Inverkan av lasthistorik på brottseghet för reaktortankstål

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Kiwa Inspecta

Trust
Quality
Progress

Outline of the presentation

- Background
- Theoretical background
- Experimental work
- Conclusions

Acknowledgments

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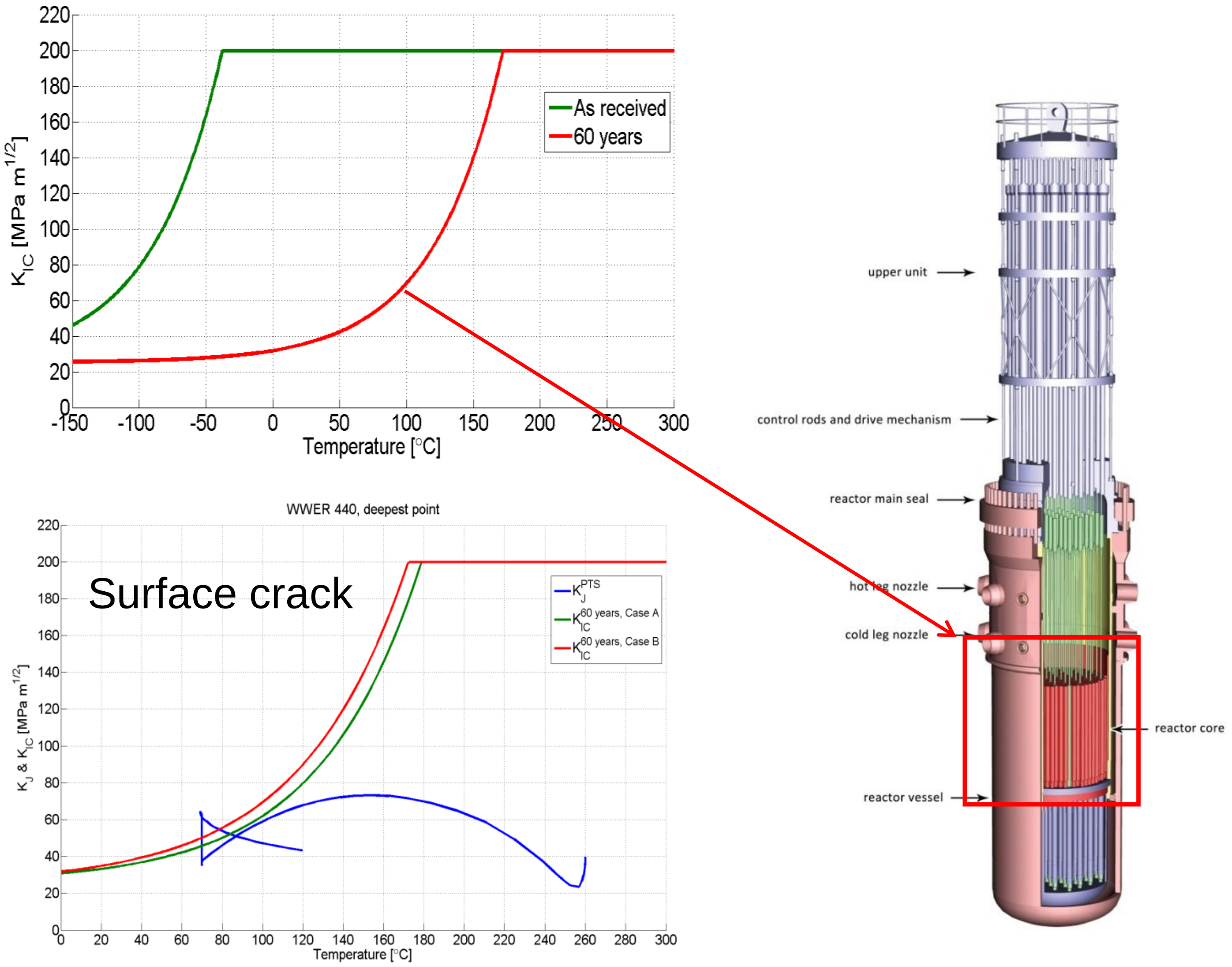
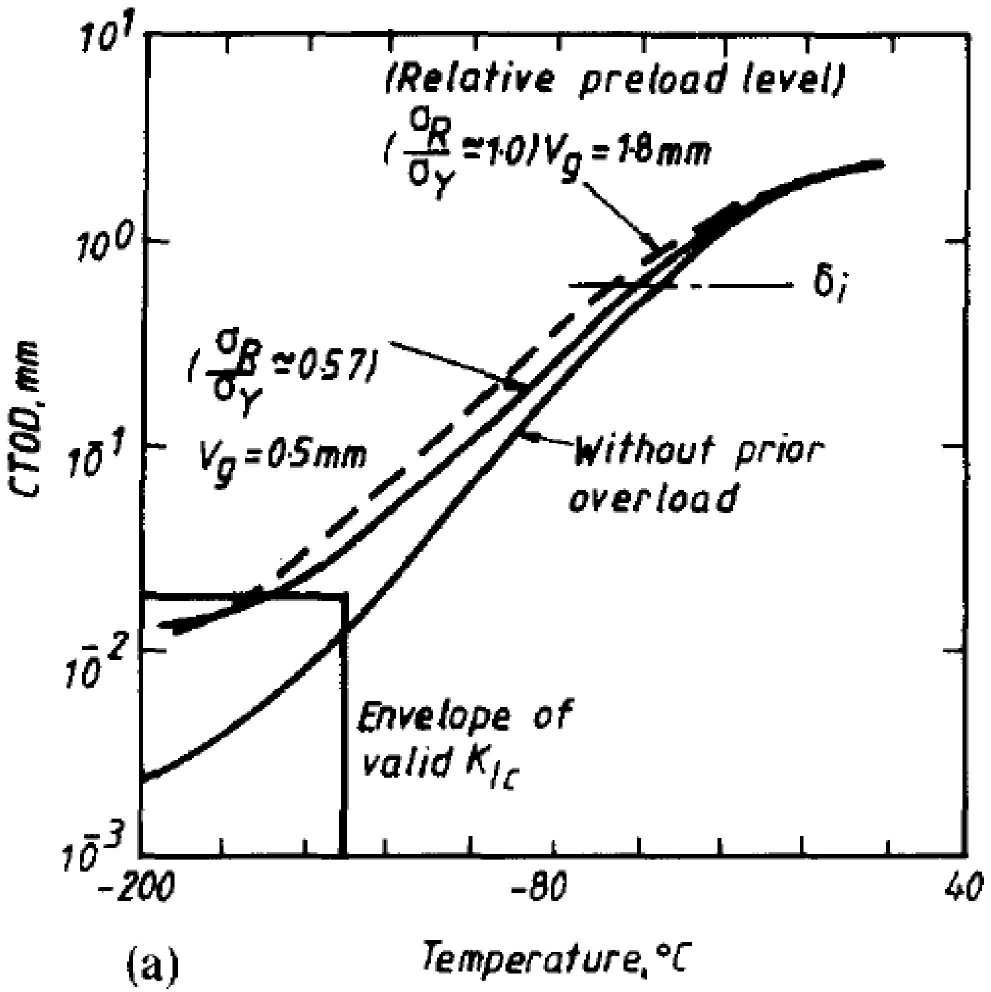
EDF France for supplying the material.

Background



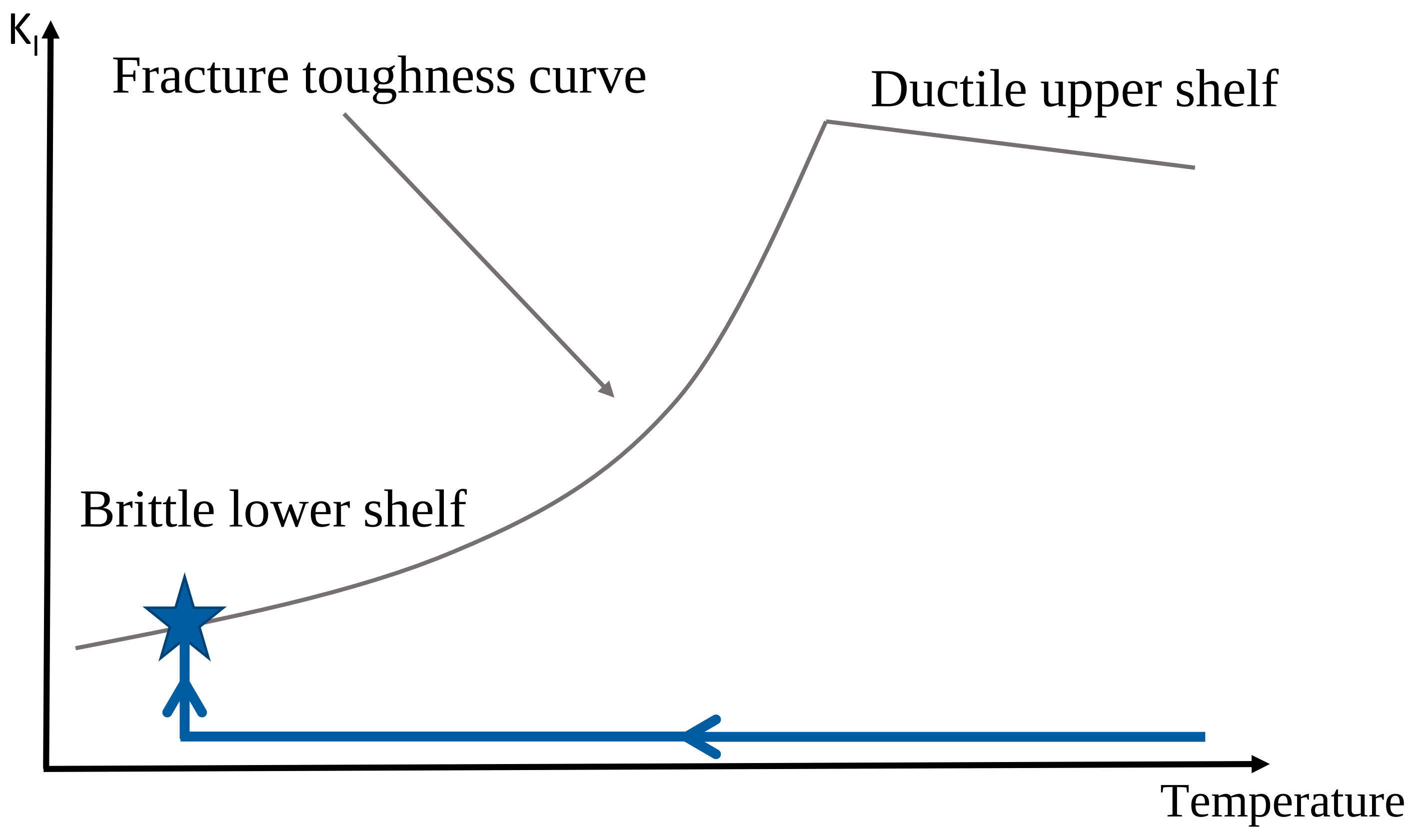


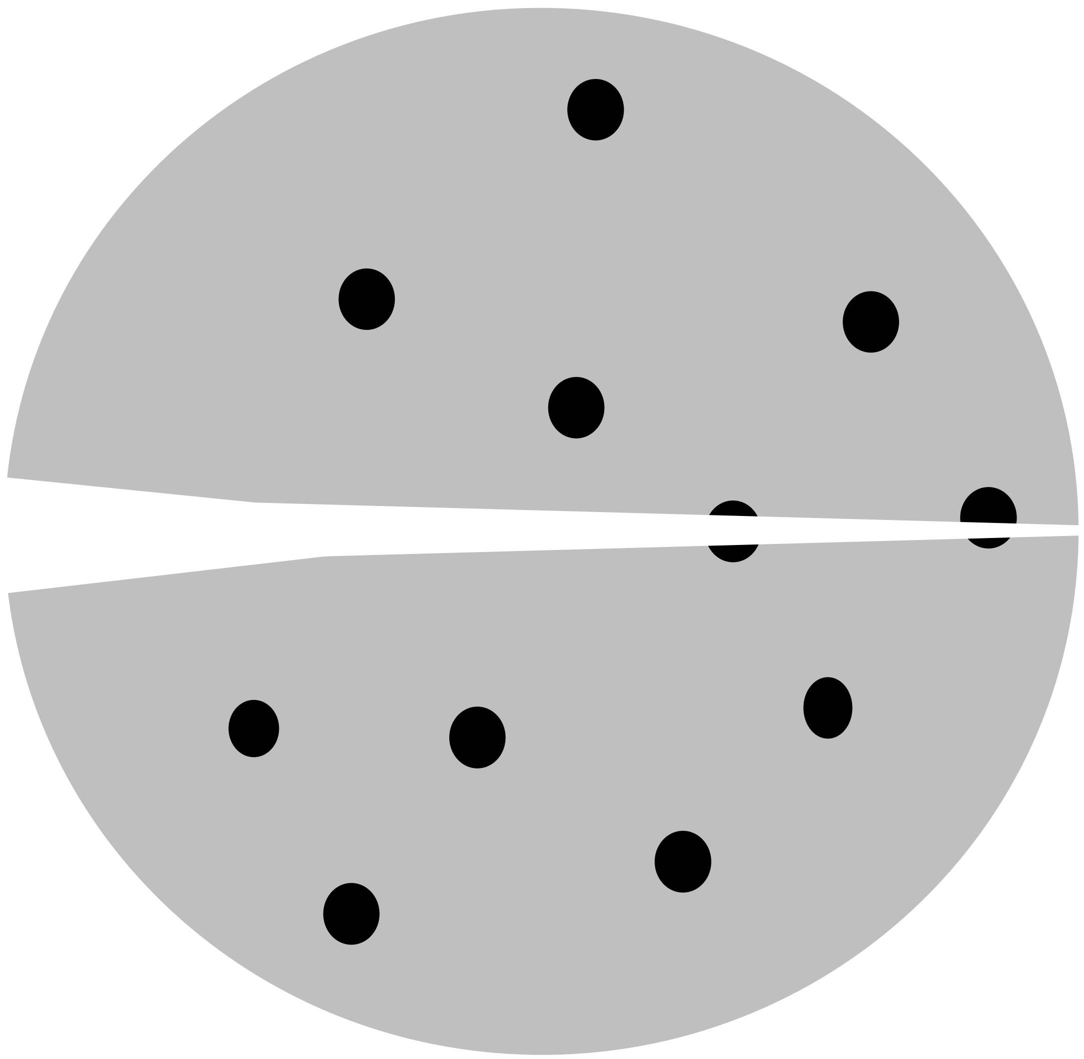
Smith *et al.*
1989

Background

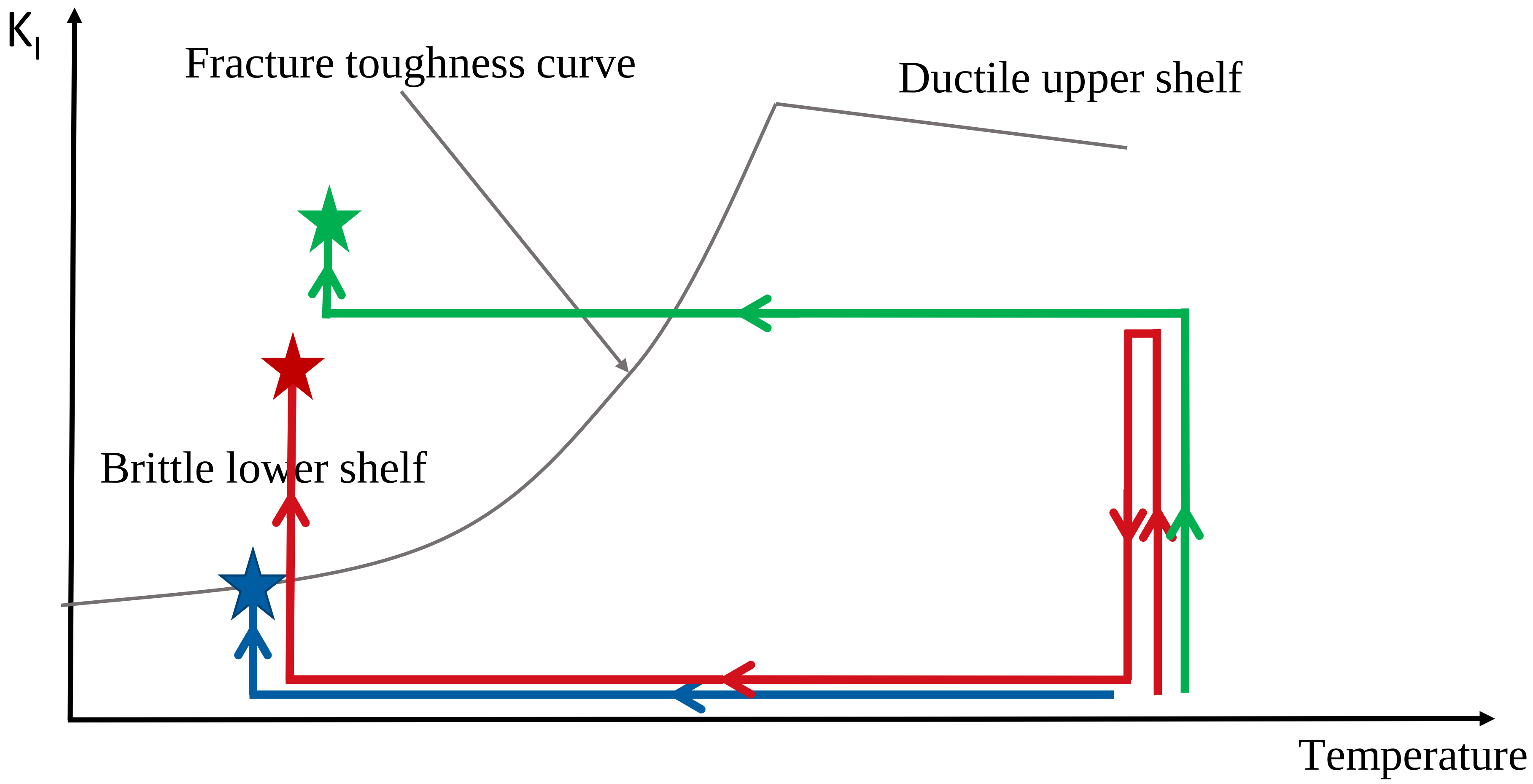
- There is already extensive experimental evidence for the Warm Pre-Stressing effect (WPS).
- There is a need to thoroughly evaluate the importance of the mechanisms behind WPS. This in order to understand the limitations and possibilities in using the WPS effect in assessments.
- The mechanisms related to the introduction of a beneficial compressive residual stress field in front of the crack tip and the change of material properties due to lowering of temperature is studied with numerical methods.
- The mechanisms related to deactivation of cleavage initiation sites and the blunting of the crack tip is studied with an experimental program.
- The goal of the research was to answers which of the main mechanisms are the active mechanisms behind the WPS effect for situations that can arise in a RPV.

Theoretical background – Brittle fracture





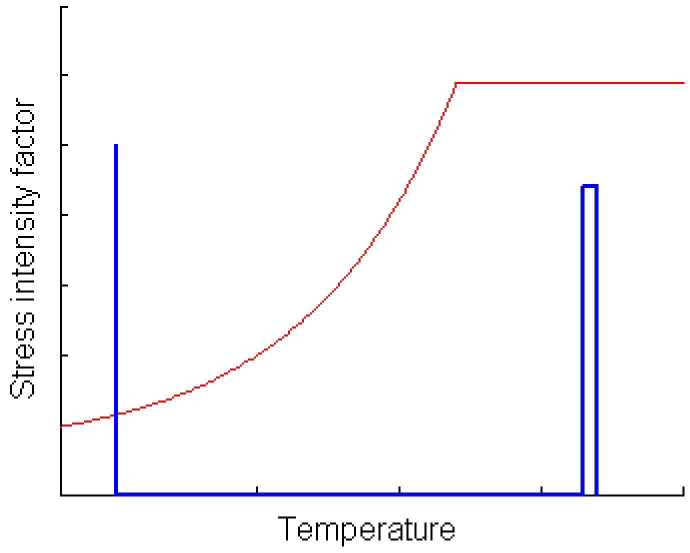
Theoretical background – Warm Pre-Stressing

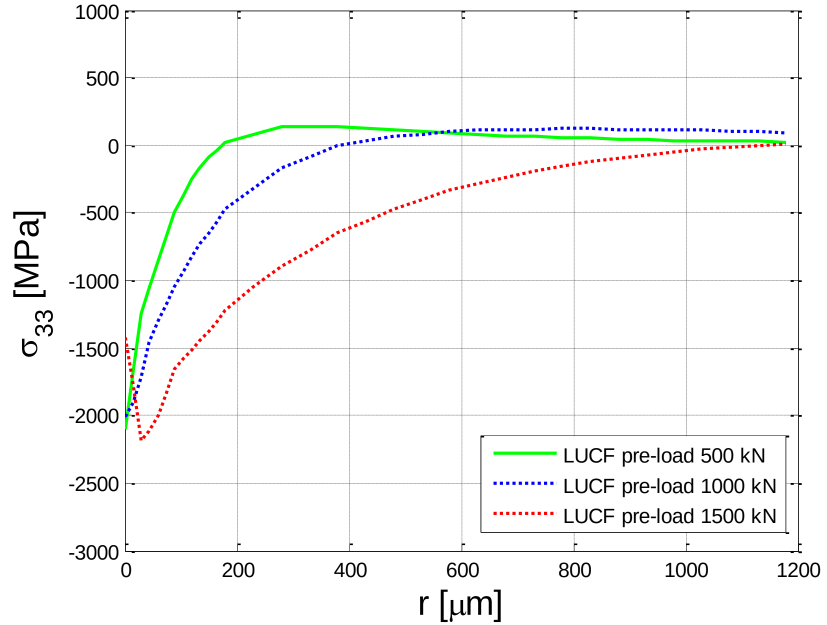


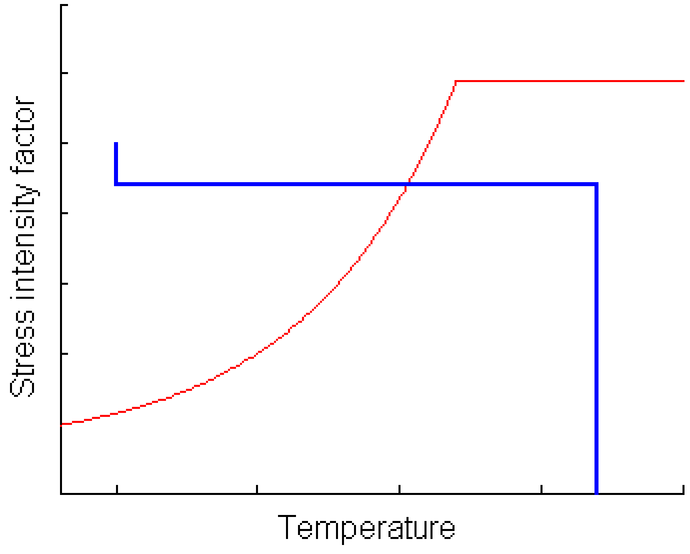
Theoretical background – Main mechanisms for WPS

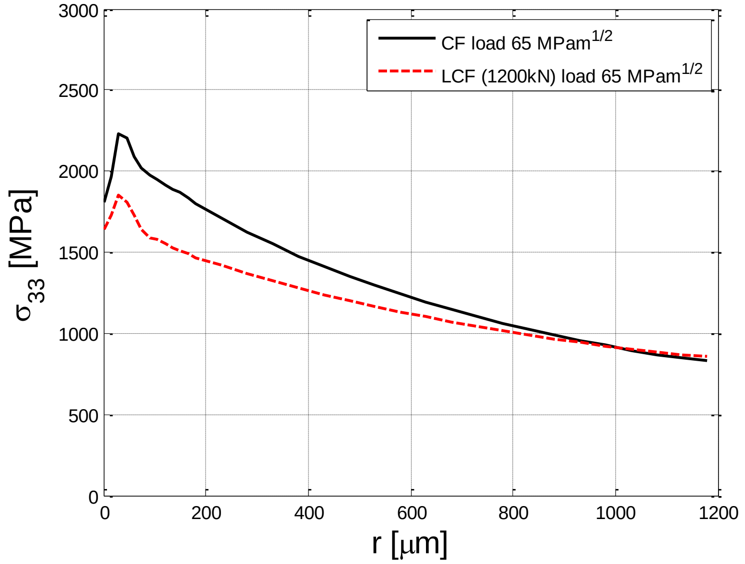
The WPS effect can be attributed to the following main mechanisms:

- Introduction of a beneficial <u>compressive residual stress</u> field in front of the crack tip, due to local plastic deformation from the preloading and unloading
- <u>Blunting</u> of the crack tip
- <u>Change of yield properties</u> due to lowering of temperature
- <u>Deactivation of cleavage initiation sites</u> by pre-straining

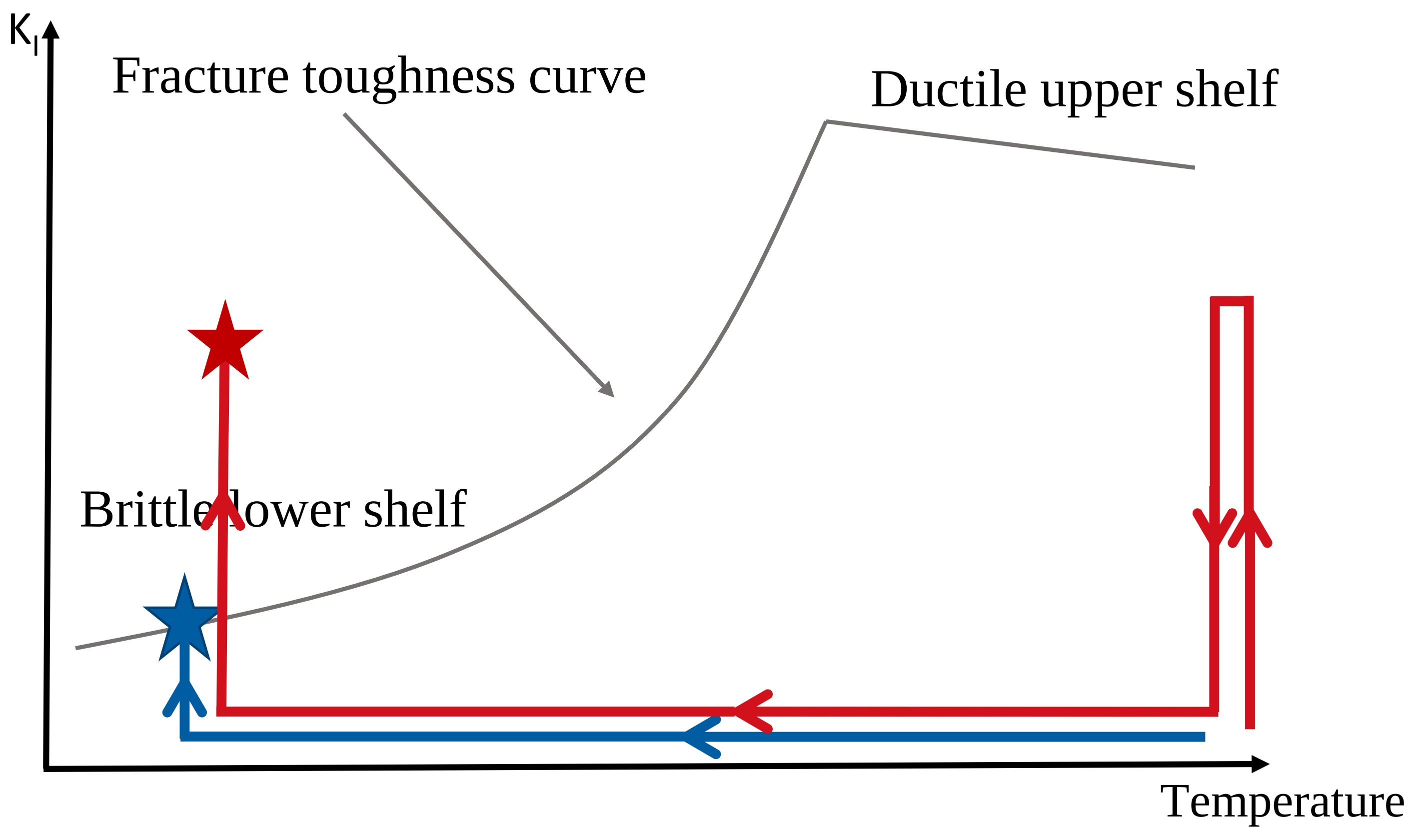


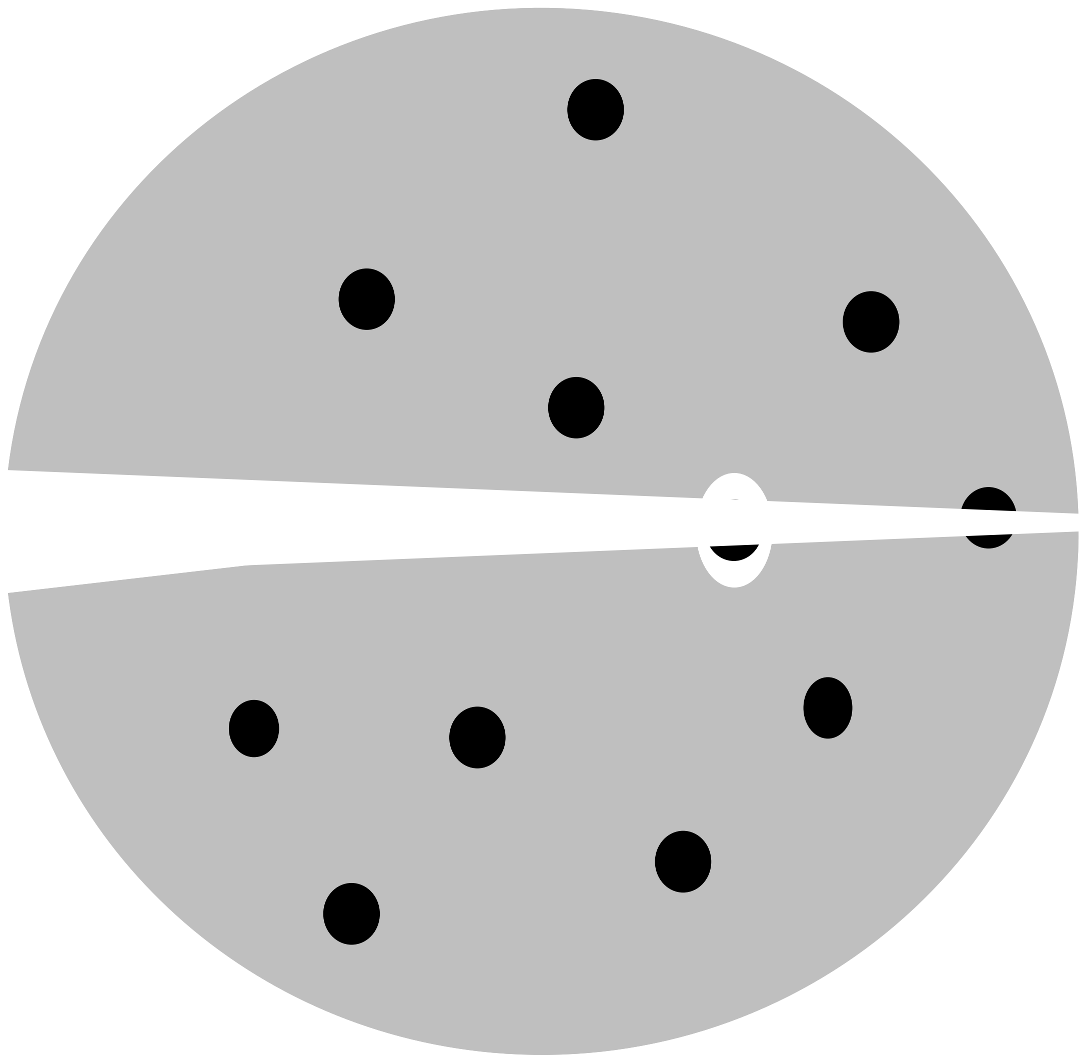






Theoretical background – Deactivation of cleavage initiation sites





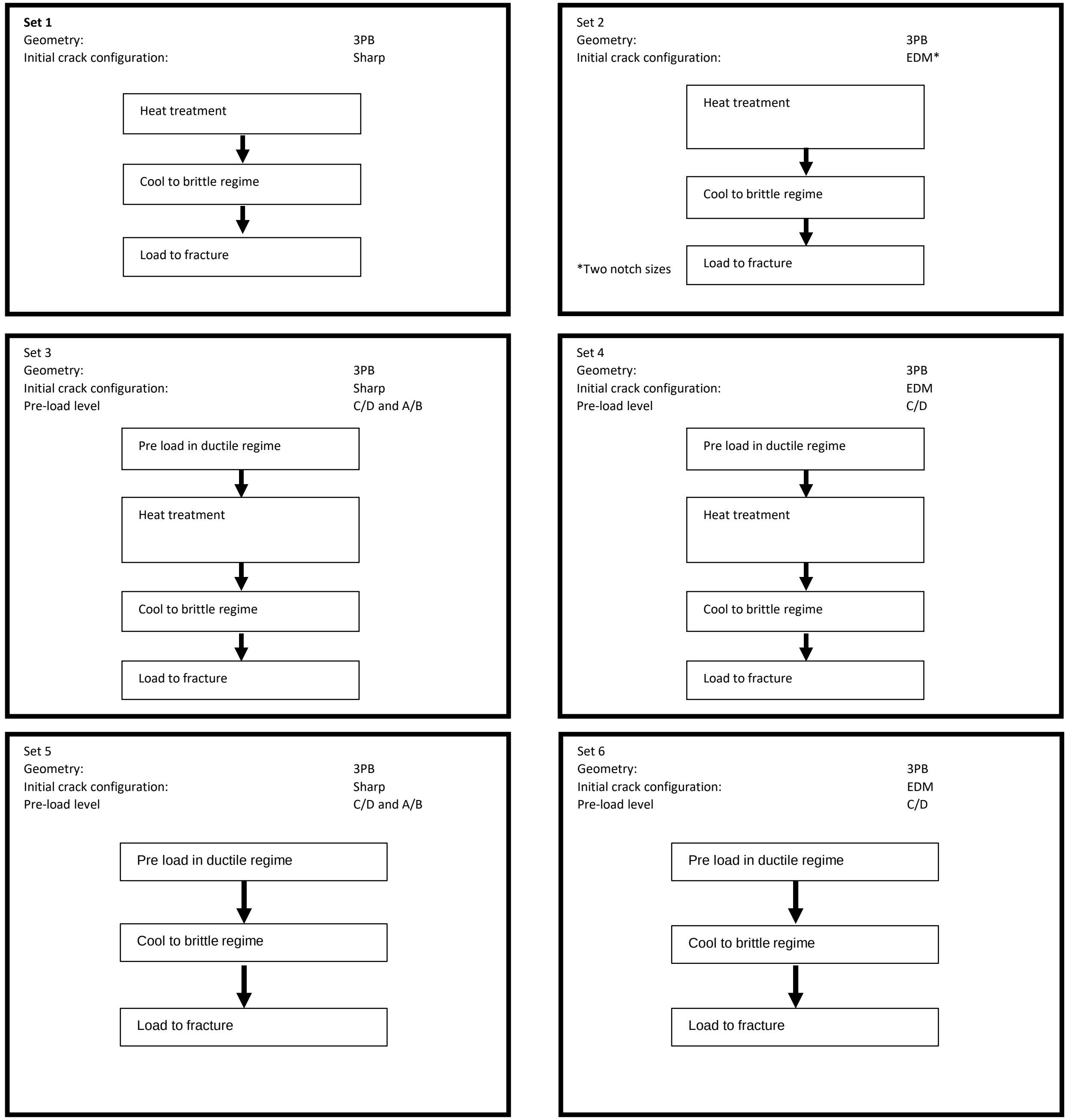
Experimental setup

- Geometry:
  Standard 3PB specimens *w*=50 mm.
- Material:
  Reactor pressure vessel steel 18 MND 5 was used in all tests (Supplied by EDF France).
- Test setups:
  Initial crack tip sharp/blunted.
  Load path cool-fracture (CF) and load-unload-cool-fracture (LUCF).
  Heat treatment and no heat treatment.
- Two pre-load levels:
  Level C/D K_I=155 $MPam^{1/2}$ and
  level A/B K_I=70 $MPam^{1/2}$

- Numerical analyses and experimental tests performed to validate heat treatment.
- A total of 9 groups of each 7 specimens giving a total of 63 performed tests.

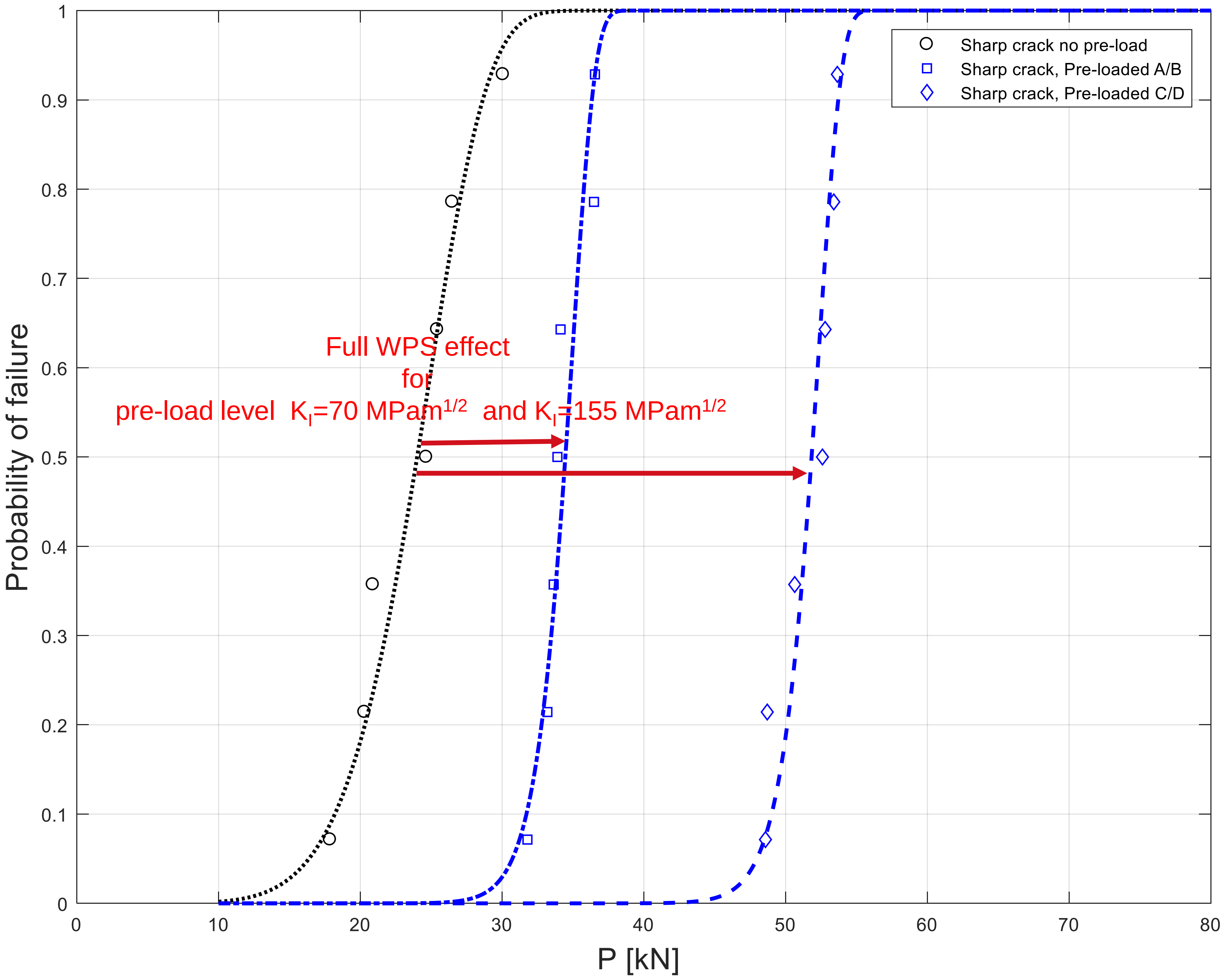
Experimental setup

- **Set 1:**
  No WPS effect
- **Set 2:**
  Effect from blunted crack tip (two levels of blunting)
- **Set 3:**
  Effect from blunting and deactivation of cleavage initiation sites
- **Set 4:**
  Effect from blunting and deactivation of cleavage initiation sites
- **Set 5:**
  Effect from blunting, deactivation of cleavage initiation sites and compressive residual stress field
- **Set 6:**
  Effect from blunting, deactivation of cleavage initiation sites and compressive residual stress field



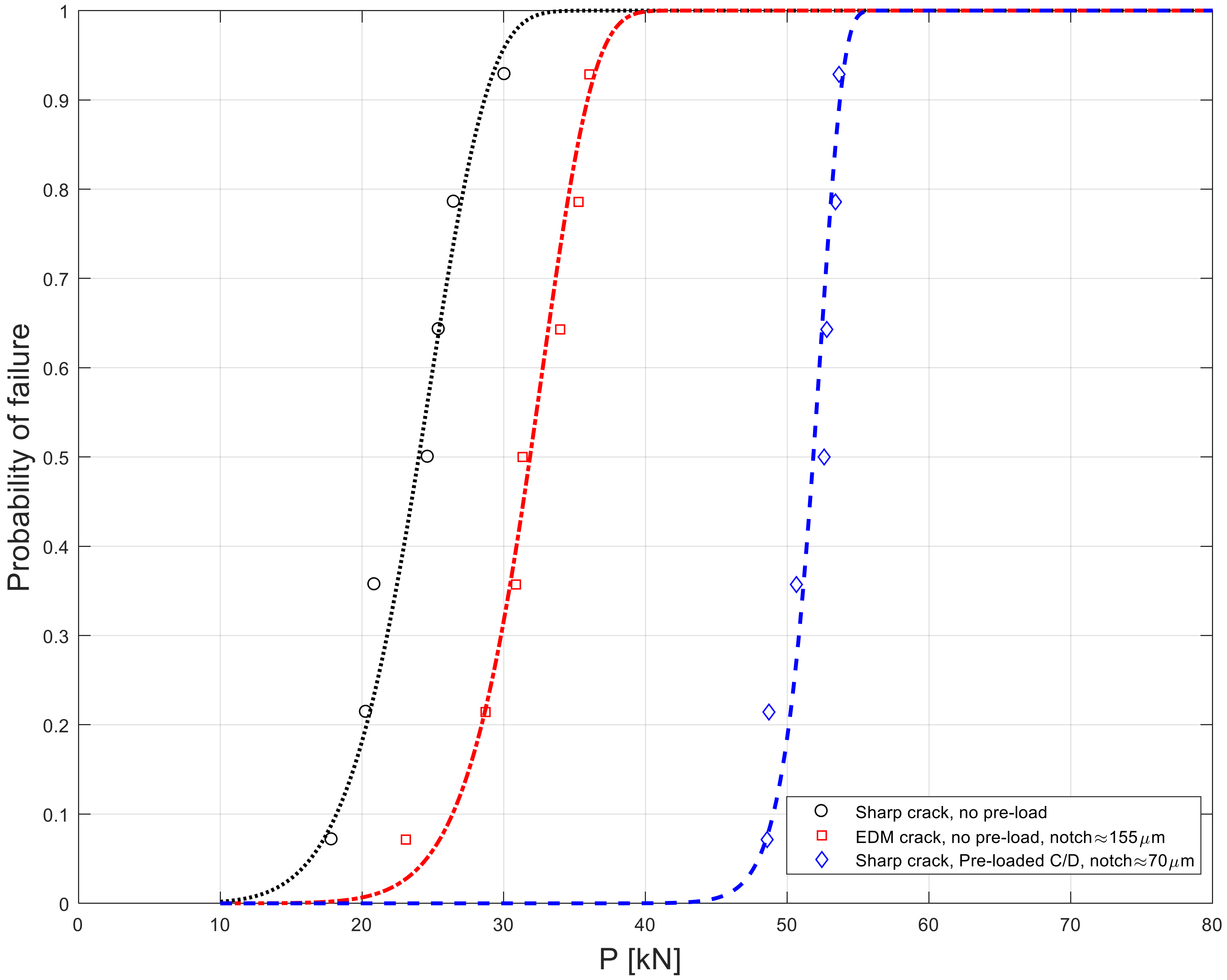
Results

- **Set 1 (Black):**
  No WPS effect
- **Set 5 (Blue):**
  Effect from blunting, deactivation of cleavage initiation sites and compressive residual stress field



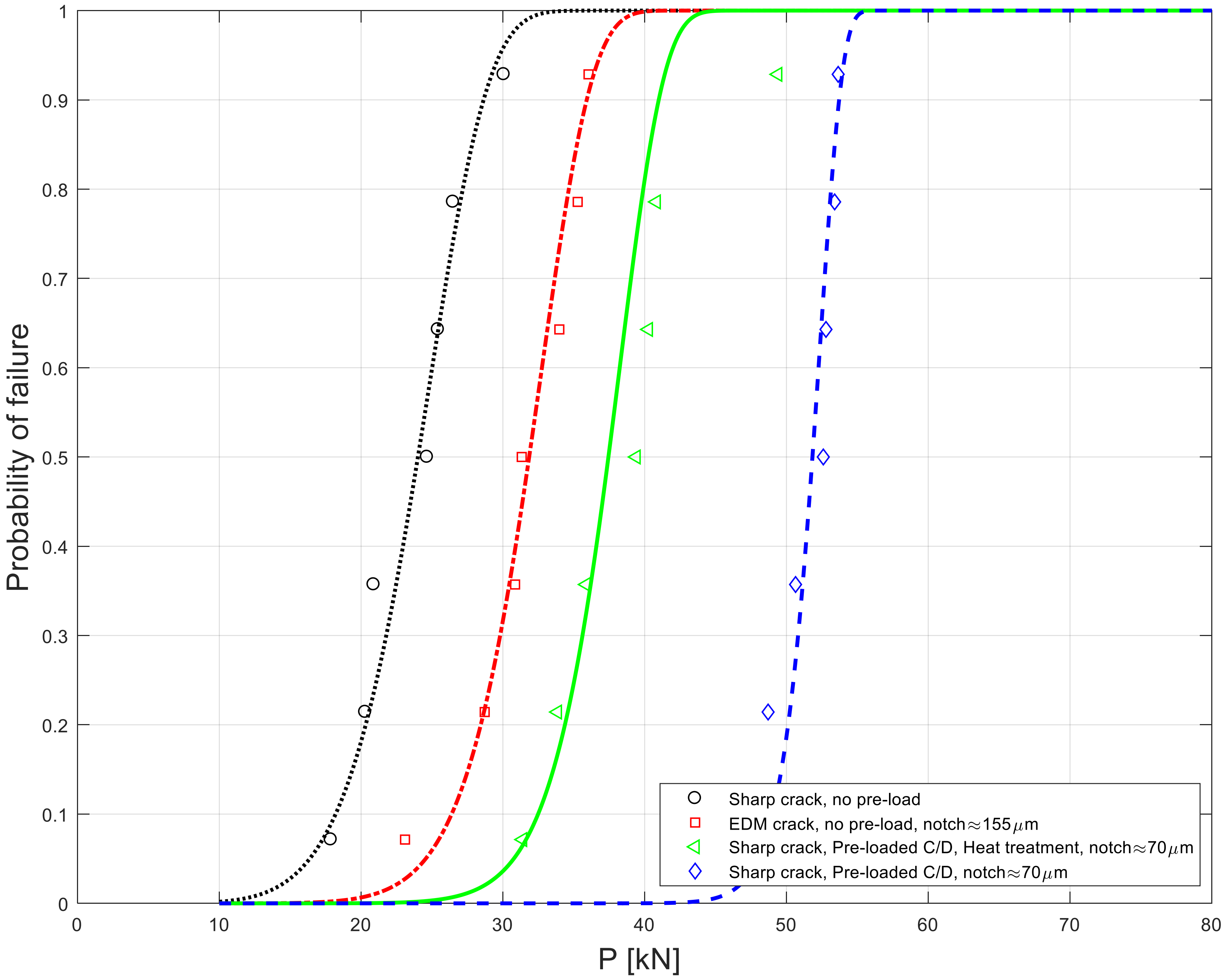
Results

- **Set 1 (Black):**
  No WPS effect
- **Set 2 (Red):**
  Effect from blunted crack tip (level of blunting 155 µm)
- **Set 5 (Blue):**
  Effect from blunting, deactivation of cleavage initiation sites and compressive residual stress field (level of blunting 70 µm)



Results

- **Set 1 (Black):**
  No WPS effect
- **Set 2 (Red):**
  Effect from blunted crack tip (level of blunting 155 µm)
- **Set 3 pre-load C/D (Green):**
  Effect from blunting and deactivation of cleavage initiation sites (level of blunting 70 µm)
- **Set 5 pre-load C/D (Blue):**
  Effect from blunting, deactivation of cleavage initiation sites and compressive residual stress field (level of blunting 70 µm)



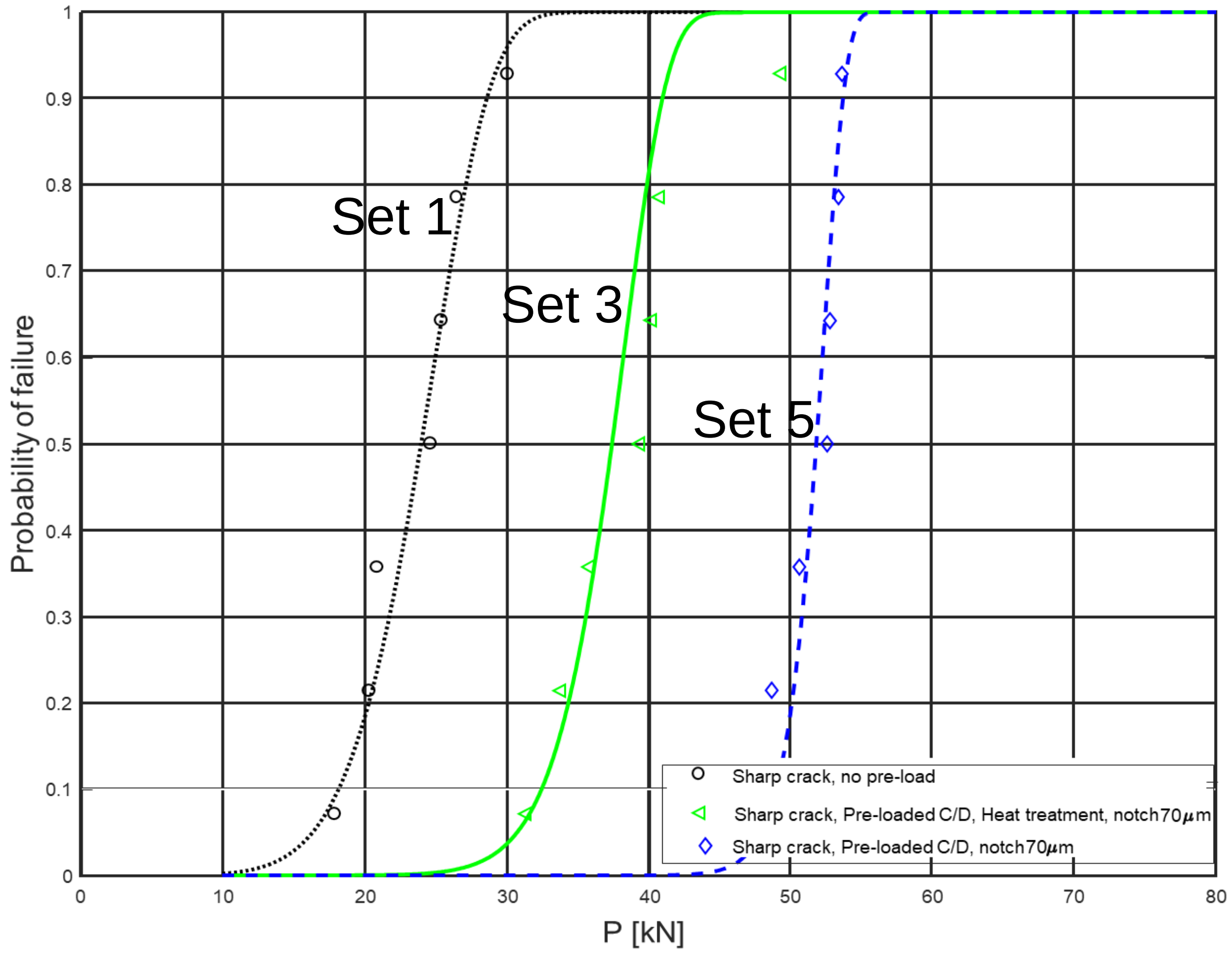
Study of fracture surface in SEM

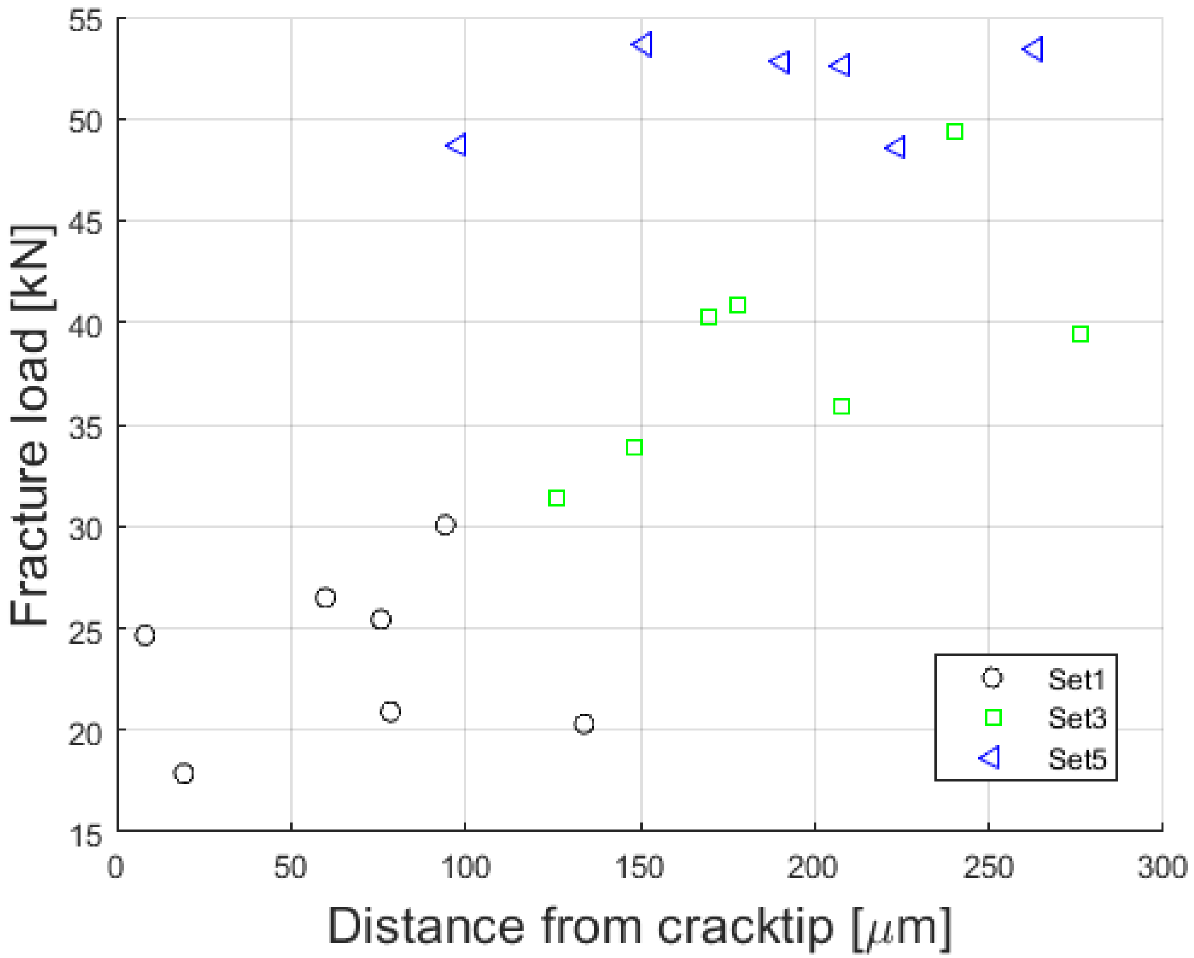
Fracture surfaces of 21 specimens were looked at.

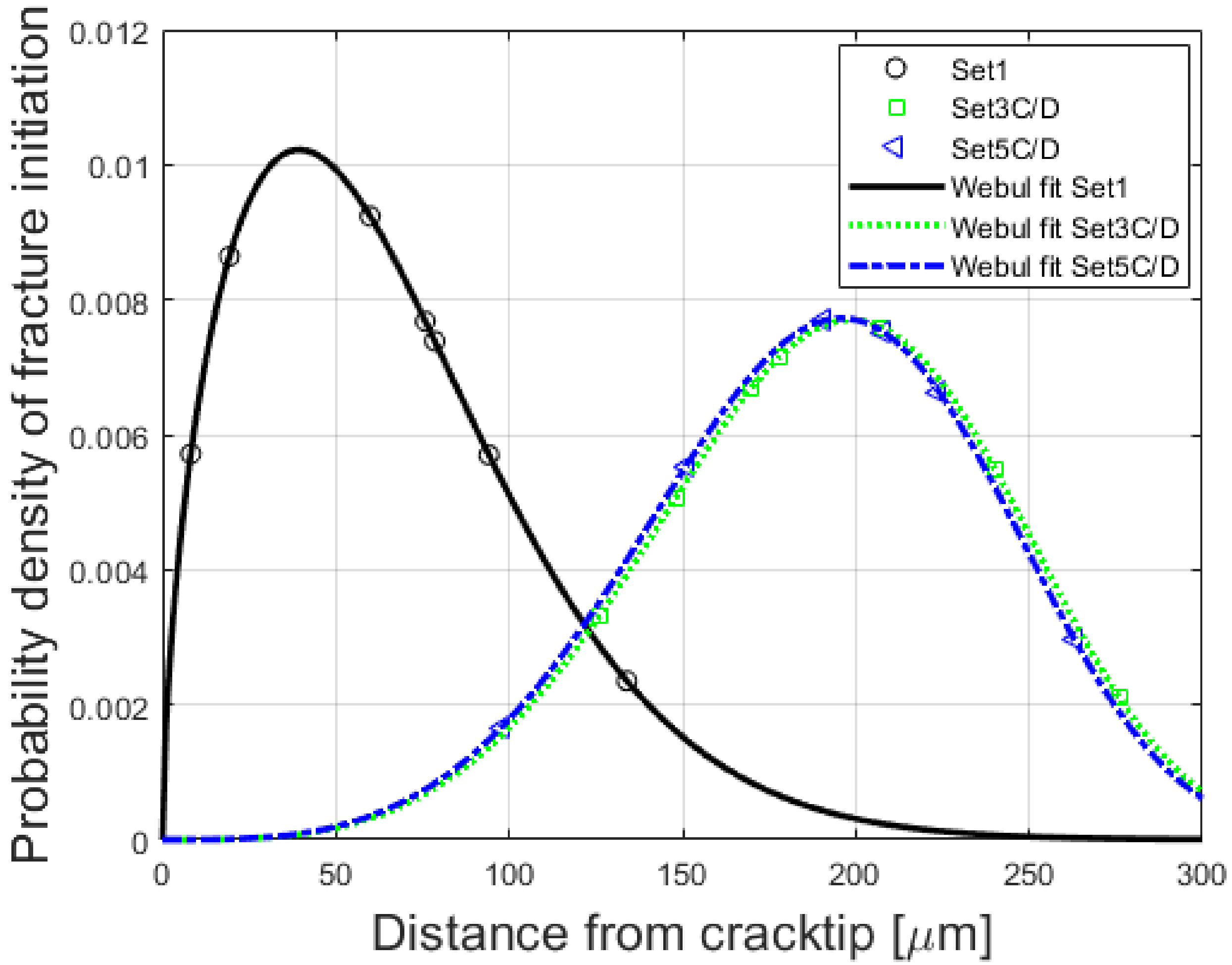
All specimens of set 1, 3 and 5.

Some observations

- Mainly transcrystaline cleavage fracture
- Some secondary cracks
- Seems to be a "clean material", no intercrystalline fracture caused by grain boundary particles

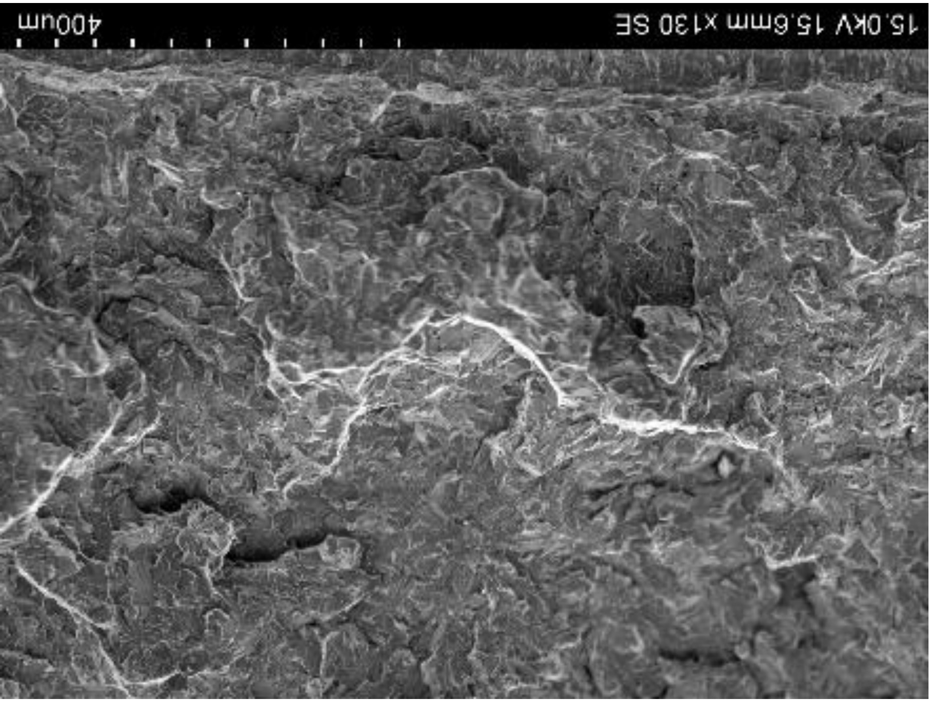



Fracture load [kN]
Distance from cracktip [μm]
Set1
Set3
Set5

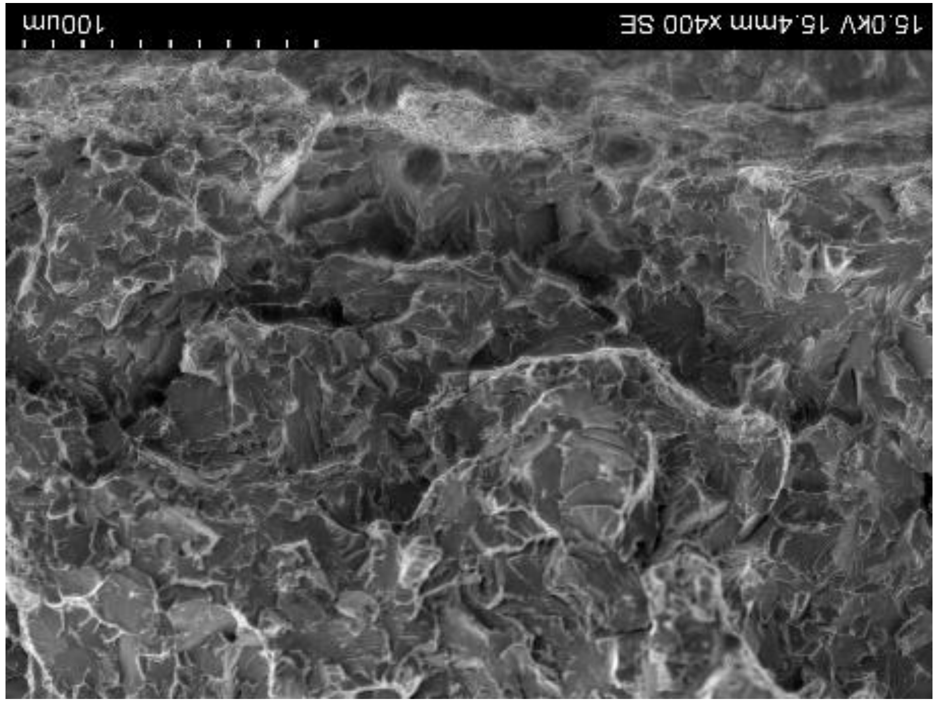

Probability density of fracture initiation
Distance from cracktip [μm]
Set1
Set3C/D
Set5C/D
Webul fit Set1
Webul fit Set3C/D
Webul fit Set5C/D

Specimen 19491, Set5

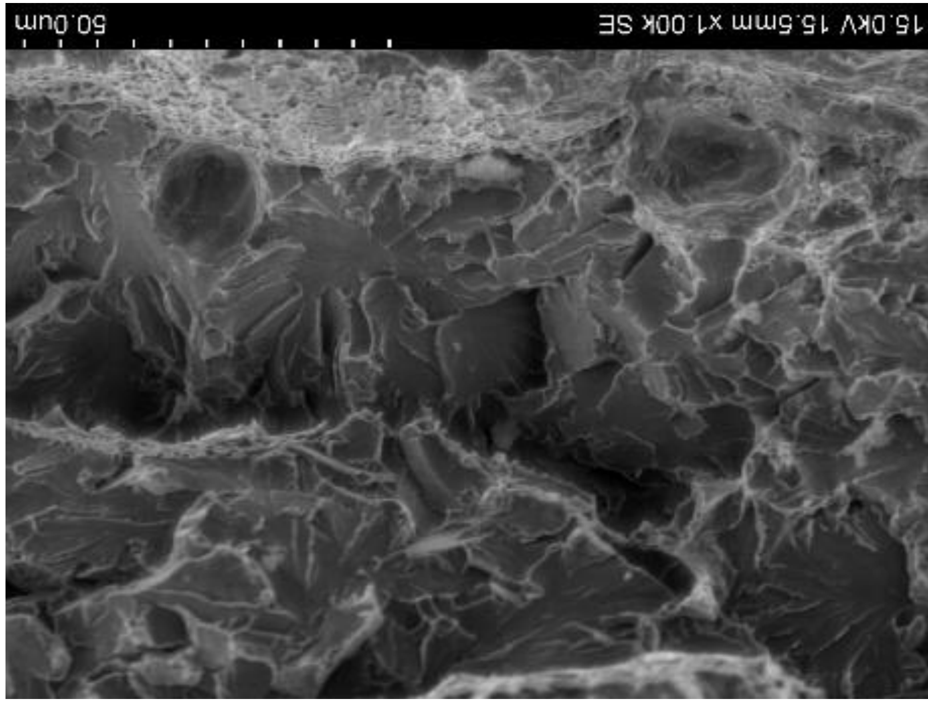
19491, Preloaded +Fatigue crack (130x)



19491, Preloaded +Fatigue crack (400x)



19491, Preloaded +Fatigue crack (1000x)



Conclusion

- The main conclusion from the results is that the deactivations of cleavage initiation sites is an active and significant mechanism of warm pre-stressing for pre-load levels relevant for the nuclear industry.

- At pre-load level A/B (K_I=70 $MPam^{1/2}$) the contribution from deactivations of cleavage initiation sites is almost as significant as the compressive residual stress field. This was not expected.

- The results clearly show a WPS effect for both pre-load levels A/B (K_I=70 $MPam^{1/2}$) and C/D (K_I=155 $MPam^{1/2}$).
  A higher pre-load gives a larger WPS effect.

- The main contribution for a load-unload-cool-fracture load path is the compressive residual stress field.

- From the results it is evident that blunting of the crack tip can have an effect if the pre-load is high enough to create extensive blunting. However at pre-load levels relevant for the nuclear industry the blunting effect is not the main contribution to the WPS effect.