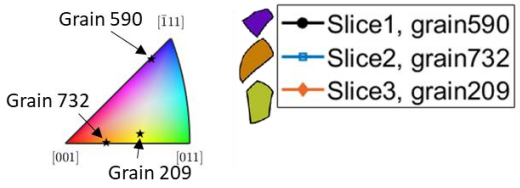
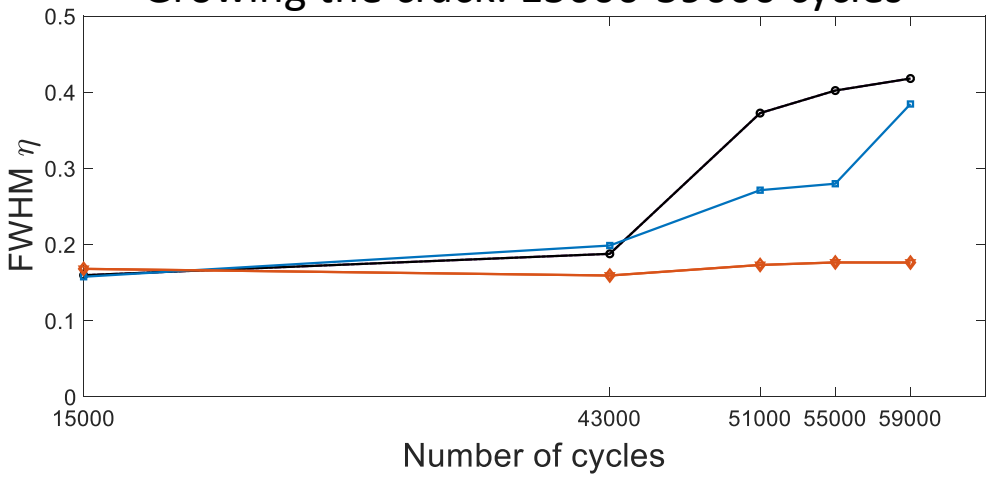
Considering the three grains at the CT in the three slices

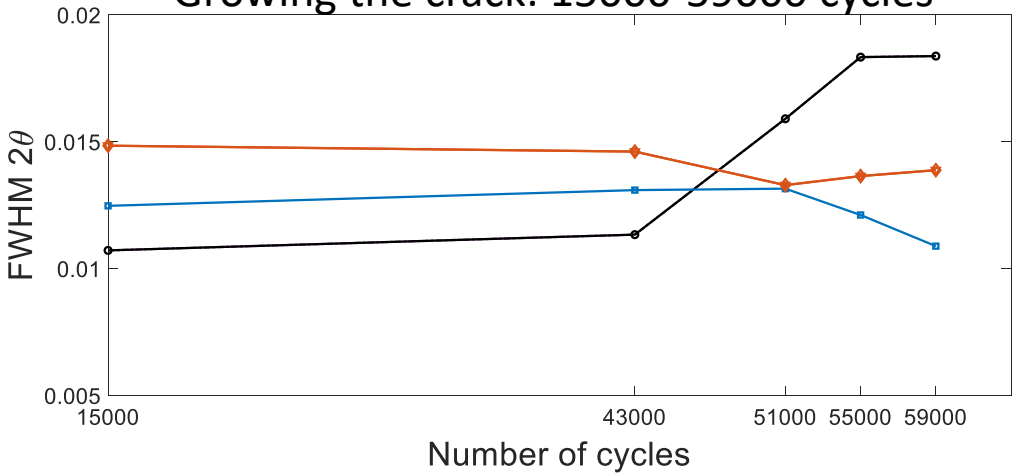
Priya Ravi



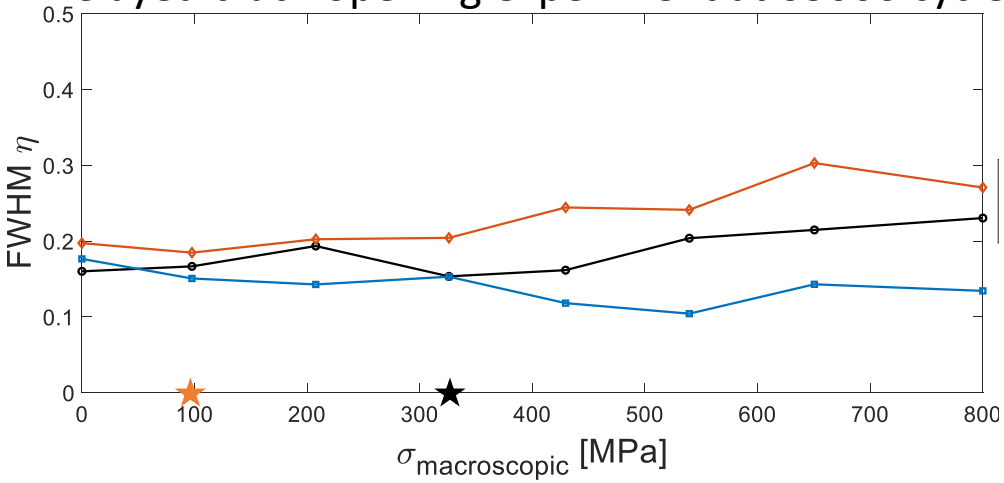
Growing the crack: 15000-59000 cycles



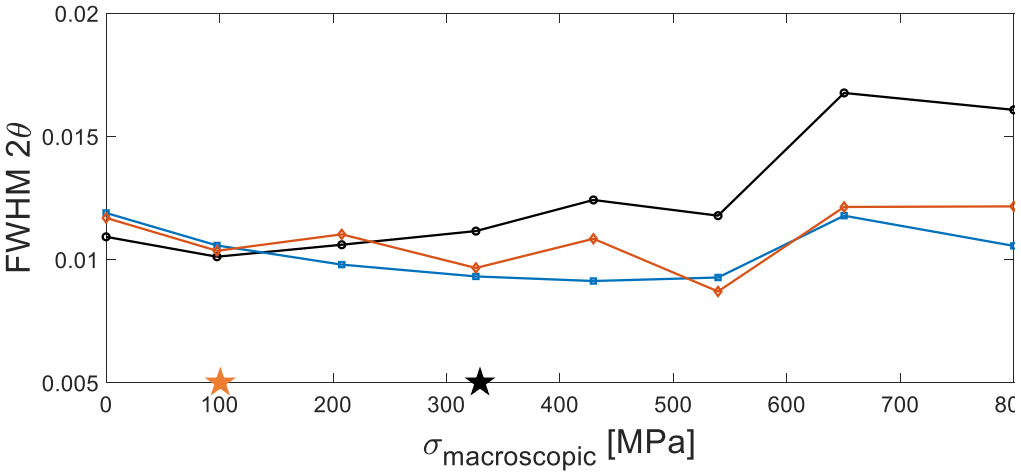
Growing the crack: 15000-59000 cycles



Delayed crack opening experiment at 63000 cycles



Delayed crack opening experiment at 63000 cycles

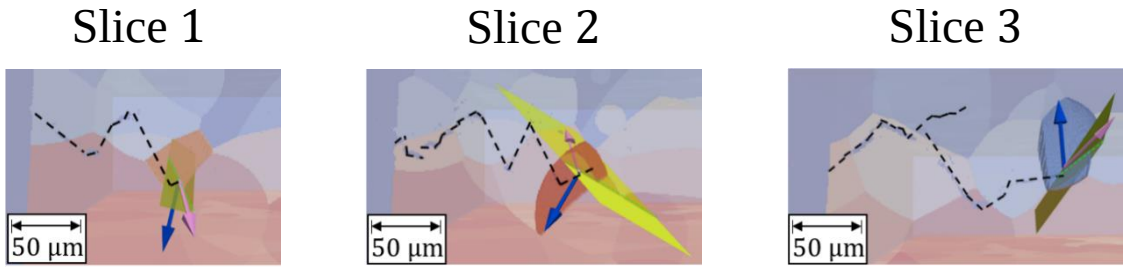


★ Crack opening determined by μ – tomo in the CT grain in slice 1

★ Crack opening determined by μ – tomo in the CT grain in slice 3

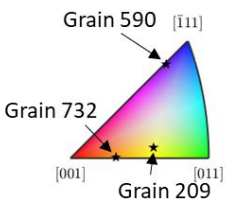
Average FWHM of the spots belonging to the (111) have been plotted

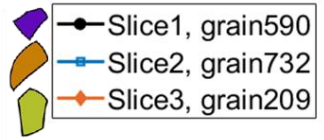
Discussion



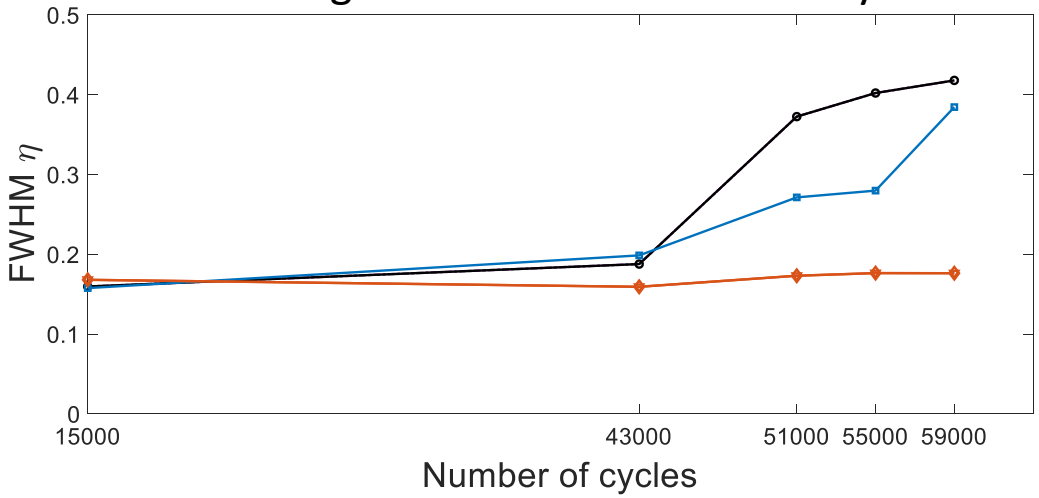
- Notes:
  - For 15000, 43000, 51000, 55000, 59000 cycles, a beam size of 125 μm was used (grain-averaged effects will be more pronounced).
  - At 63000 cycles, a beam size of 20 μm was used.
- Grain 209 (in slice 3) opens first:
  - Considering FWHM evolution during 15k-59k cycles, this grain has lower accumulated plasticity compared to the other two
  - At 63k cycles, the $\mathrm{FWHM}\eta$ increases monotonically after it opens at 98 MPa
- Grain 732 (slice 2) does not open – can be attributed to PICC and RICC
  - Considering 15k-59k cycles, it has a high degree of accumulated plasticity.
  - At 63k cycles, PICC is reflected in the $\mathrm{FWHM}\eta$ not increasing. Furthermore, the crack surface is very tortuous, enabling RICC.
- Grain 590 (slice 1) opens ~325MPa applied stress:
  - From 15k-59k, the plasticity in the grain increases, which is reflected in an increase of $\mathrm{FWHM}\eta$ and $\mathrm{FWHM}2\theta$. It has the **highest** $\mathrm{FWHM}\eta$ and $\mathrm{FWHM}2\theta$ of all three grains.
  - This high degree of accumulated plasticity in the grain (due to the penetrating crack) is responsible for delayed crack opening.
  - At 63k, the $\mathrm{FWHM}\eta$ and the $\mathrm{FWHM}2\theta$ increase monotonically after the crack in the grain opens.

Considering the three grains at the crack tip in the three slices

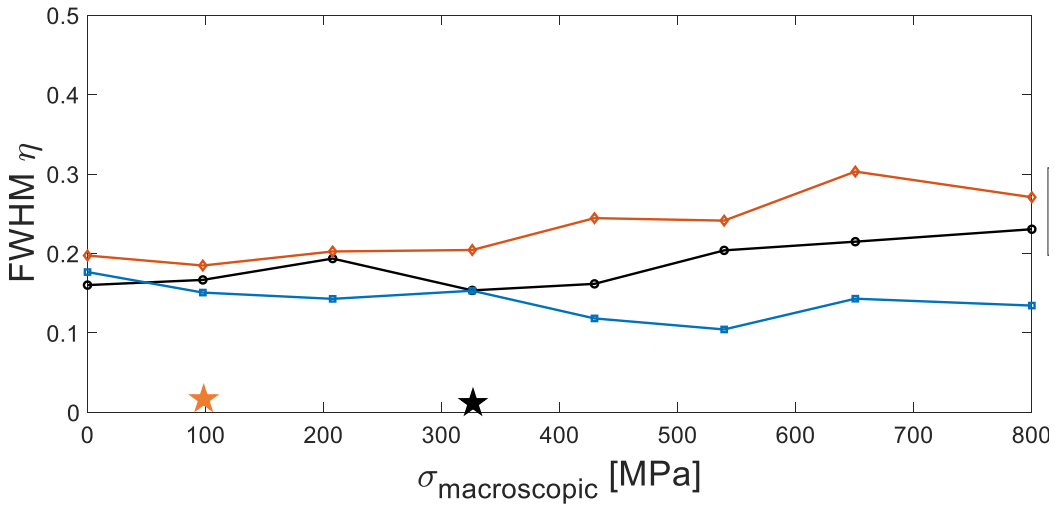




Growing the crack: 15000-59000 cycles



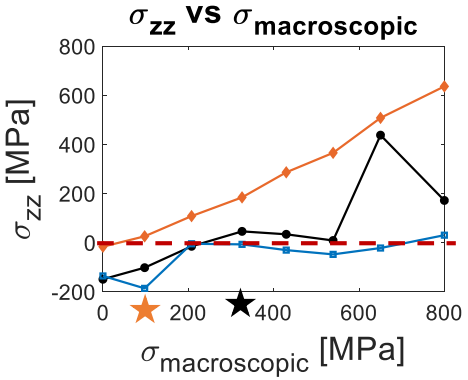
Delayed crack opening experiment at 63000 cycles

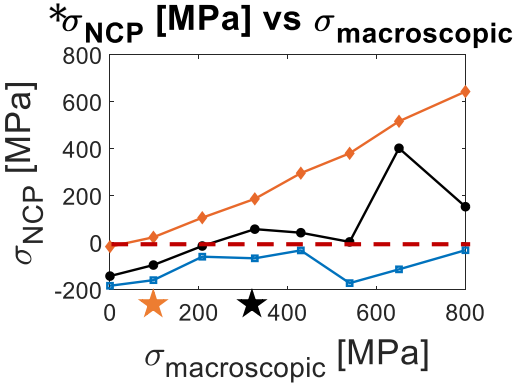


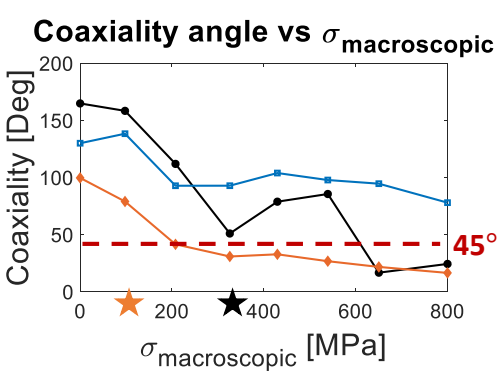
Average FWHM of the spots belonging to the (111) have been plotted

Delayed crack opening experiment at 63000 cycles

There is a direct correlation between crack tip opening and stress reversal from compression to tension at the crack tip







★ Crack opening determined by μ – tomo in the CT grain in slice 1

★ Crack opening determined by μ – tomo in the CT grain in slice 3

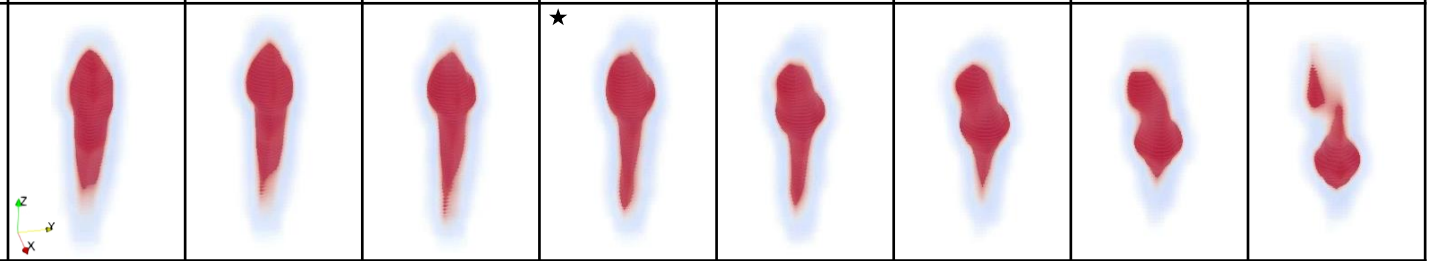
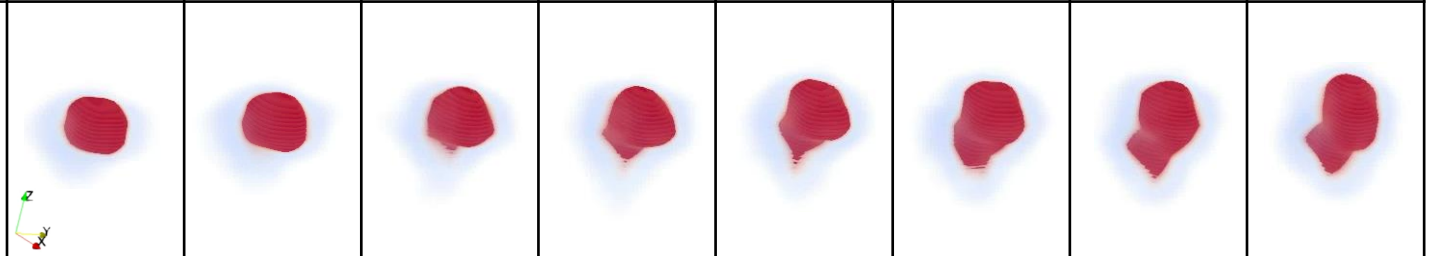
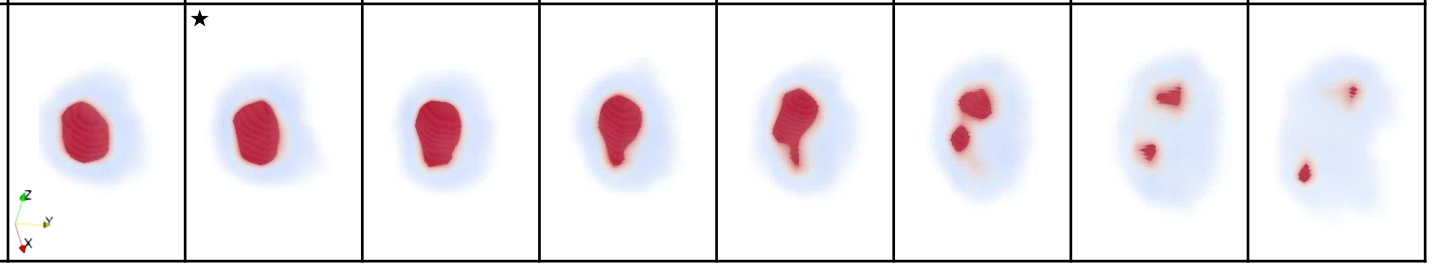
∗ σ_{NCP}=stress normal to the crack plane

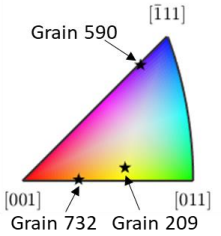
Considering the three grains at the CT in the three slices…

Grain 590
Slice1

Grain 732
Slice2

Grain 209
Slice3

$\sigma_{applied}$	0 MPa	98 MPa	208 MPa	326 MPa	430 MPa	540 MPa	650 MPa	800 MPa
$(\bar{1}11)$				★				
$(00\bar{2})$								
(022)		★						



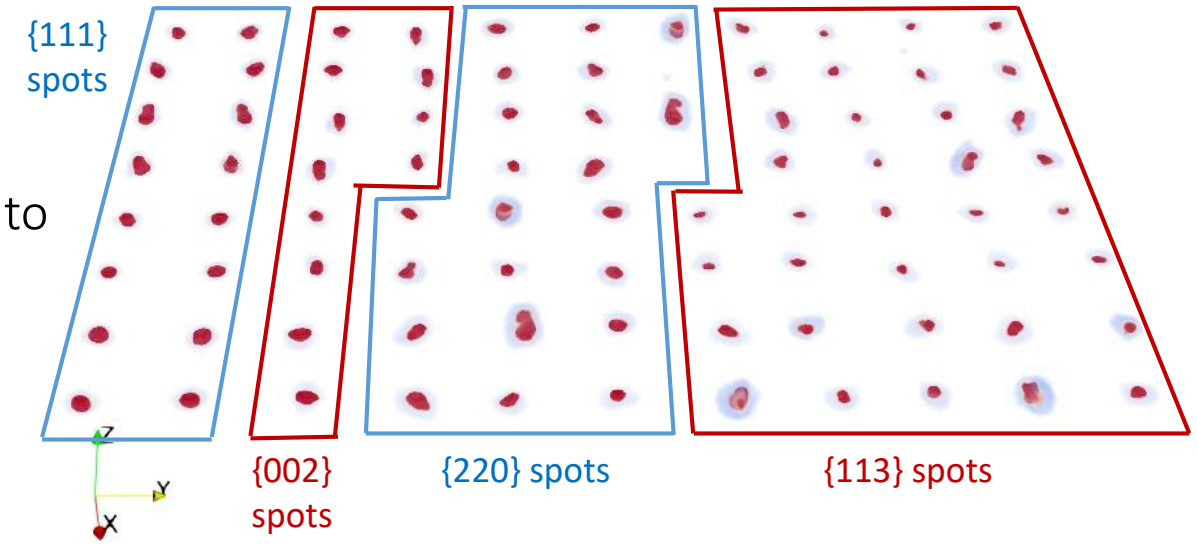
★ Local crack opening determined by µtomo

Note: CT in grain 732 does not open

- The spot from the (hkl) that was best **aligned with the crack plane** was chosen. This spot is the best candidate to capture local crack opening.
  - Spot splitting is unable to capture local CT opening – could be because of grain averaged effects
- At the final load step, the **diffraction spot has split for the grains in which the crack tip opens (slice 1 and slice 3),** whereas the **spot remains intact for the grain in slice 2**.
- Is this validation that the CT in slice 2 does not open?
  To confirm: Investigate all spots at the final step for spot splitting events.

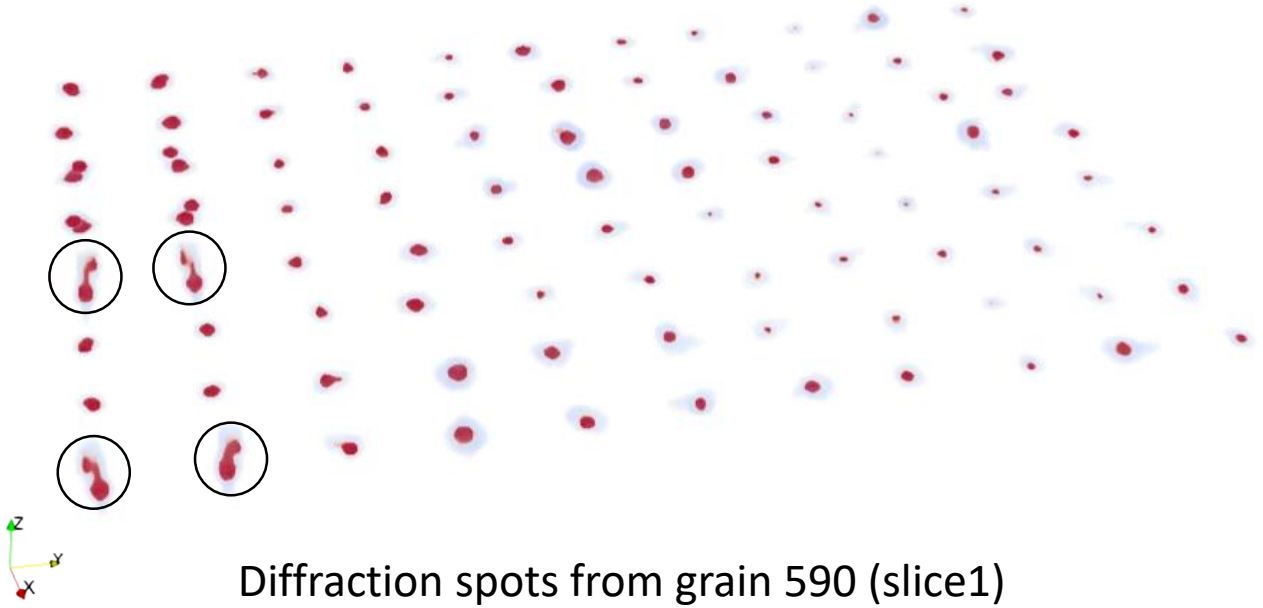
At $\sigma_{applied} = 800$ MPa

Diffraction spots belonging to Grain 732

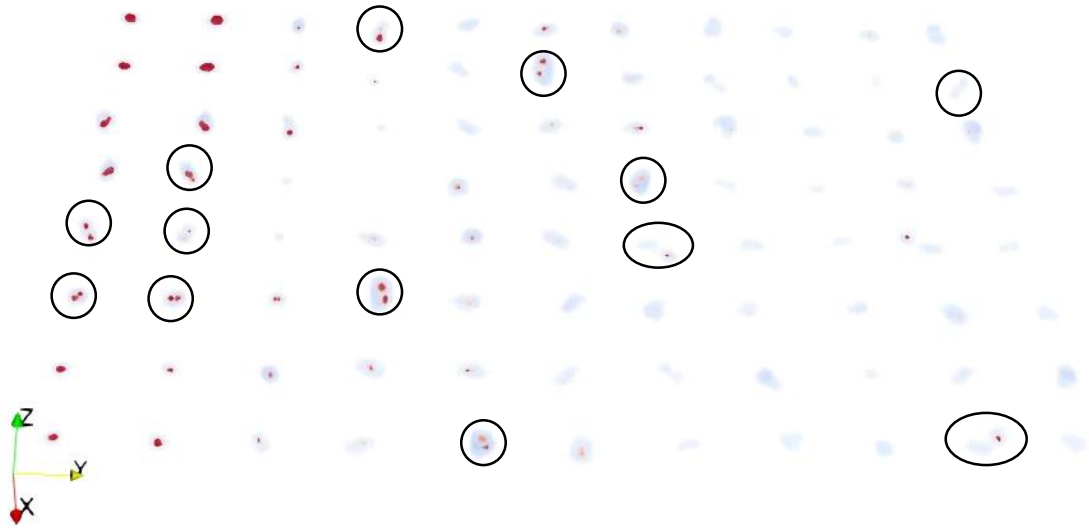


All the **diffraction spots are intact** – no evidence of splitting: confirms µtomo CT analysis results that the **CT in grain 732 does not open**

Comparing this with the diffraction spots from **grains 590 (slice1) and 209 (slice 3)**, we see **clear evidence of spot splitting** (encircled)



Diffraction spots from grain 590 (slice1)



Diffraction spots from grain 209 (slice3)

When does the crack enter each grain?

Why is this important?

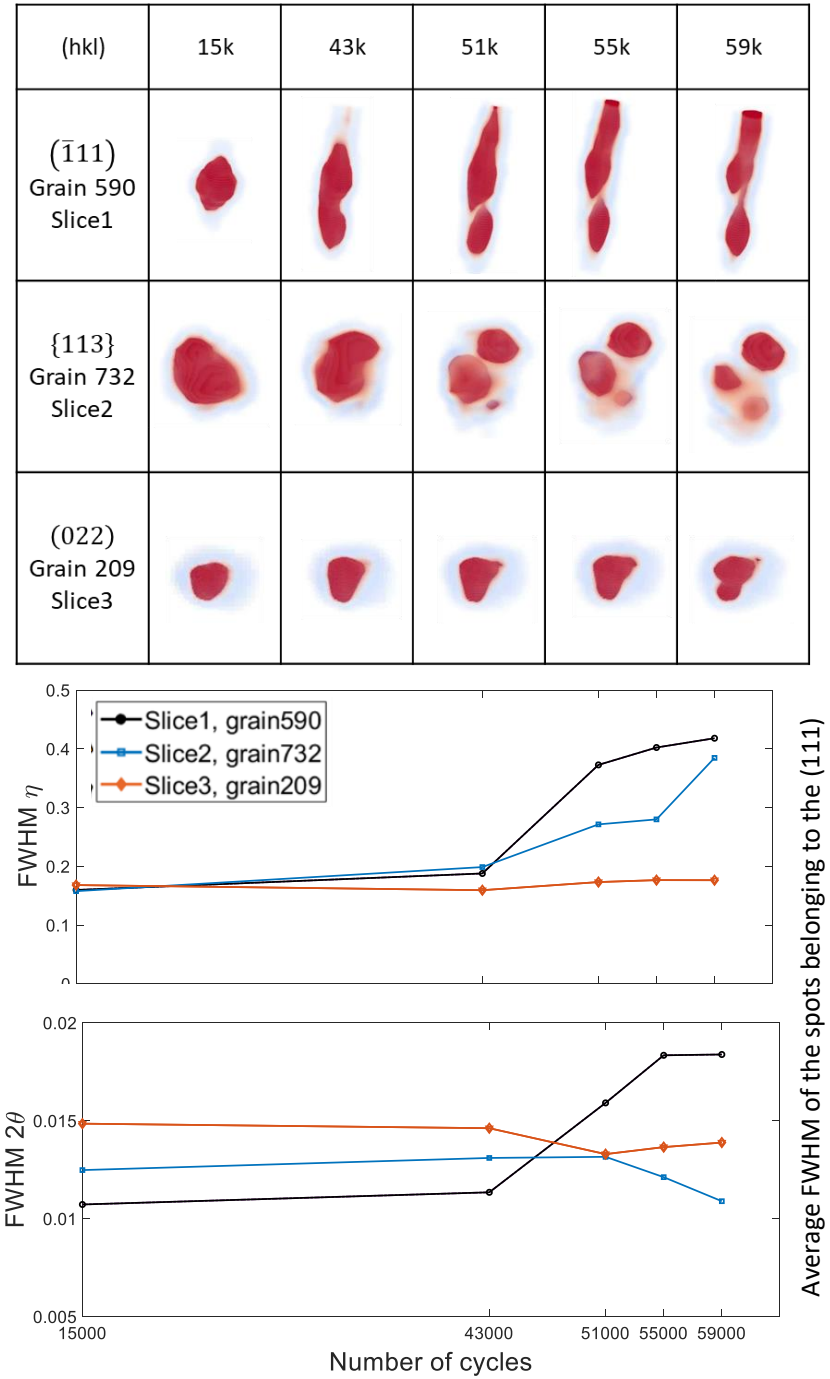
Hypothesis: Earlier grain penetration by the crack front could lead to an increase in the amount of accumulated damage in the grain at the crack tip, therefore increasing the propensity of PICC, which will in turn lead to a further delay in crack opening.

- In grain 590, there is evidence that the crack front has approached the grain at 43k-51k cycles.
- Similarly, in grain 732, there is evidence that the crack front has approached the grain at 43k-51k cycles.
- In grain 209, the crack front approaches the grain approximately after 59k cycles.

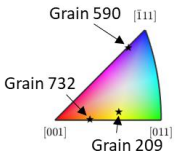
<u>Conclusion 1:</u> At 63k cycles, grain 209 should open first, since the magnitude of PICC in the grain will be lesser compared to the other two grains. This concurs with the experimental evidence.

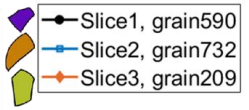
- In grain 732, there are some spots which **split into 3** – could be due to greater amount of damage/plasticity induced due to the crack plane being very tortuous in the grain (evidenced in tomography images)

<u>Possible conclusion 2:</u> This could serve as further proof that at 63k, the crack tip in grain 732 remains shut due to PICC and RICC



Correlations between FWHM and σ_{ZZ}

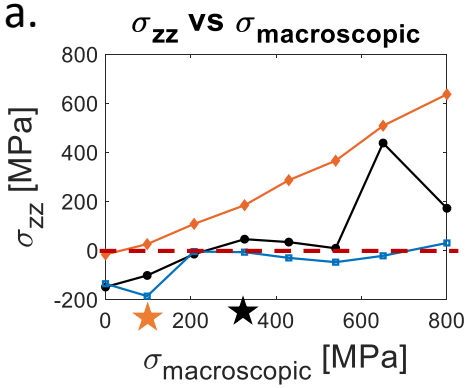




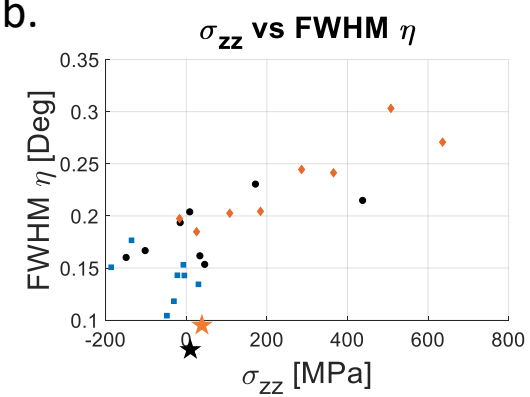
★ Crack opening determined by μ – tomo in the CT grain in slice 1

★ Crack opening determined by μ – tomo in the CT grain in slice 3

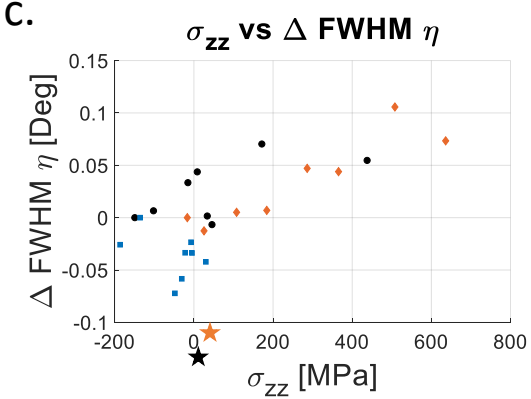
a.



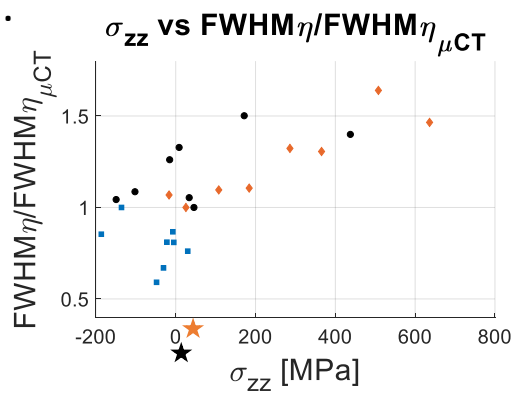
b.



c.



d.



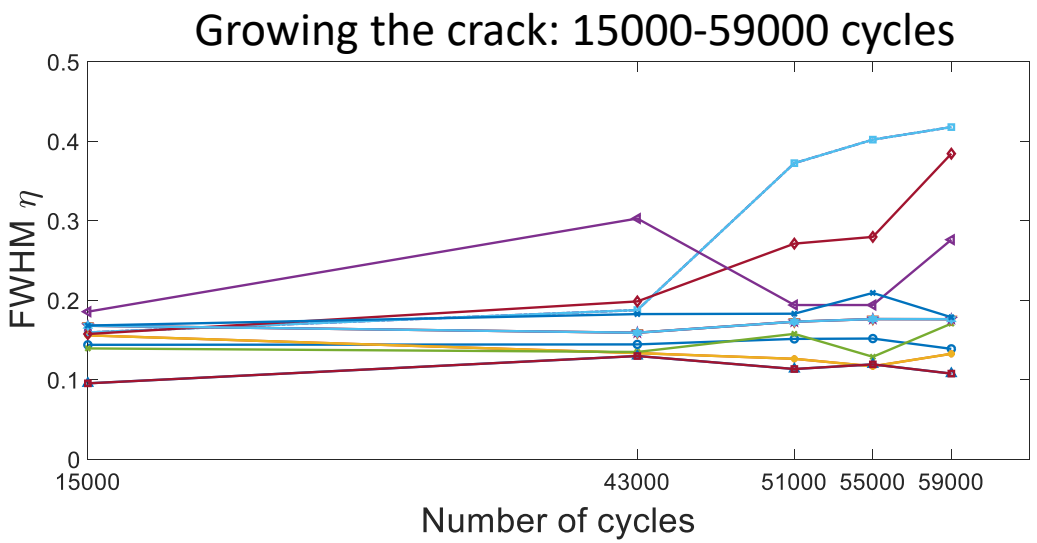
a. There is a direct correlation between crack tip opening and stress reversal from compression to tension at the crack tip

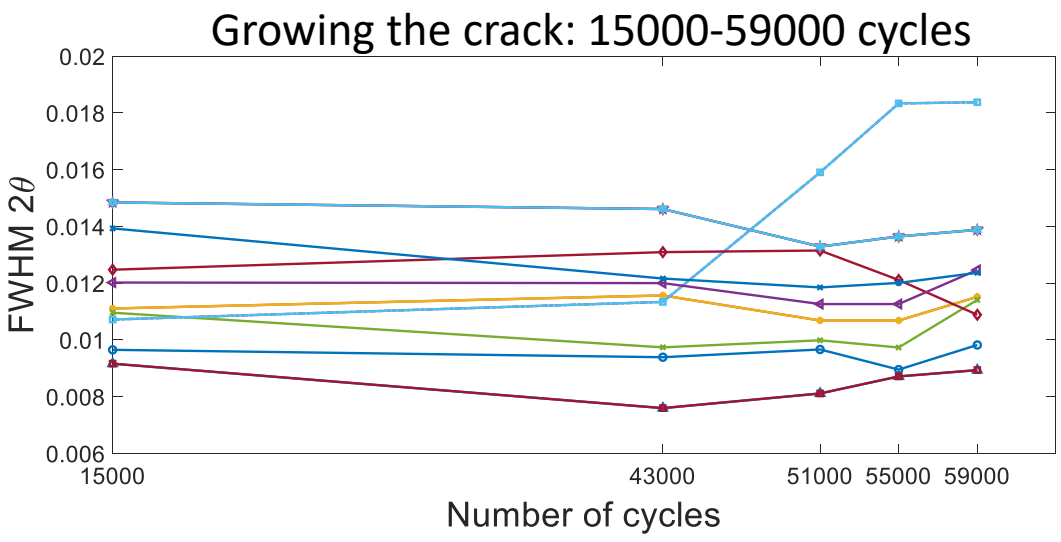
b. There is a strong positive correlation between FWHMη and σ_{ZZ} - this is expected, since loading will cause the CT to open in the grain, thus causing an increase in the intragranular misorientation.
   - There is no correlation between the two metrics in grain 732

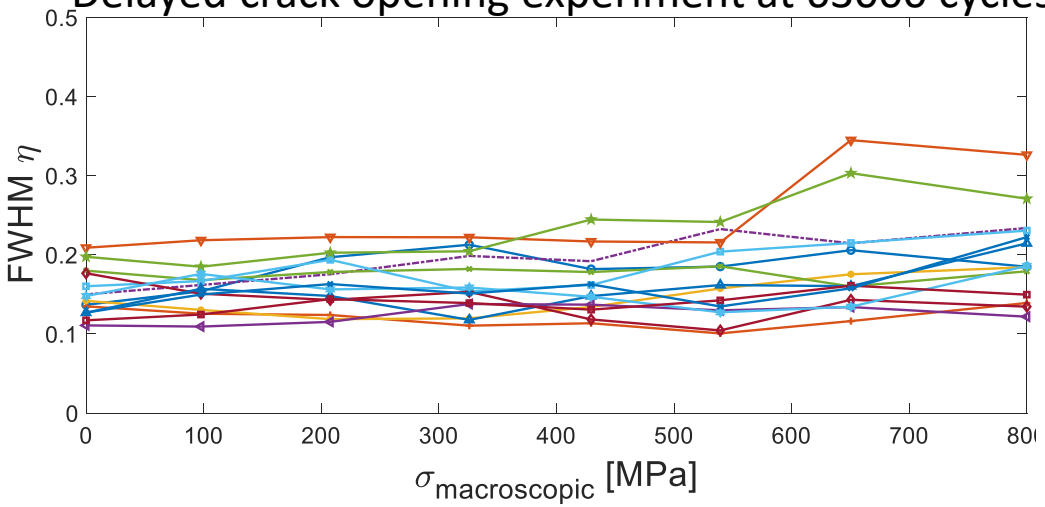
c. There is a positive correlation between ΔFWHMη and σ_{ZZ}. The crack opens when $\sigma_{ZZ} > 0$ and when $\Delta FWHM\eta > 0$ (approximately)

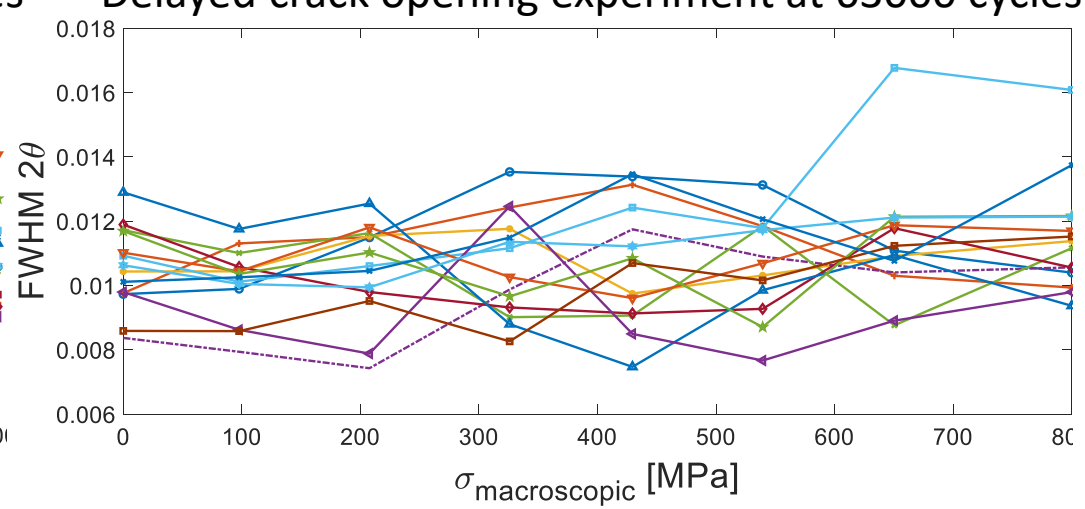
d. This plot shows $FWHM\eta$ normalized by the value of $FWHM\eta$ when the crack opens (determined by μtomo). The crack opens when $\sigma_{ZZ} > 0$ and when $FWHM\eta/FWHM\eta_{\mu CT} > 1$.

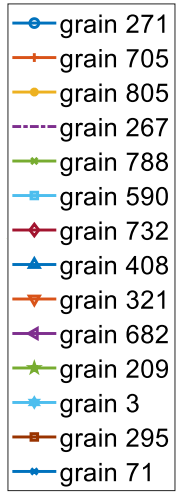
All the grains at the crack-front





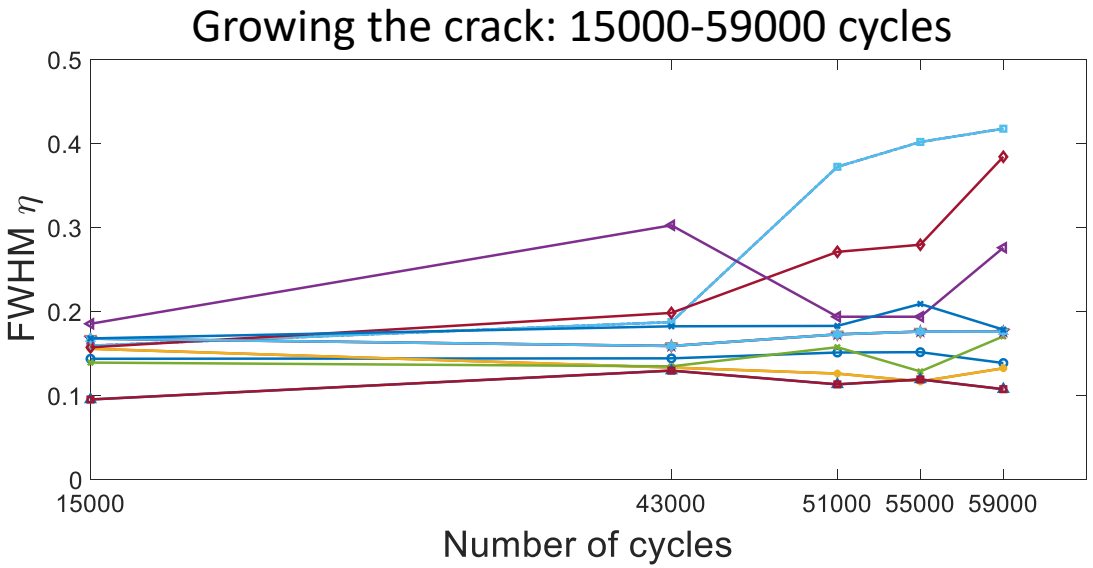


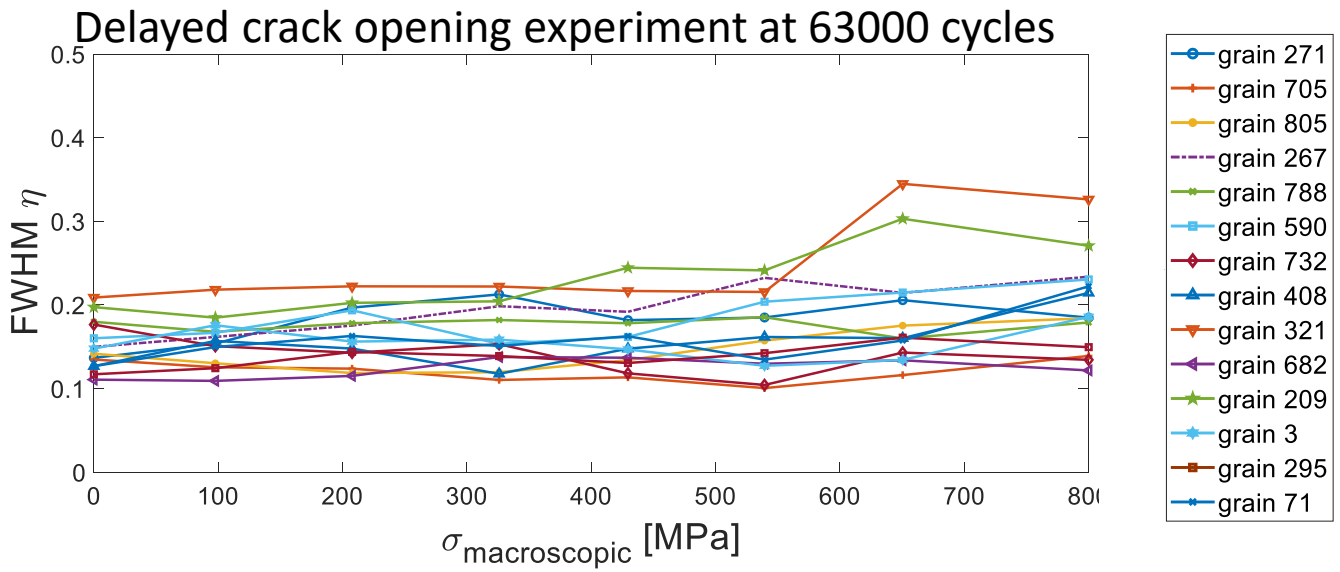




Average FWHM of the spots belonging to the (111) have been plotted

All the grains at the crack-front

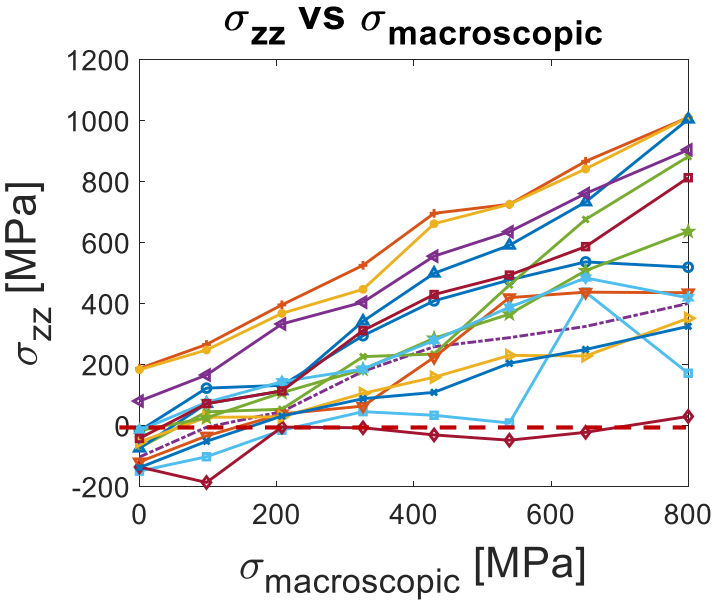


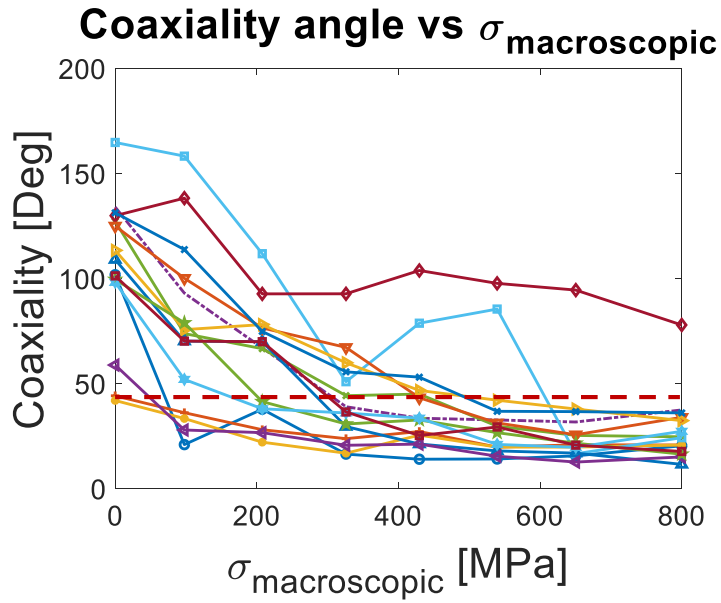


Average FWHM of the spots belonging to the (111) have been plotted

Delayed crack opening experiment at 63000 cycles

- The opening of a crack is spatio-temporally heterogeneous due to a non-uniform stress distribution, as a consequence of PICC, at the crack-front. The effect of plasticity on delayed crack opening has been captured.
- Looking at the evolution of FWHMη:
  - Low accumulated plasticity quantified by FWHM: in grains 705, 805, 271, 295, 408,788,209 – the stress reversal from compression to tension is very early in the loading cycle
  - High accumulated plasticity quantified by FWHM: in grains 732, 590 – the stress reversal is much later in the loading cycles



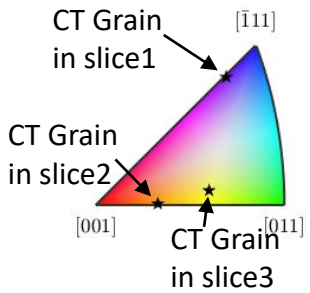


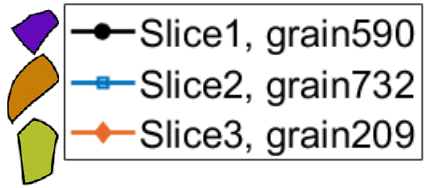
Priya Ravi

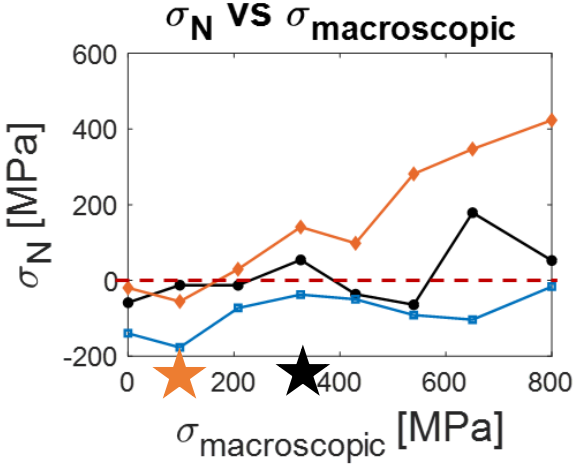
Appendix – Considering the three grains at the crack tip in the three slices

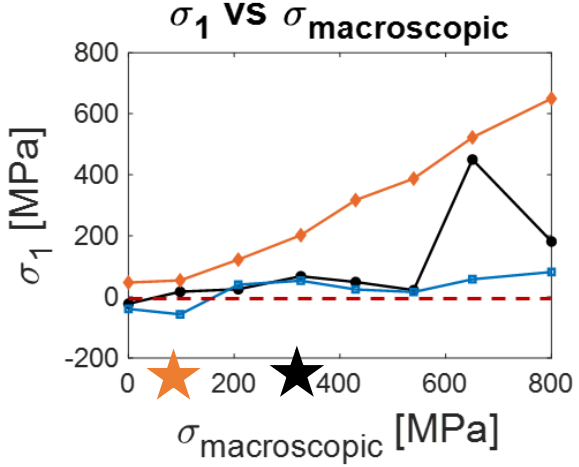
Key:
σ_N= Stress normal to critical slip plane
σ_1= maximum principal stress
σ_{NCP}=stress normal to the crack plane

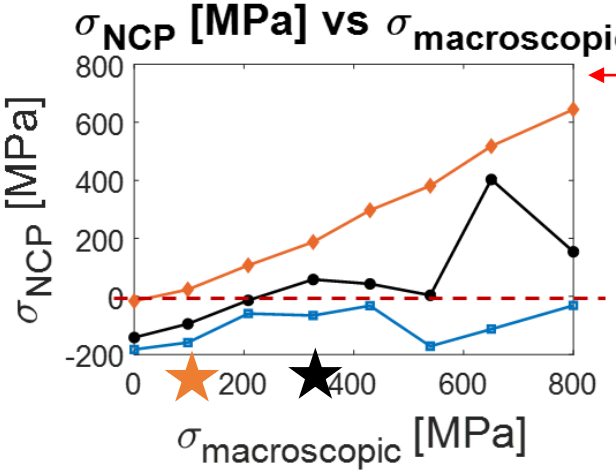
ϕ= angle between crack plane and σ_N
θ= angle between crack plane and σ_1



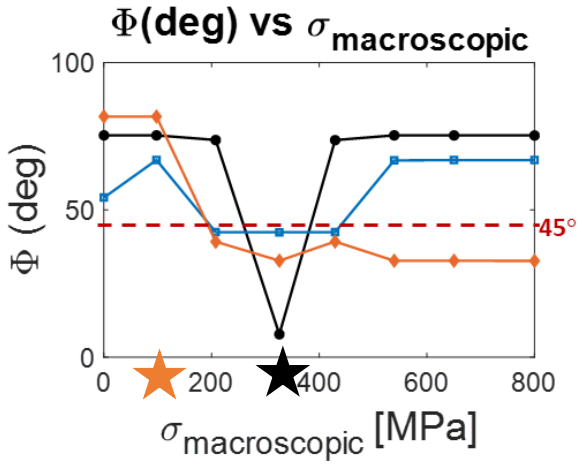


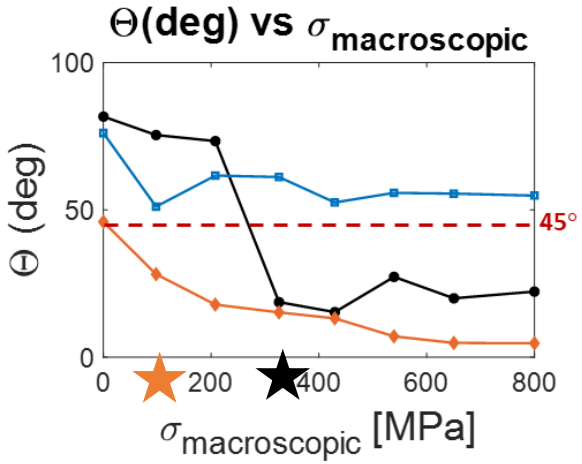


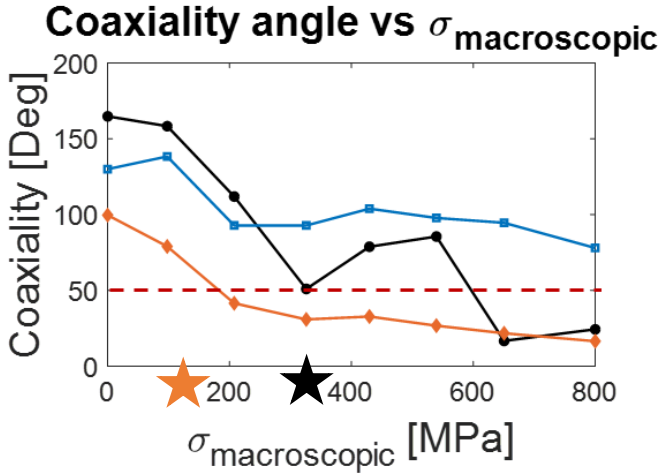




Direct correlation between crack tip opening and stress reversal at the crack tip







★ Crack opening determined by μ – tomo in the CT grain in slice 1

★ Crack opening determined by μ – tomo in the CT grain in slice 3

*Shown previously

Appendix – all the grains at the crack front

Priya Ravi