Rise#5 July 10-12, 2019

RCF damage experienced in Japan and evaluation of RCF deterioration from a material aspect

Motohide Matsui

Frictional Materials, Materials Technology Division
Railway Technical Research Institute
E-mail: matsui.motohide.69@rtri.or.jp

Outline

- Background

  Rail defects in Japan

- Scope

- Application of X-ray analysis to RCF deterioration

  RCF evaluation by X-ray from material aspect

  In-house tests (2-disk tests)

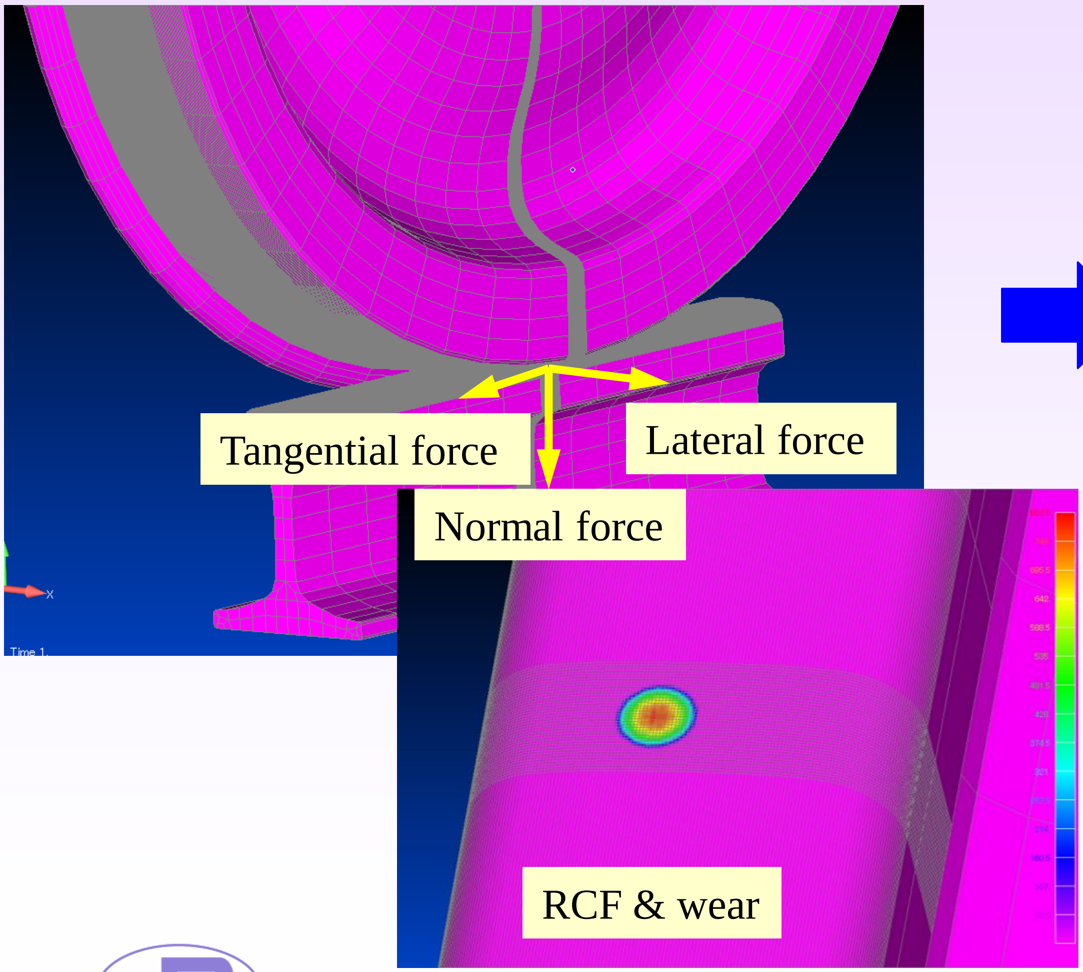
  Analyses of serviced rails

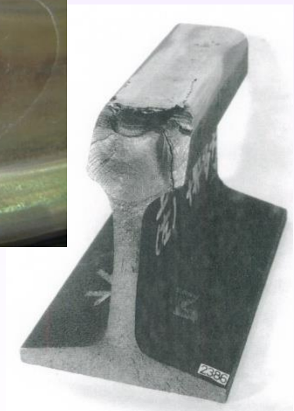
  How to remove RCF layer by rail grinding

- Summary

Background

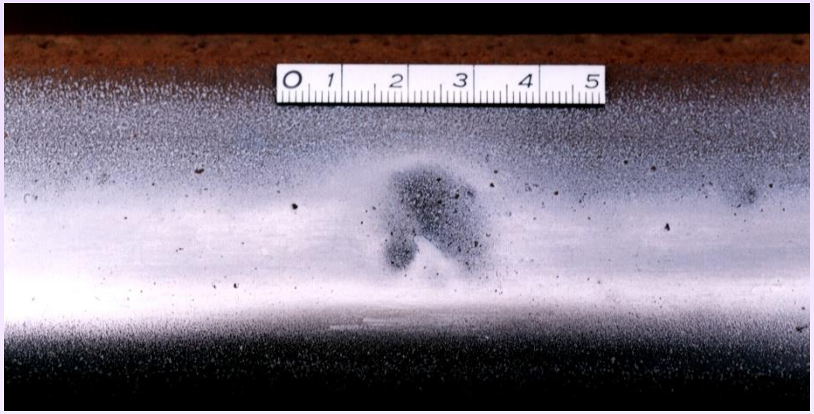
RCF problem between rail and wheel





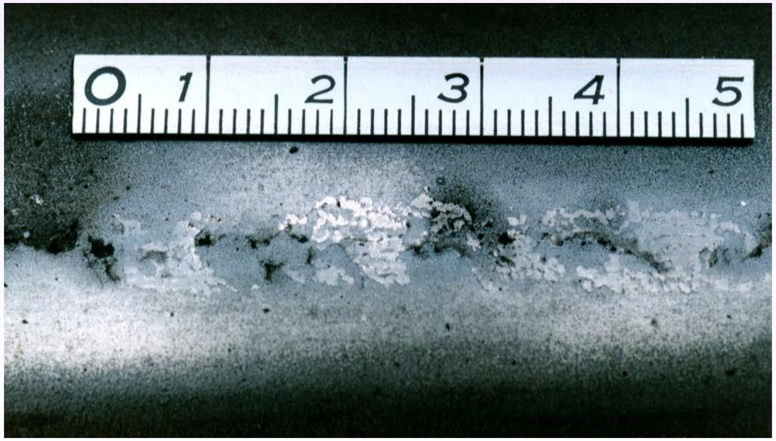
Squats, head checks, wear, corrugation, flaking, etc.

Types of squats



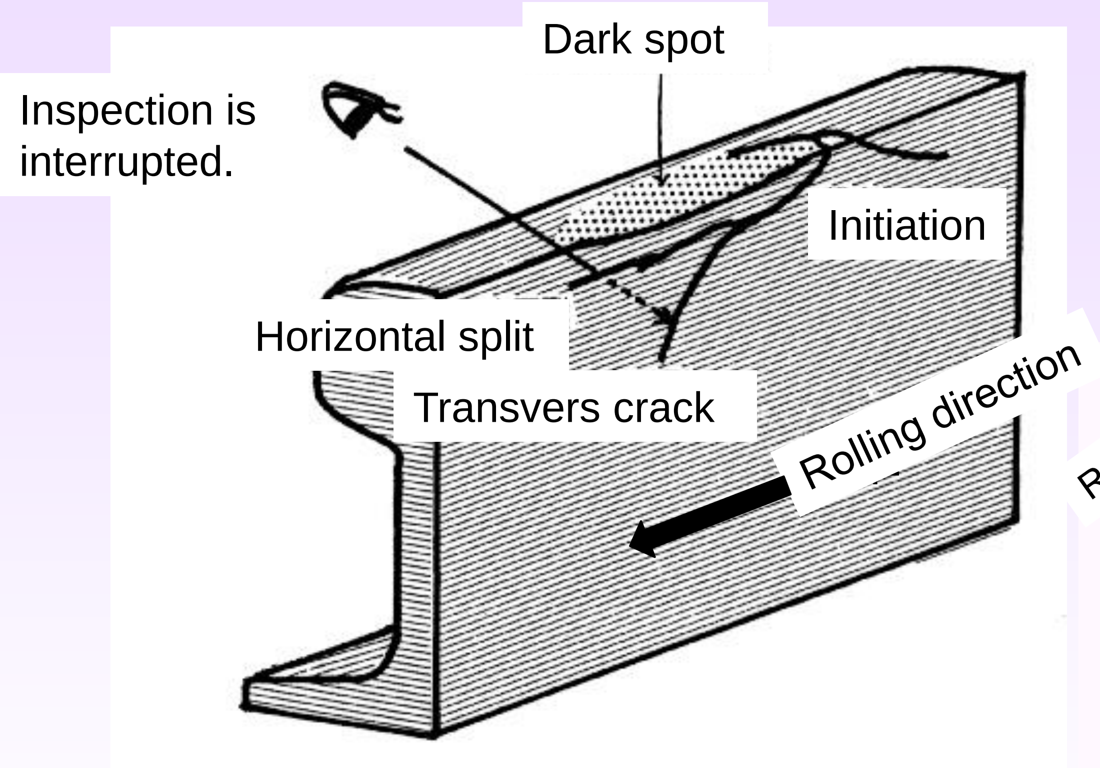
(1) Individual

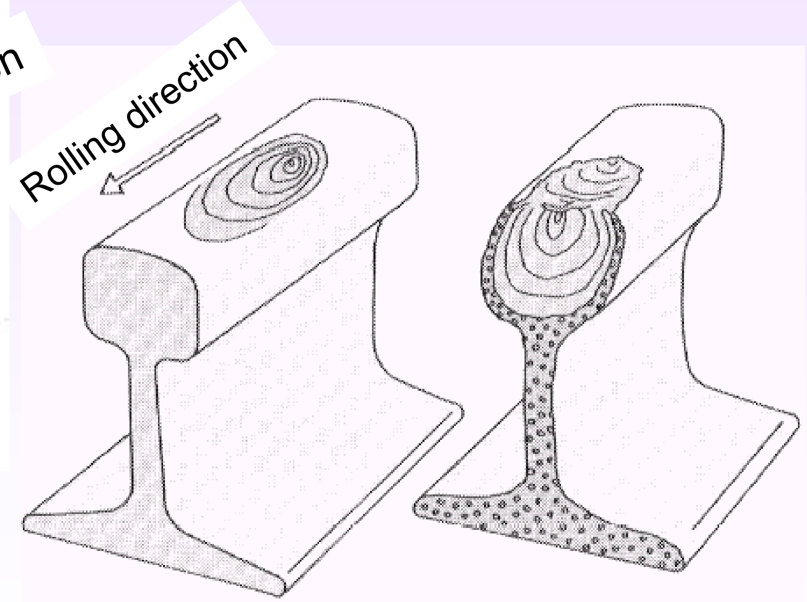
(2) Consecutive



(3) White etching layer (Consecutive)

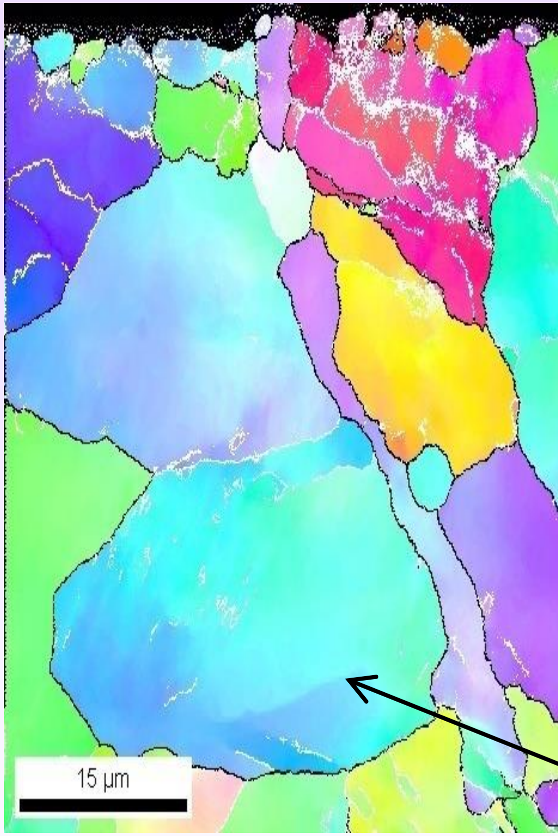
Crack morphology of squat





A transvers crack is branched into downward along rolling direction.

What microscopically goes on with RCF



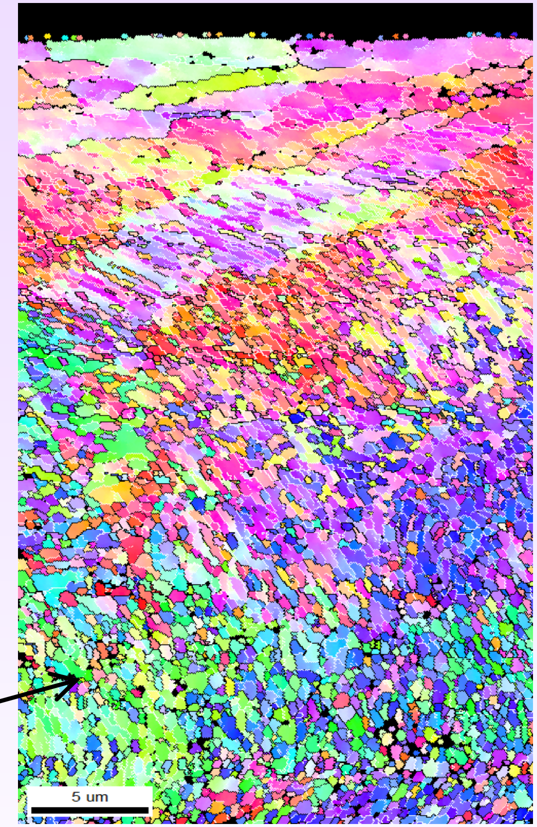
Virgin microstructure

Microstructure evolution of RCF (refinement, plastic flow)

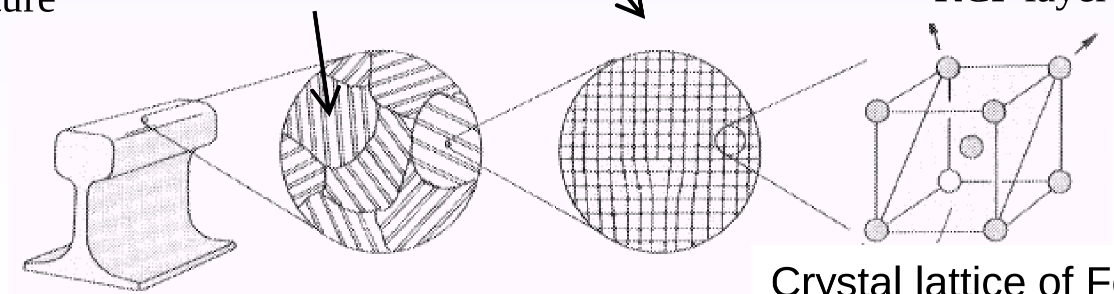
Plastic strain induced

(dislocation induced at the atomic level)

Crystal grain composing of rail



RCF layer



Crystal lattice of Fe

Mitigating action

http://www.speno.ch/

Rail grinding is being operated to remove the RCF layer on a rail.

However it is essential to determine the removal depth and the interval considering the limitation of operation in order to increase the efficiency especially for the unmitigated rails ever.

Scope

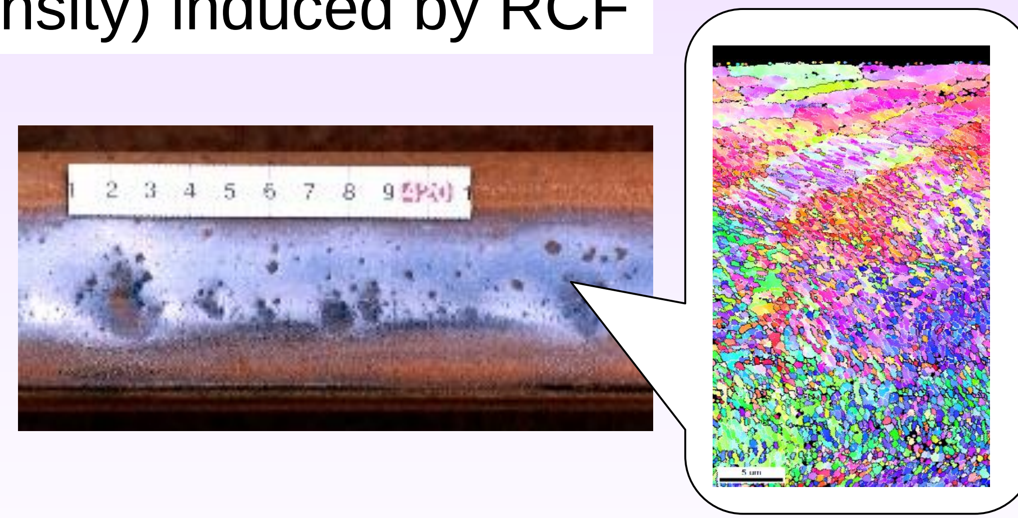
We focus on the RCF damage, especially a squat and a GCC. RCF increases the plastic strain(dislocation density at the atomic level), which provides the microstructure evolution.

Plastic strain (dislocation density) induced by RCF

RCF layer formation

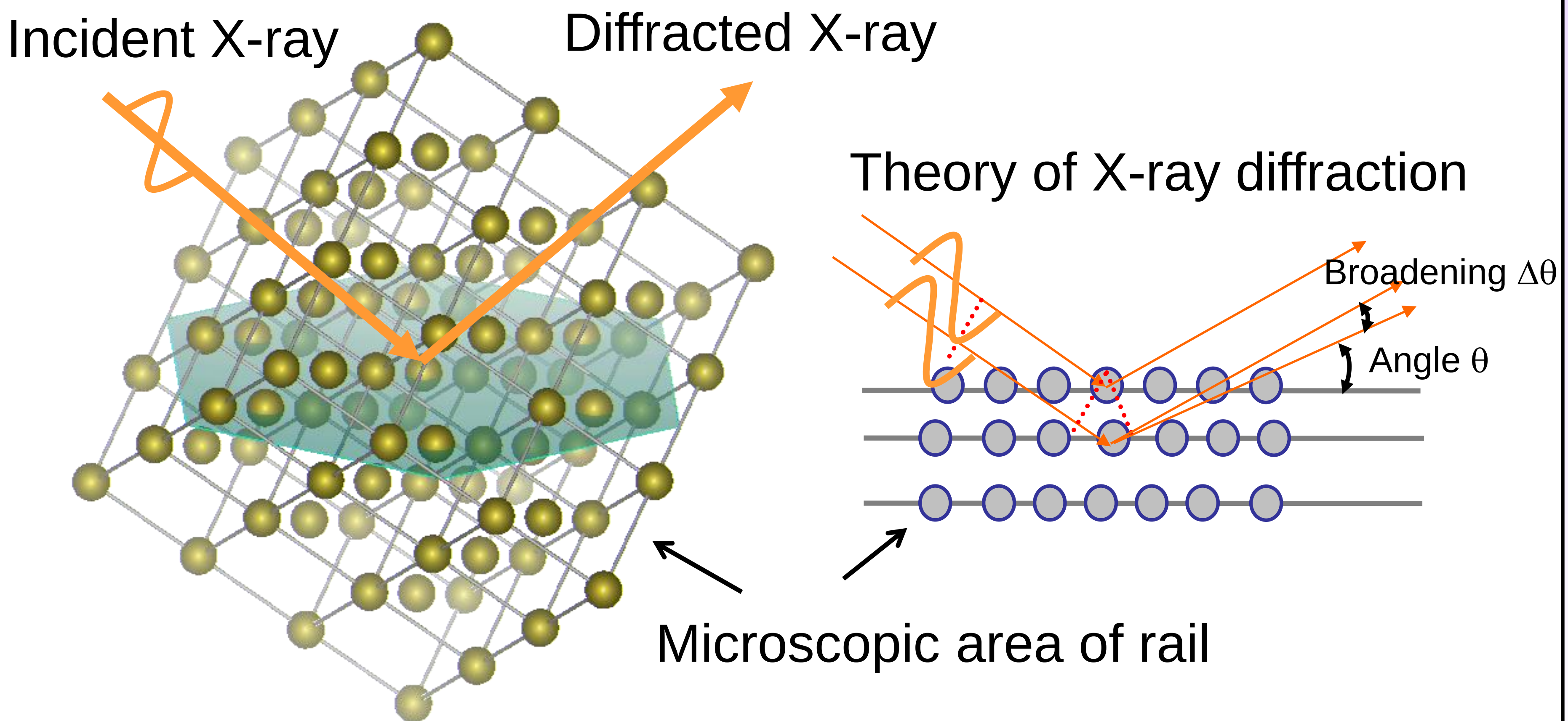
=

Microstructure evolution (refinement, etc.)



By quantifying RCF evolution in the RCF layer with the X-ray analysis, the policy of effective mitigating actions for the unmitigated in-service rails is determined.

What is X-ray ?

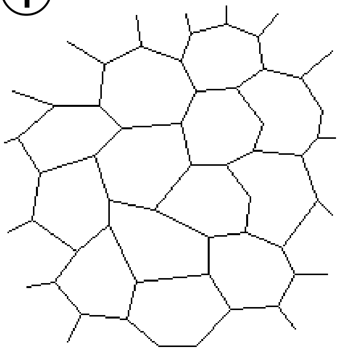


The diffracted X-ray includes the information of microscopic area evolution with the X-ray peak broadened.

Effect of RCF on microstructure and X-ray broadening

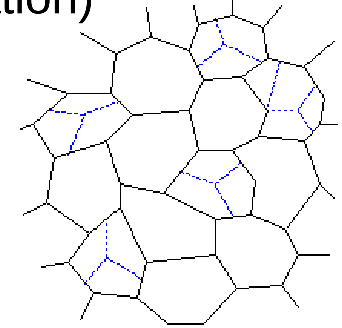
Virgin

①

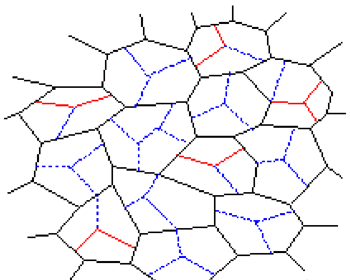


Plastic strain (dislocation) induced

②

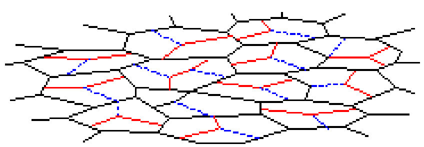


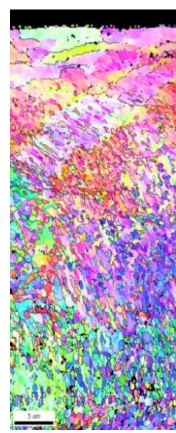
③



Dislocation wall, cell formation

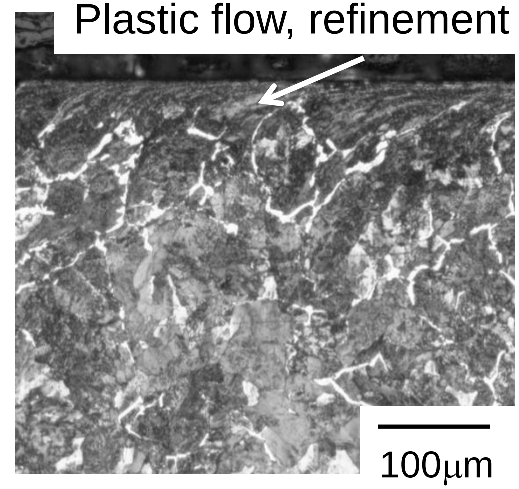
④





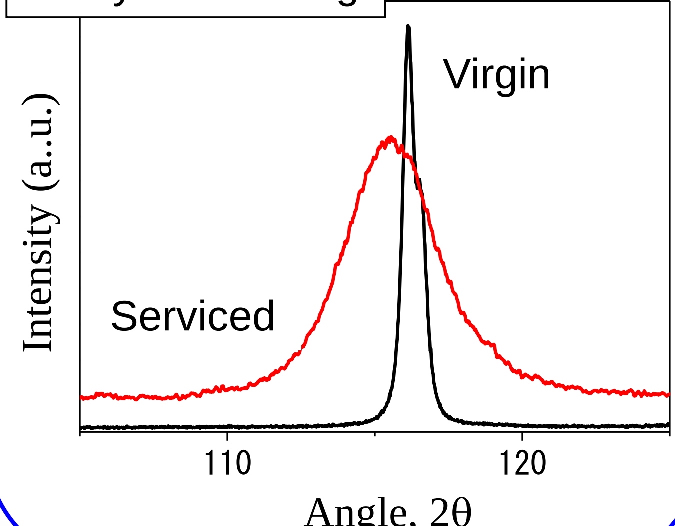
Refinement, plastic flow observed in RCF affected layer

Plastic flow, refinement

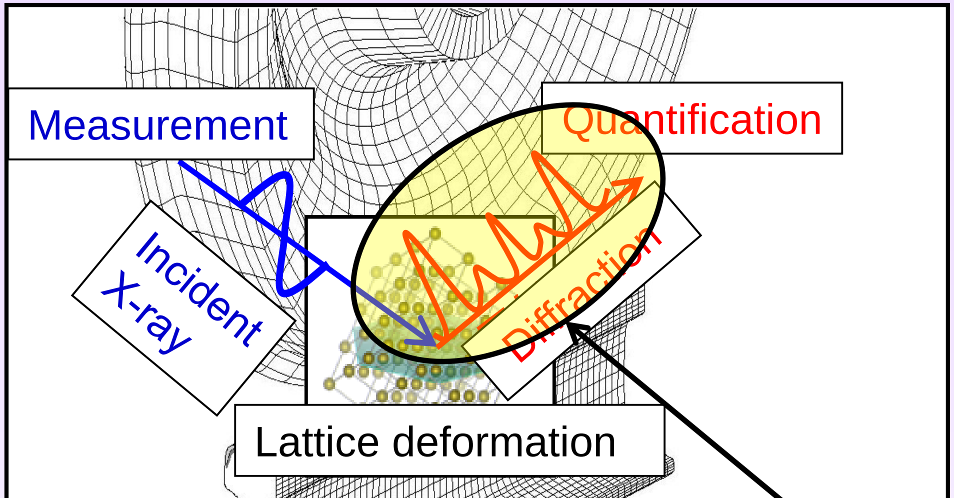


Optical microscope for RCF

X-ray broadening



X-ray measurement condition & X-ray Analysis



Analyze the diffracted peak position, the peak width and the line profile for each diffracted peak obtained.

The diffracted peak information of 110, 200, 211, 220, 310 and 222 crystal planes are employed.

*Measuring condition :
- Equipment : RINT2500,
- Incident X-ray : Cu Ka
- Standard sample : LaB_6

① Williamson-Hall equation

$$\beta \frac{\cos\theta}{\lambda} = 2\eta \frac{\sin\theta}{\lambda} + \frac{1}{\varepsilon}$$

ε: initial crystallite size
η: non-uniform distortion
λ: wave length of X-ray

② Modified Williamson-Hall equation

$$\Delta K = \alpha' + \beta K \bar{C}^{1/2} + O(K^2 \bar{C})$$

$$\alpha' = \frac{1}{\varepsilon'}$$

$$\bar{C} = \bar{C}_{h00}(1 - qH^2)$$

$$K = \frac{2\sin\theta}{\lambda}$$

q, β, O: constant

$$\frac{\Delta K^2 - \alpha^2}{K^2} \cong \beta^2 \bar{C}_{h00}(1 - qH^2)$$

③ Modified Warrren-Averbach equation

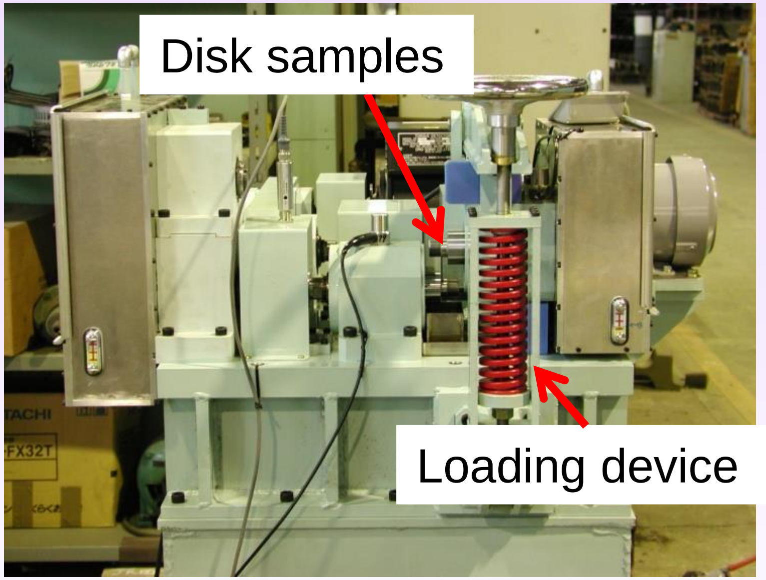
$$\ln A(L) = \gamma - X(L)(K^2 \bar{C}) + P(K^2 \bar{C})^2$$

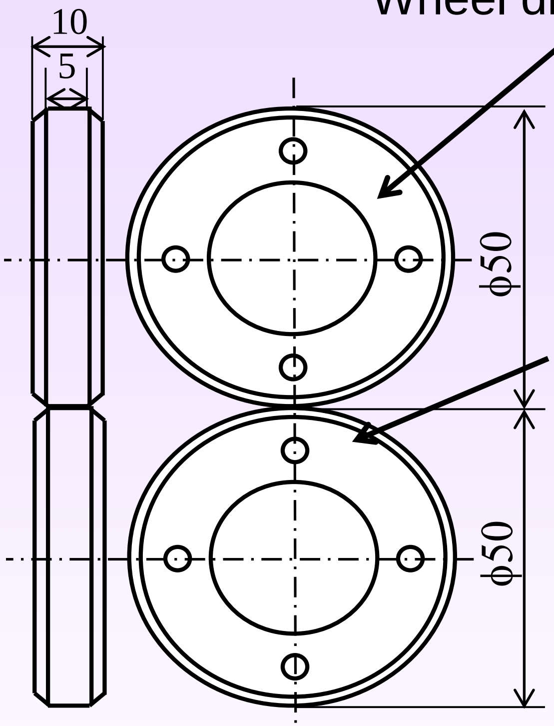
$$X(L) = \frac{\pi b^2 L^2}{2} \rho \ln\left(\frac{R_e}{L}\right)$$

$A(L)$: Fourier coefficient
L : Fourier length
Others: constant

Application of X-ray analysis to RCF deterioration - 2-disk RCF tests

2-disk RCF test





2-disk RCF tests were carried out under the test conditions with the different contact pressure, slip ratios and number of cycles.

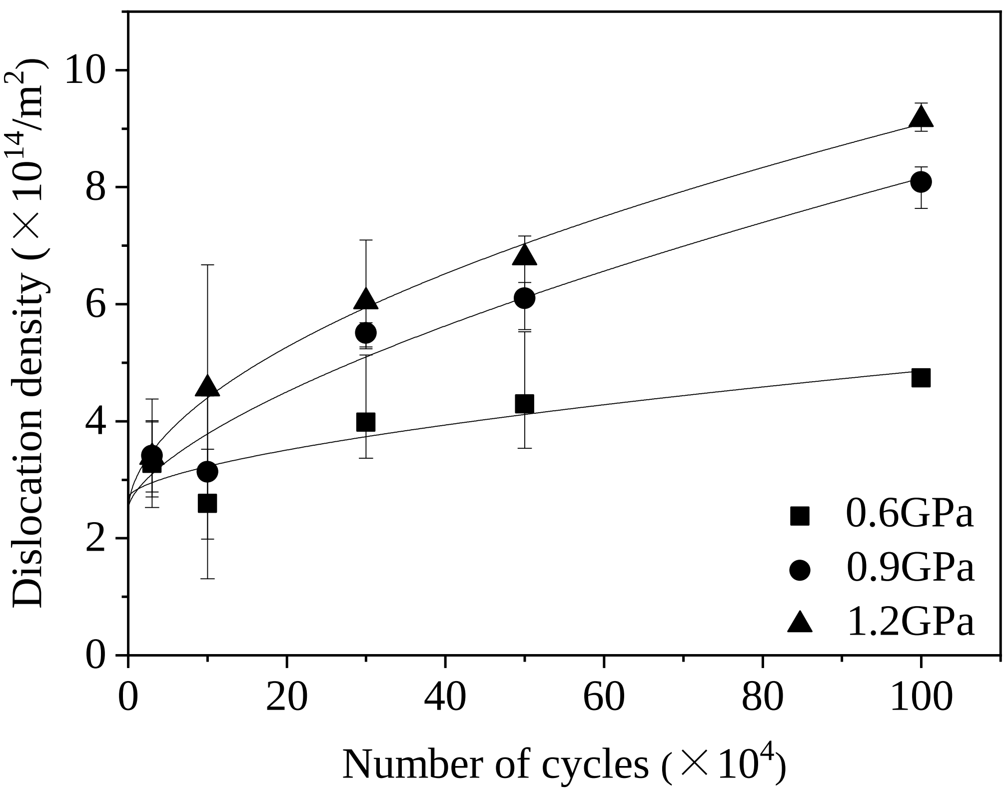
Small samples were cut out of the rail disks for the X-ray measurements.

2-disk RCF test conditions ①

Conditions	Contact pressure (GPa)	Slip ratio(%)	Number of cycles($\times 10^4$)	Speed(rpm) & Atmosphere
①	0.6	0	3, 10, 30, 50, 100	850, Dry
②	0.9	0	3, 10, 30, 50, 100	850, Dry
③	1.2	0	3, 10, 30, 50, 100	850, Dry

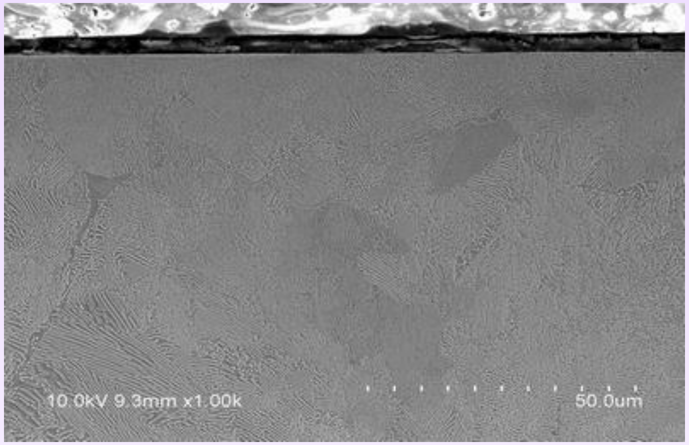
RCF deterioration behavior is quantified by the X-ray analysis in each 2-disk test condition.

RCF deterioration under test conditions ①

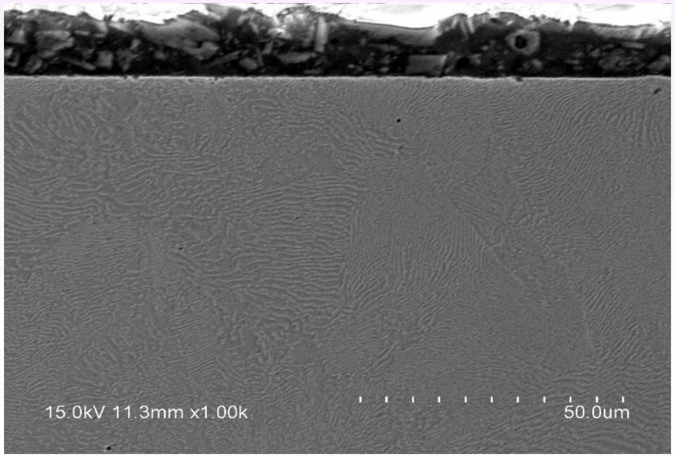


*Average value of 3 X-ray measurements each test condition.

(a) 0.6GPa, 0%, 10^5cycles



(b) 1.2GPa, 0%, 10^6 cycles



RCF deterioration is quantified by the X-ray analysis in each 2-disk test condition.

Small RCF crack initiation is not observed.

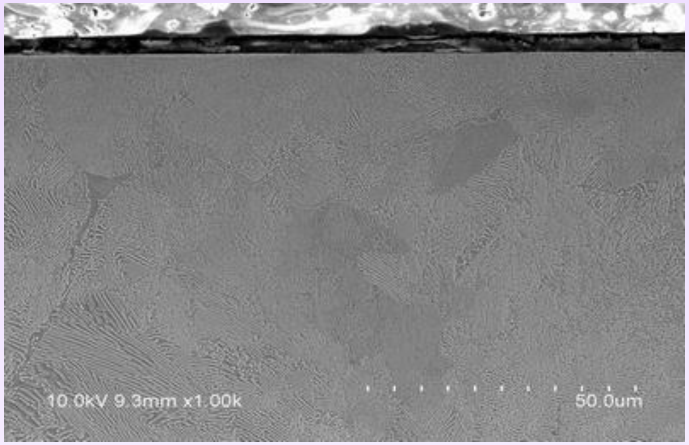
2-disk RCF test conditions ②

Conditions	Contact pressure (GPa)	Slip ratio(%)	Number of cycles(×10^4)	Speed(rpm) & Atmosphere
①	0.6	0	3, 10, 30, 50, 100	850, Dry
②	0.9	0	3, 10, 30, 50, 100	850, Dry
③	1.2	0	3, 10, 30, 50, 100	850, Dry
④	0.6	0.2, 0.6	10	850, Dry
⑤	1.2	0.2	3, 10, 100	850, Dry

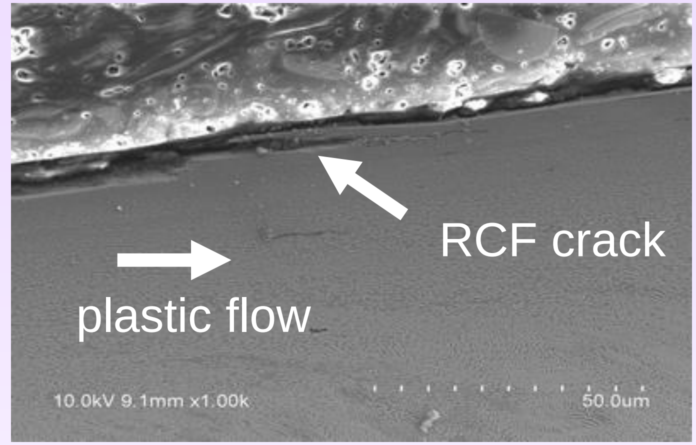
The crack initiation is more dominated by tangential stress. Some tests are carried out with the slip ratio loaded in order to investigate when the small RCF crack is formed.

SEM observation on RCF layers

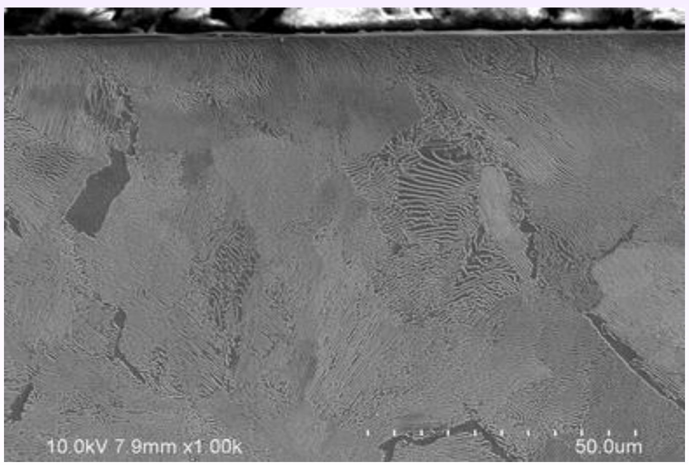
(a) 0.6GPa, 0%, 10^5cycles



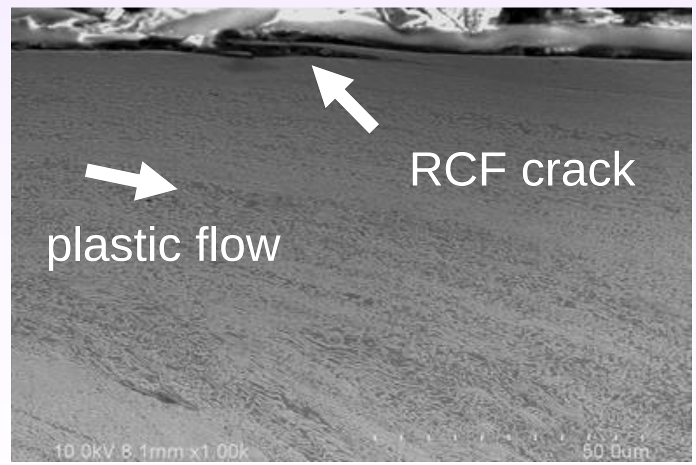
(b) 0.6GPa, 0.2%, 10^5cycles



(c) 1.2GPa, 0%, 3×10^4 cycles

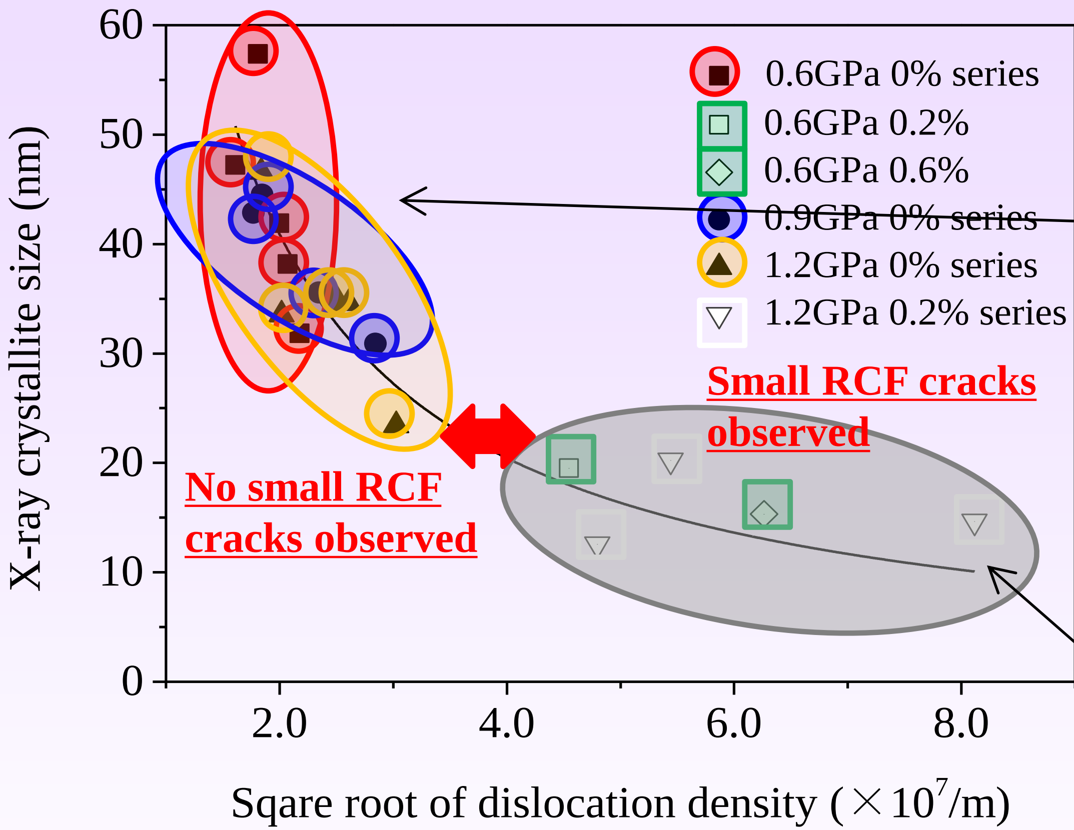


(d) 1.2GPa, 0.2%, 3×10^4cycles



Small RCF cracks were initiated with the formation of plastic flow by loading the slip ratio (tangential stress).

RCF deterioration evaluated by X-ray Analysis



RCF deterioration is progressive with increasing the contact pressure and the number of contact cycles.

Tangential stress is influential on the initiation of small RCF cracks.

（Equivalent stress at the contact surface :

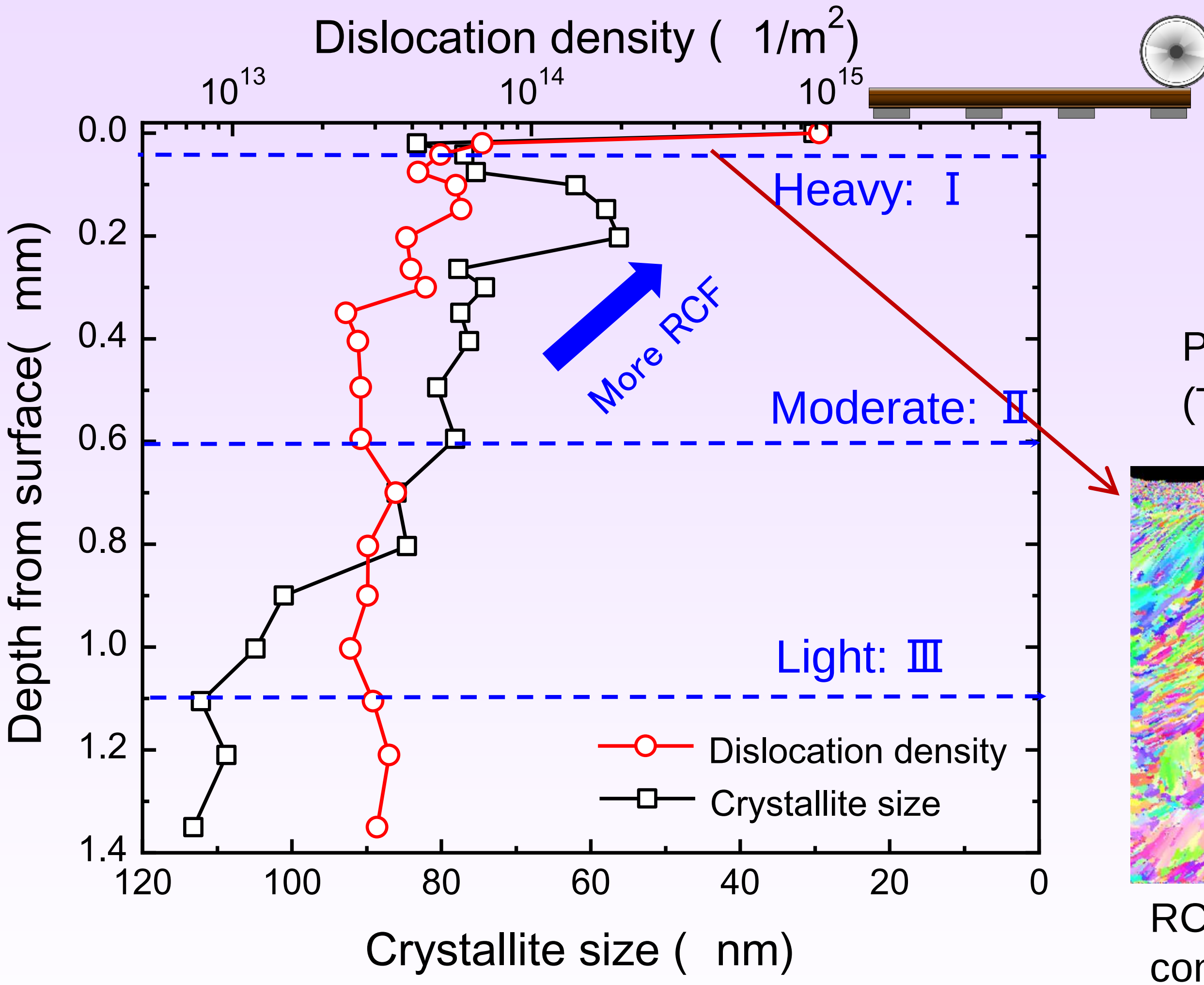
0.6GPa 0.2% ： 358MPa 、0.9GPa 0% ： 360MPa）

*Small RCF crack initiation evaluated at the magnification level of microscope.

*Average value of 3 X-ray measurements each test condition.

Small RCF cracks could be observable in the order of dislocation density of 10^{15} /m^2.

RCF layer formed in unmitigated and serviced rail (450MGT)



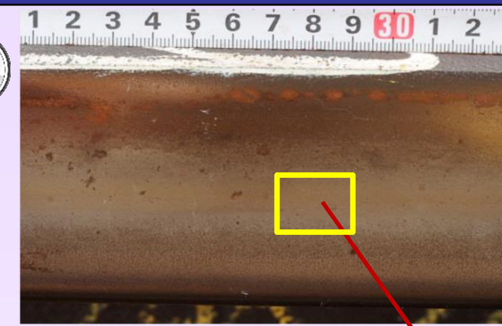
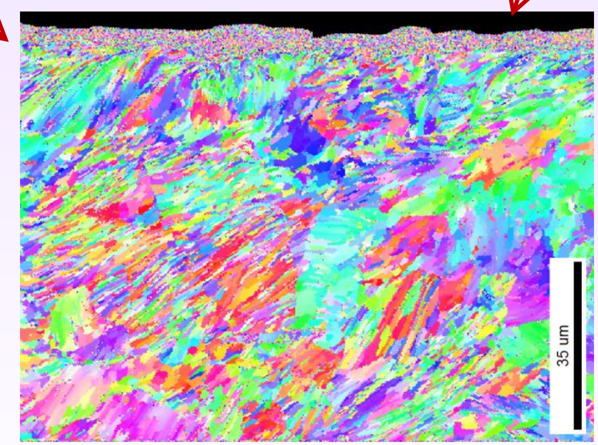


Photo of rail top surface
(Tangent rail)

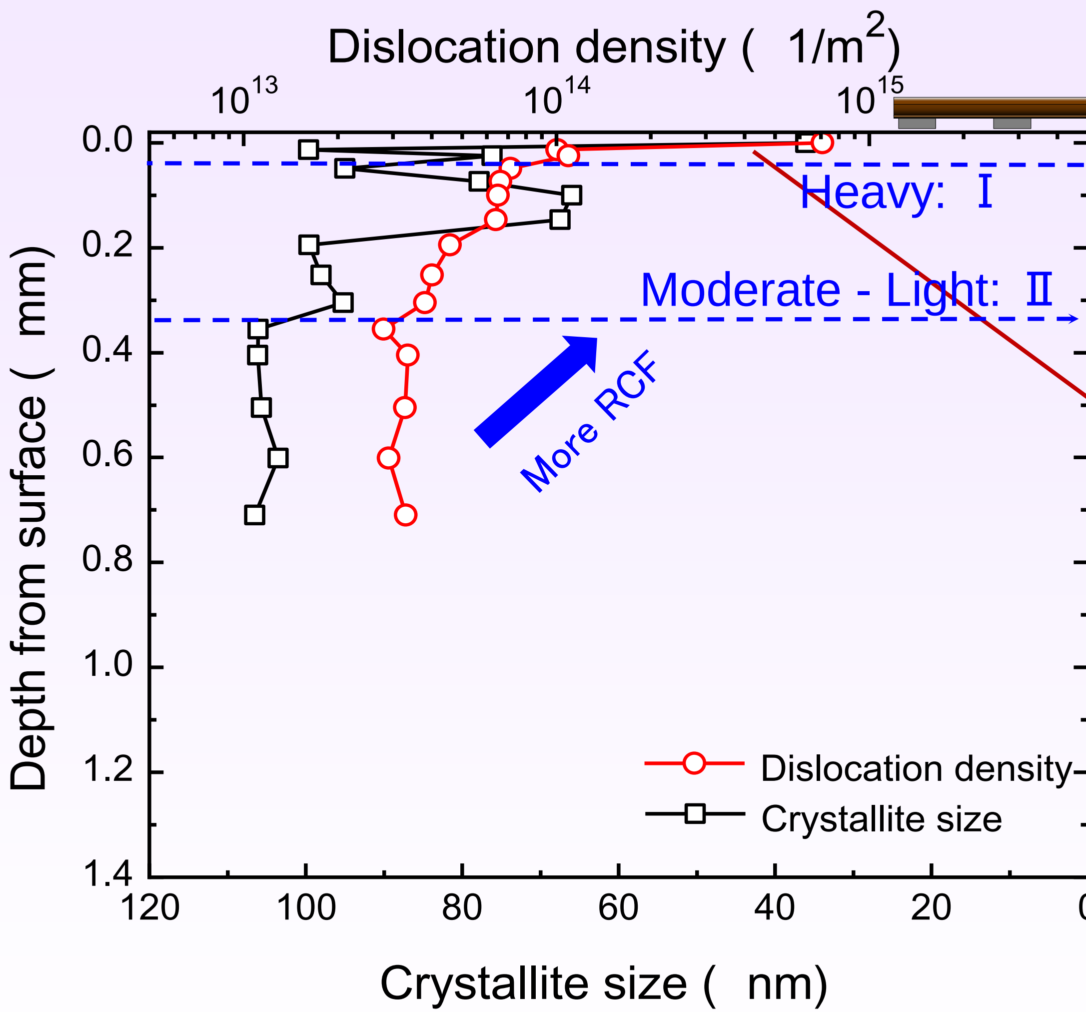
Pickup



RCF layer formed in the contact band

RCF deterioration can be determined by the X-ray analysis.
It is separated into the three regions with the degree of RCF deterioration.

RCF layer formed in unmitigated and serviced rail (50MGT)



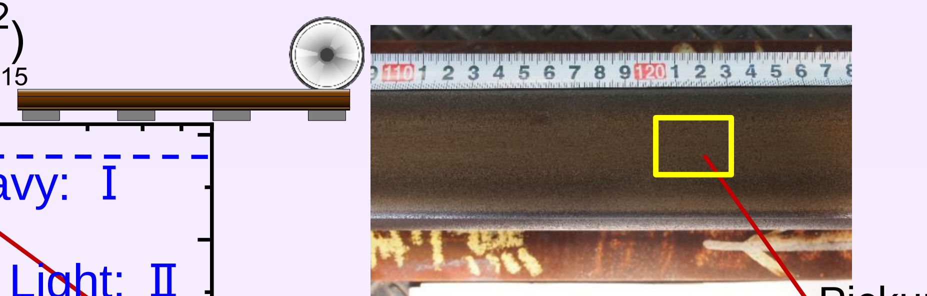
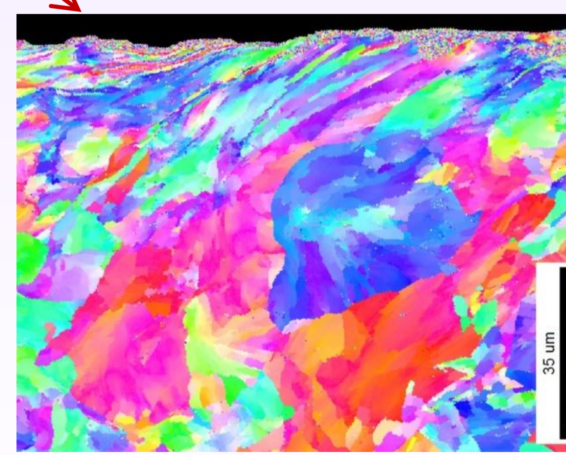


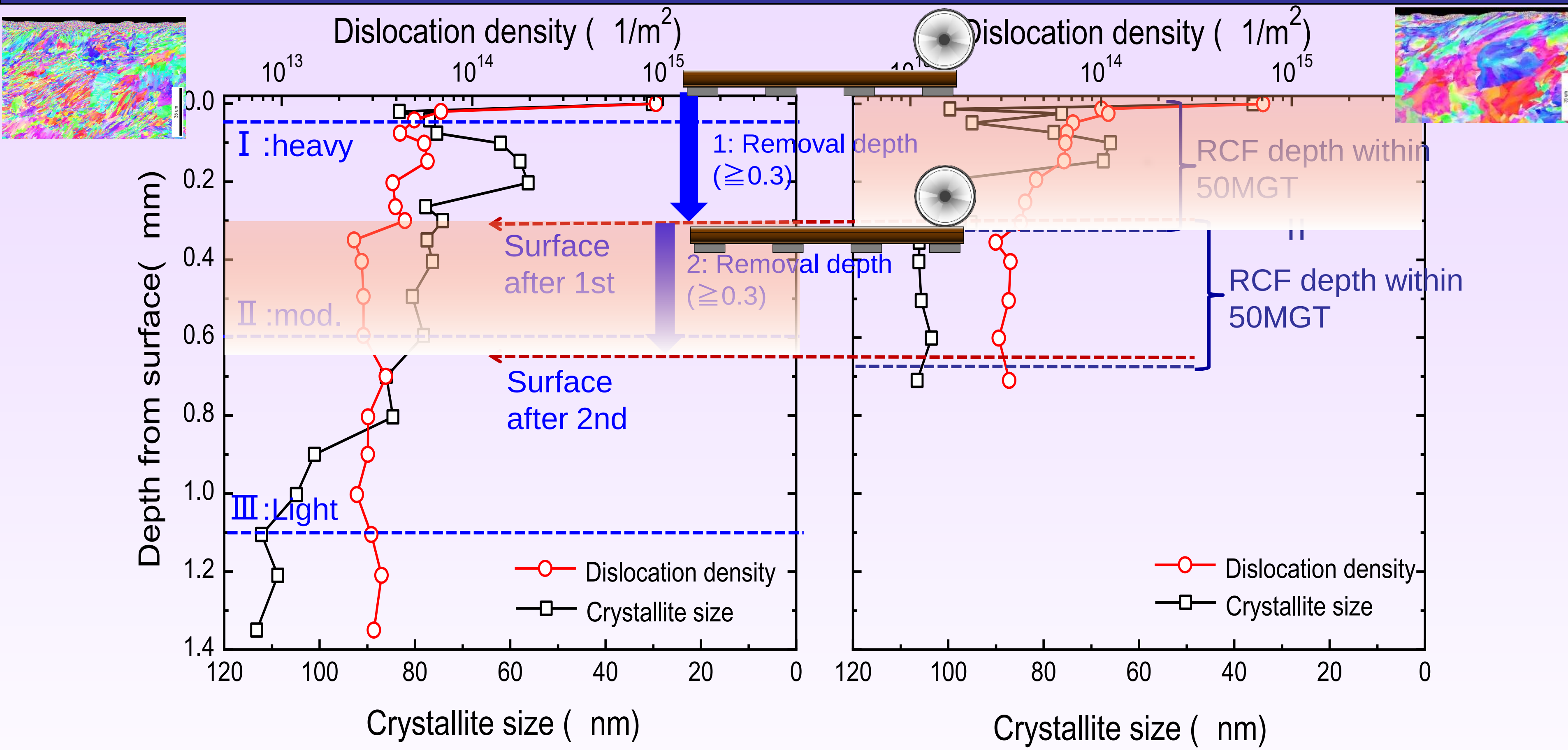
Photo of rail top surface (Tangent rail)



RCF layer formed in the contact band

RCF influential depth is smaller compared with the 450MGT rail.

How to remove RCF layer on the subsequent actions

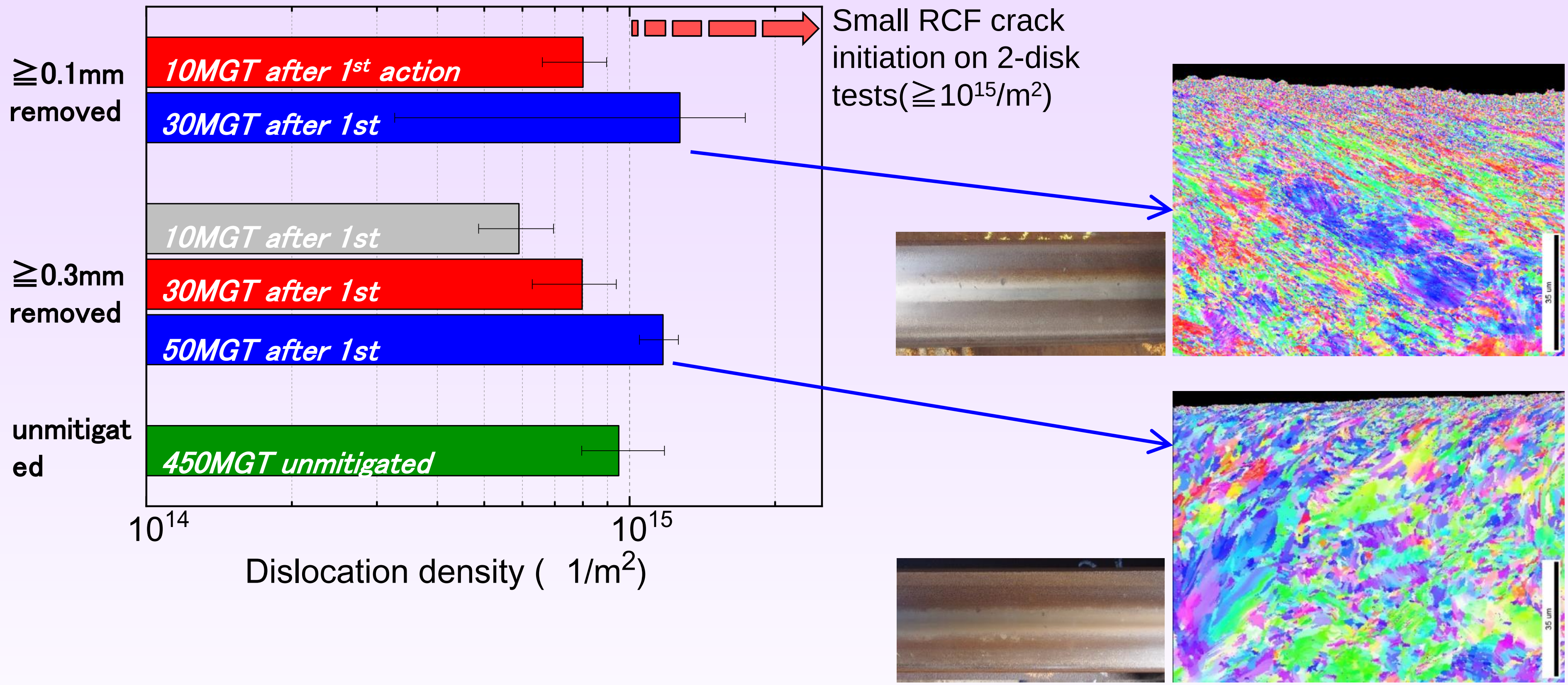


Unmitigated tangent rail (450MGT) Unmitigated tangent rail (50MGT)

The regions Ⅰ and Ⅱ (more influential depth) should be removed on the subsequent actions.

Compared with the variation of X-ray analysis results, how to remove the large RCF layer formed in the unmitigated rail can be decided.

How to remove RCF layer on the subsequent actions



The surface RCF deterioration can determine the interval of actions compared with the results of in-house tests and the unmitigated rail with X-ray analysis.

In this case, if 0.3mm depth on the action is kept, the 2nd action can follow approximately 50MGT after 1st , otherwise the 2nd action should come earlier.

Summary

The rail damage experienced in Japan has been introduced. There are several types rail damages. In particular, we focus on the RCF damage to quantify the degree of RCF deterioration using the X-ray analysis.

X-ray analysis enables to describe the whole depth of RCF affected layer and how deteriorated each depth region is, from a material aspect. Based on the analyses results of serviced rails and in-house tests, X-ray analysis will help you obtain the policy of rail grinding actions for unmitigated in-service rails.

ขอขอบคุณสำหรับความสนใจของคุณ *!*

Thank you for your attention !