatigue is possible.

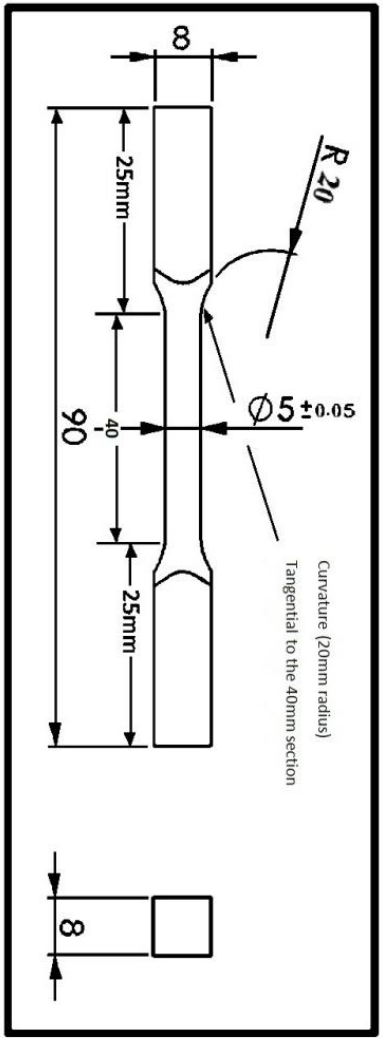
Fatigue Testing (Stress-controlled)



Fatigue testing with a sinusoidal load of 25 Hz.
Minimum load at 0.1 kN
Runout limit = 2×10^6cycles

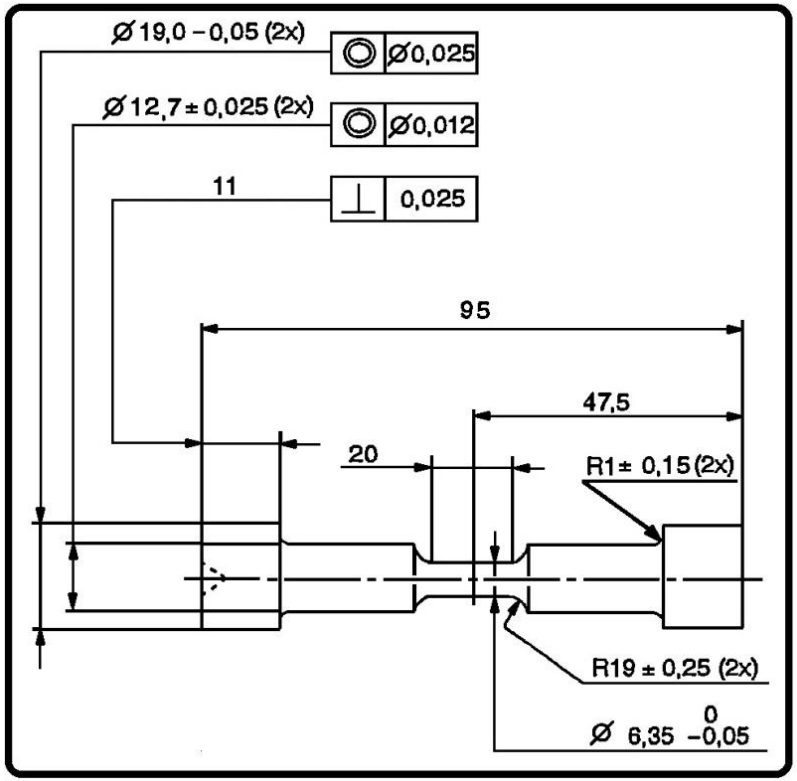
Up and Down method was used to locate the fatigue limit, starting at ~0.3×UTS

Tungsten Specimen Dimensions



Room temperature

Gauge lenght 40 mm



High tempereture

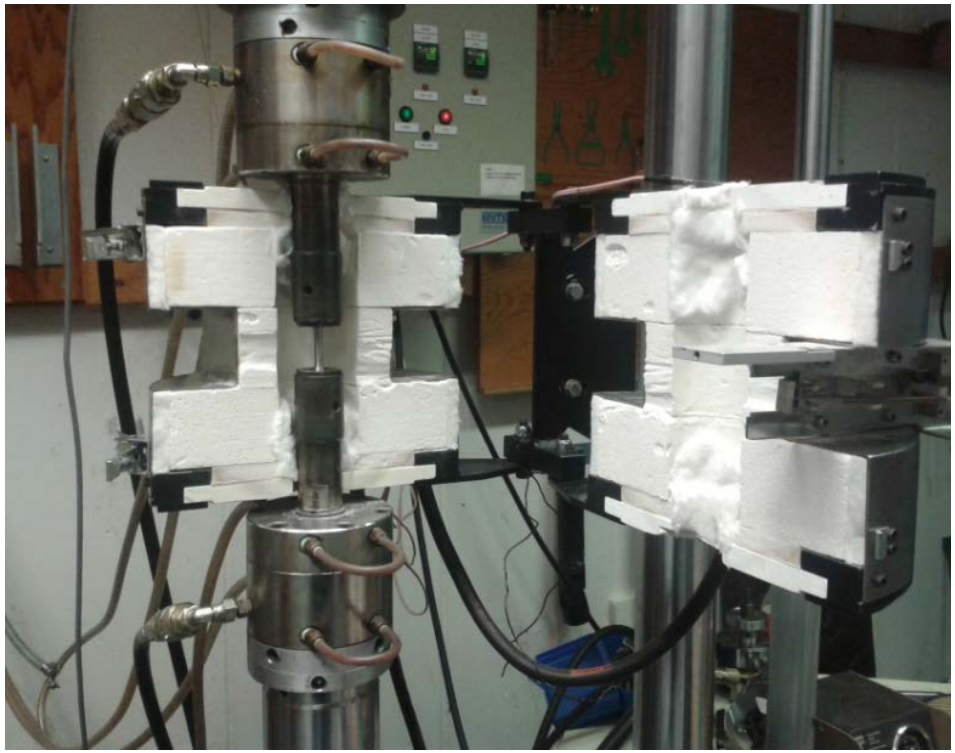
Gauge length 20 mm

Experimental Set-up

MTS max load :250 kN, Control system: INSTRON, servo-hydraulic

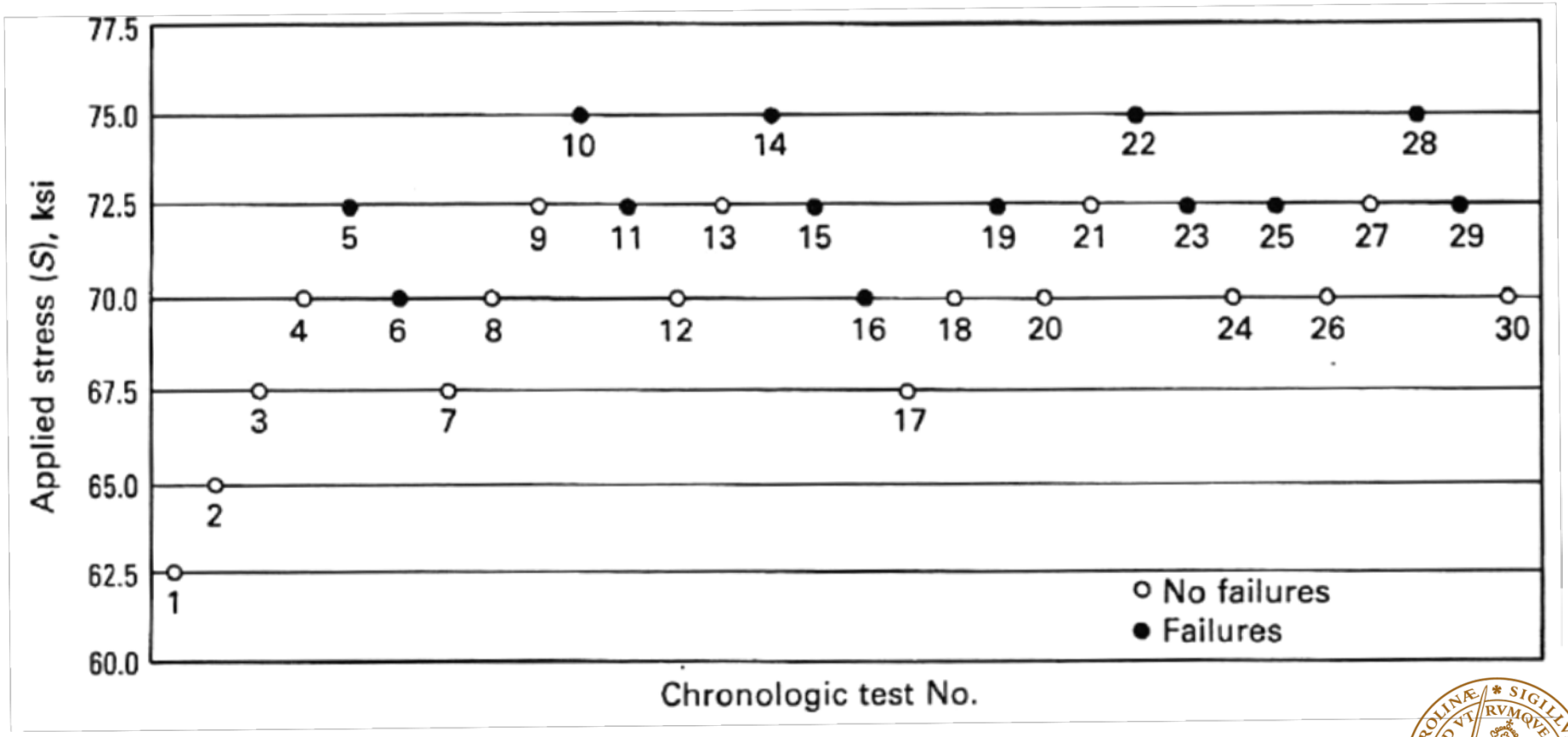
Specimen Grips

Room Temperature

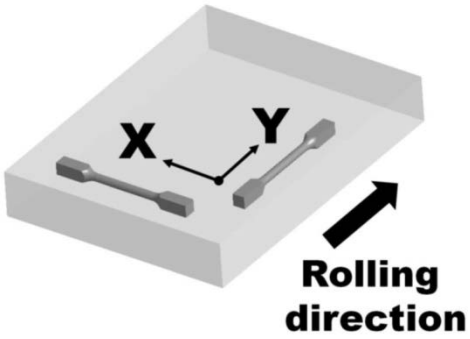


High Temperature

The Up and Down method



Tungsten Specimens



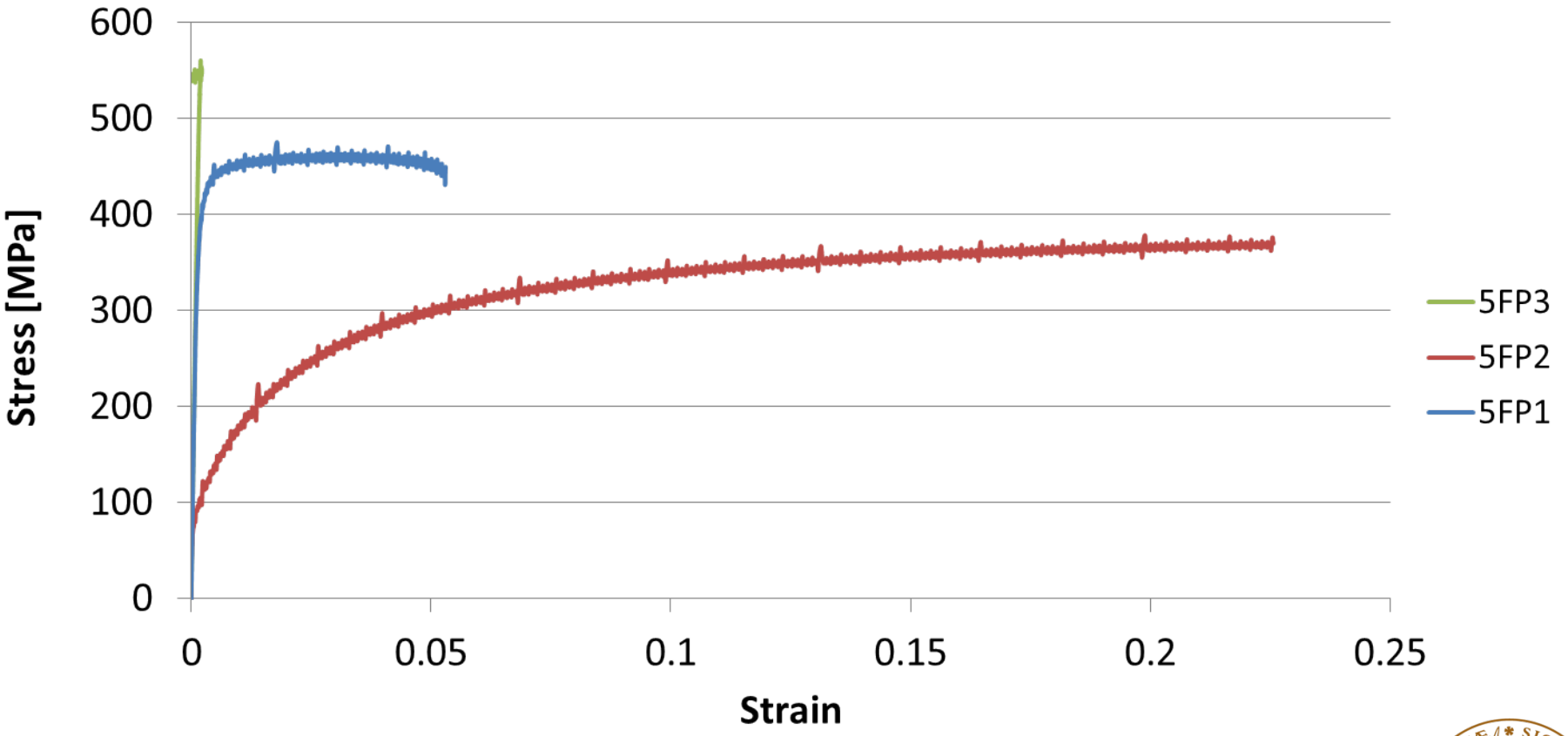
- Tungsten powder, pressed and sintered
  - Rolled
    - Rolled Direction Y
      - Polished
      - Unpolished
    - Transverse Direction X
      - Polished
      - Unpolished
  - Forged
    - Polished
    - Unpolished

Summary – Tensile Tests
Ultimate tensile stength [MPa]

Condition \ Temp.		25°C		300°C		500°C	
		U	*P*	U	*P*	U	*P*
Rolled	X	399	*457*	500	*521*	455	*465*
	Y	484	*673*	588	*615*	447	*450*
Forged		519	*734*	507	*540*	535	*525*

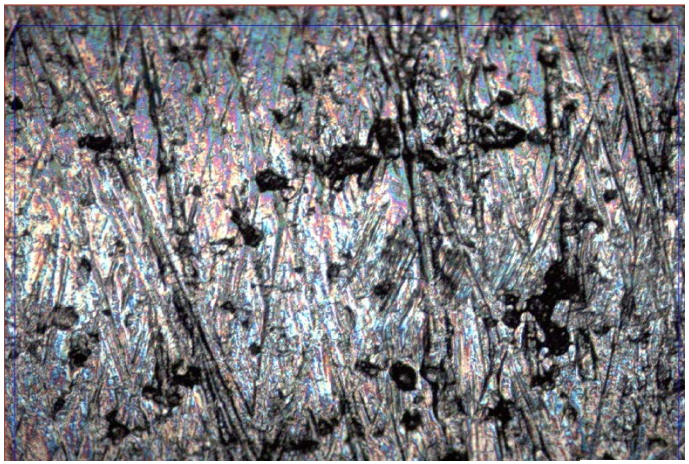
U – Unpolished, P – Polished

Tensile Test Results
Polished Forged Specimens at 500°C

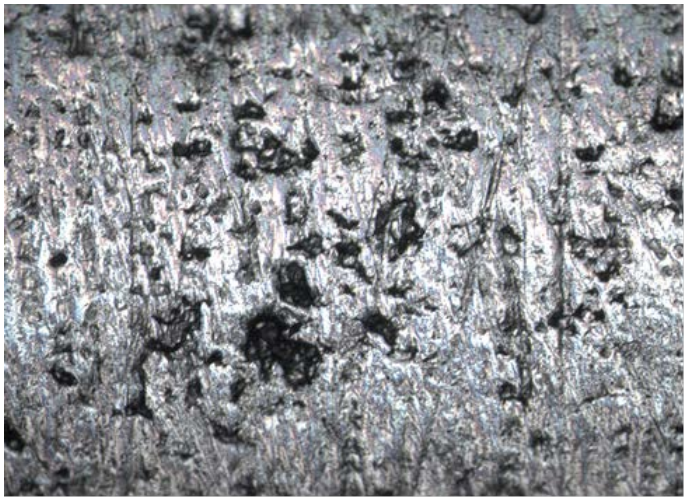


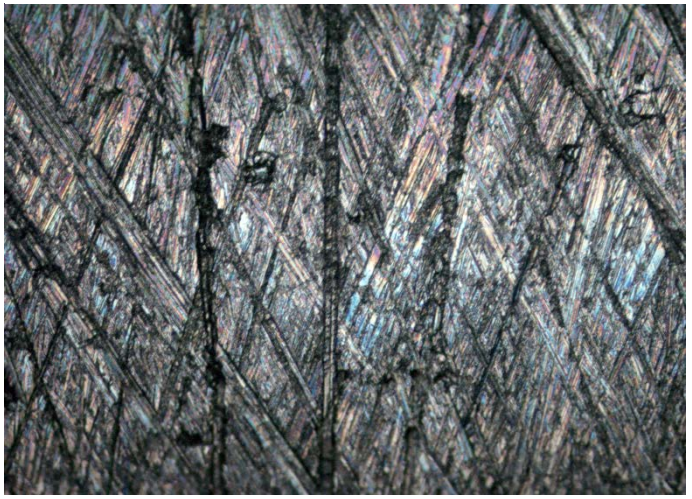
Three samples, three very different results

Tungsten Specimen Surfaces (Forged)



E-polished 100x Unpolished





Fatigue Limits from Stress-controlled Tests

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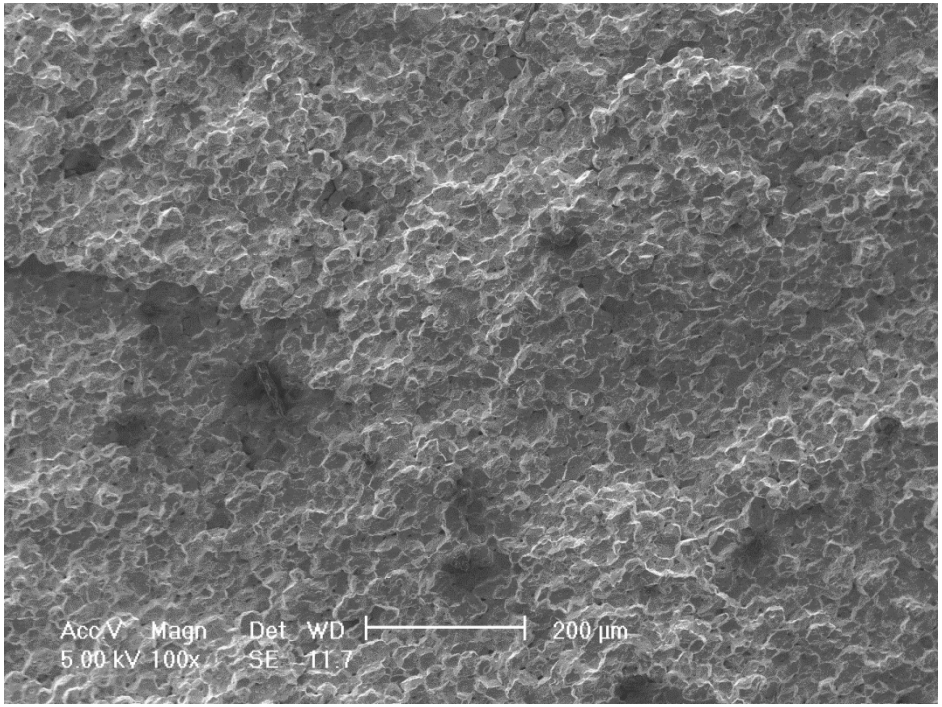
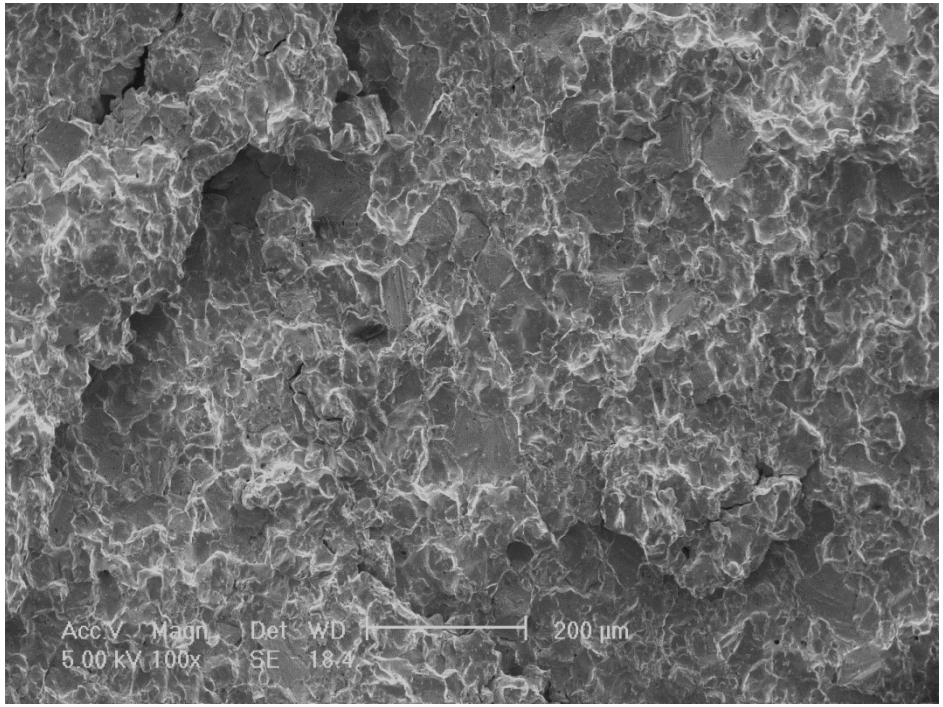
Sample				Highest runout stress amplitude [MPa]	Highest stress amplitude without failure [MPa]	Number of specimens tested
25°	Rolled	X	U	150	**150**	3
			P	137.5	**137.5**	3
		Y	U	337.5	**150**	22
			P	300	**237.5**	16
	Forged		U	200	**175**	9
300°	Rolled	Y	U	300	**300**	2
			P	290	**252.5**	12
	Forged		U	300	**242.5**	12
			P	250	**212.5**	9
500°	Rolled	Y	U	150	**150**	6
	Forged		P	187.5	**175**	9

Fracture Surfaces of Forged Specimens, 300°C





After tensile testing
-More ductile mode

After fatigue testing
-Less ductile mode

Effect of Temperature on Fatigue Fracture

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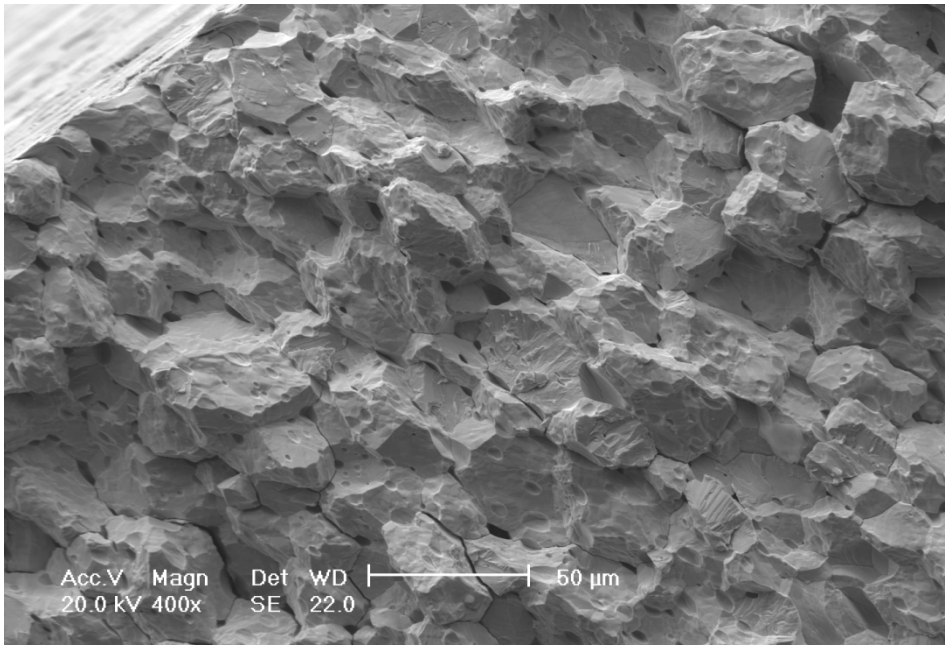
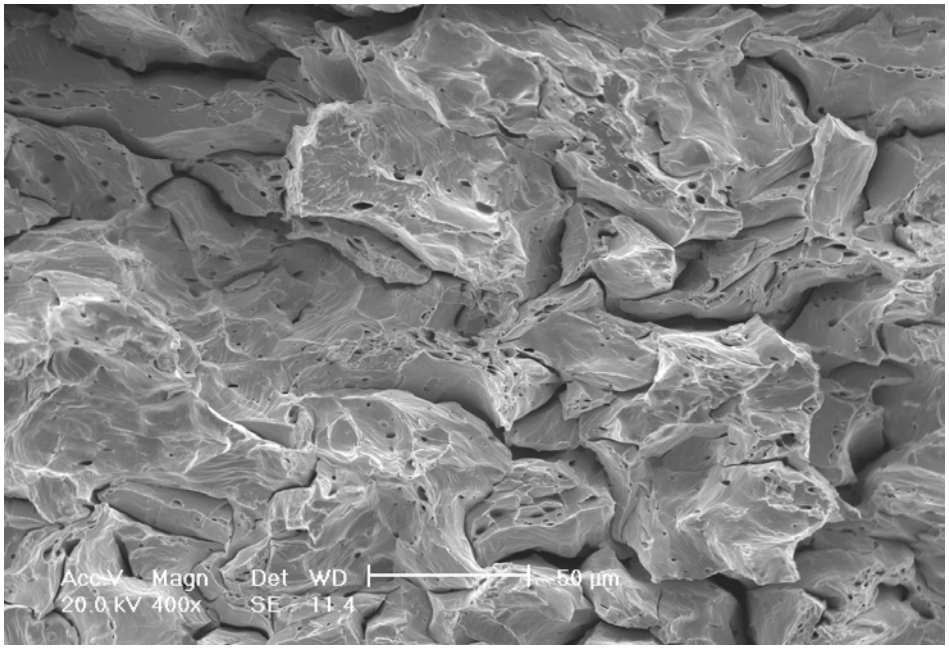
Forged Specimens



300°C

- Brittle
- Clearly visible cleavage planes
- Mainly intergranular fracture



500°C

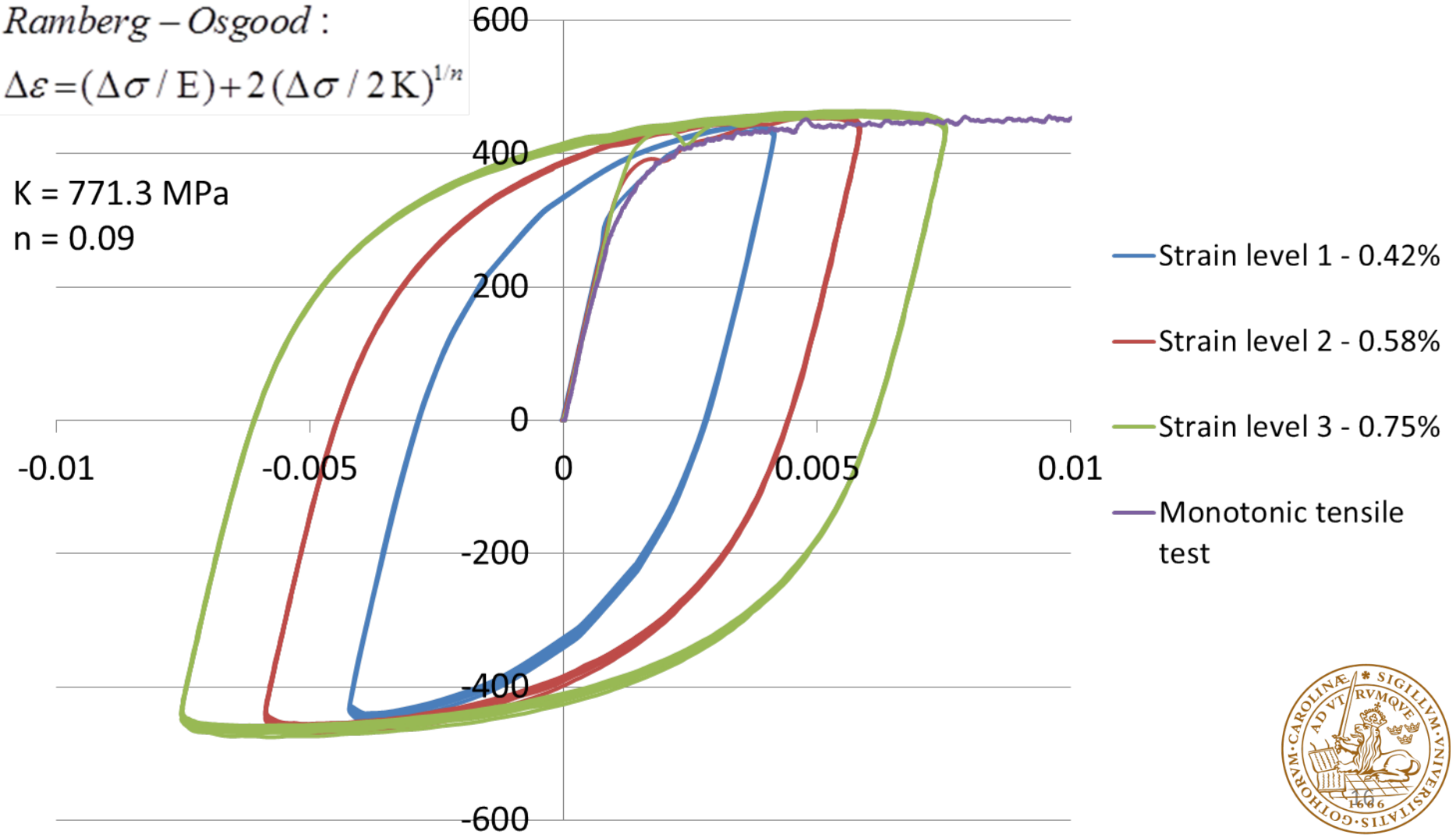
- More ductile
- Local deformation observed
- Mixed inter-/transgranular fracture

Strain-controlled Fatigue Test (Forged specimen, 500°C)

$$Ramberg - Osgood:$$

$$\Delta\varepsilon = (\Delta\sigma / E) + 2(\Delta\sigma / 2K)^{1/n}$$

K = 771.3 MPa
n = 0.09



Conclusions

- Wide scatter in tensile and fatigue data
  - Brittle nature of Tungsten, specially at low T.
  - Surface condition (Polished and Unpolished)
  - Volume fraction porosity
  - Grain orientation
  - Manufacturing method (Forged and Rolled)
- At high temperatures, fatigue properties are slightly better
  - Rolled samples have relatively higher fatigue limits
- Strain-controlled test show marginal cyclic hardening
- Increase in DBTT after irradiation must be taken into account in target design