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Evaluation of material deterioration of rails subjected to rolling contact fatigue using x-ray diffraction

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Overview

1) Background

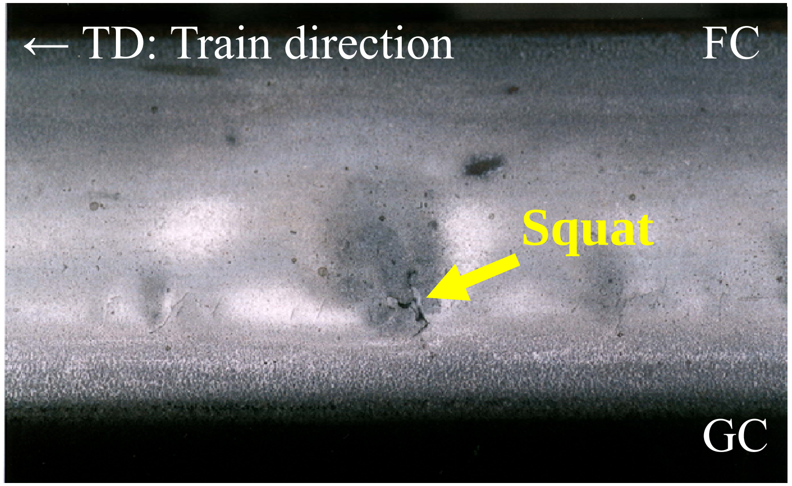
2) Purpose of this work

3) Experimental

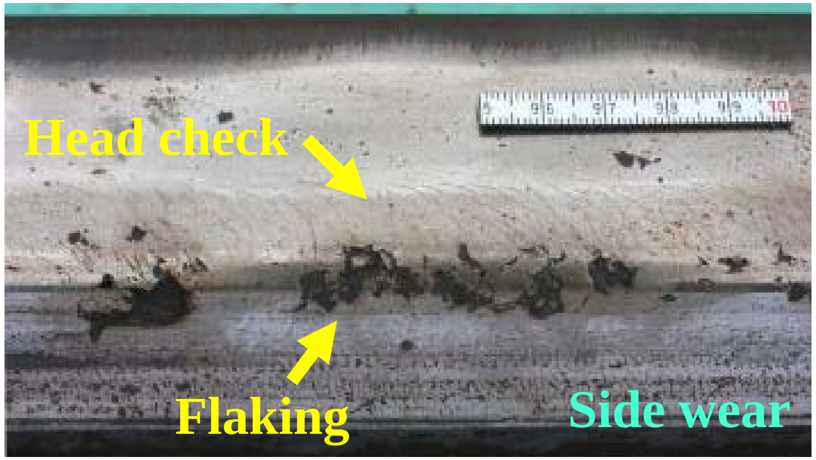
4) Results of x-ray examinations

5) Conclusions

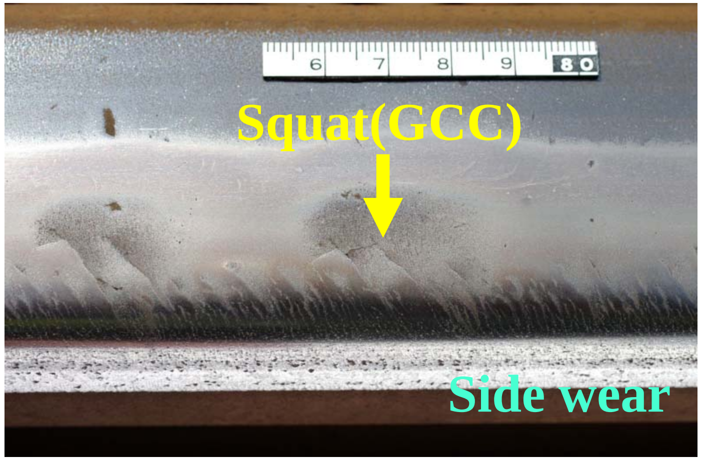
Appearance of rail RCF damage



As-rolled (tangent)



Head-hardened (curve)



Head-hardened (curve)

Other problem:
- **side wear**
- **corrugation**
- **corrosion fatigue(bottom side)**

etc..

Chemical composition of rail in Japan

(mass%)

	C	Si	Mn	P	S	Cr
As-rolled	0.63-0.75	0.15-0.30	0.70-1.10	≦0.030	≦0.025	-
Head hardened (HH340)	0.72-0.82	0.10-0.55	0.70-1.10	≦0.030	≦0.020	≦0.20

:JIS (Japanese Industrial Standard)

As-rolled : tangent rail

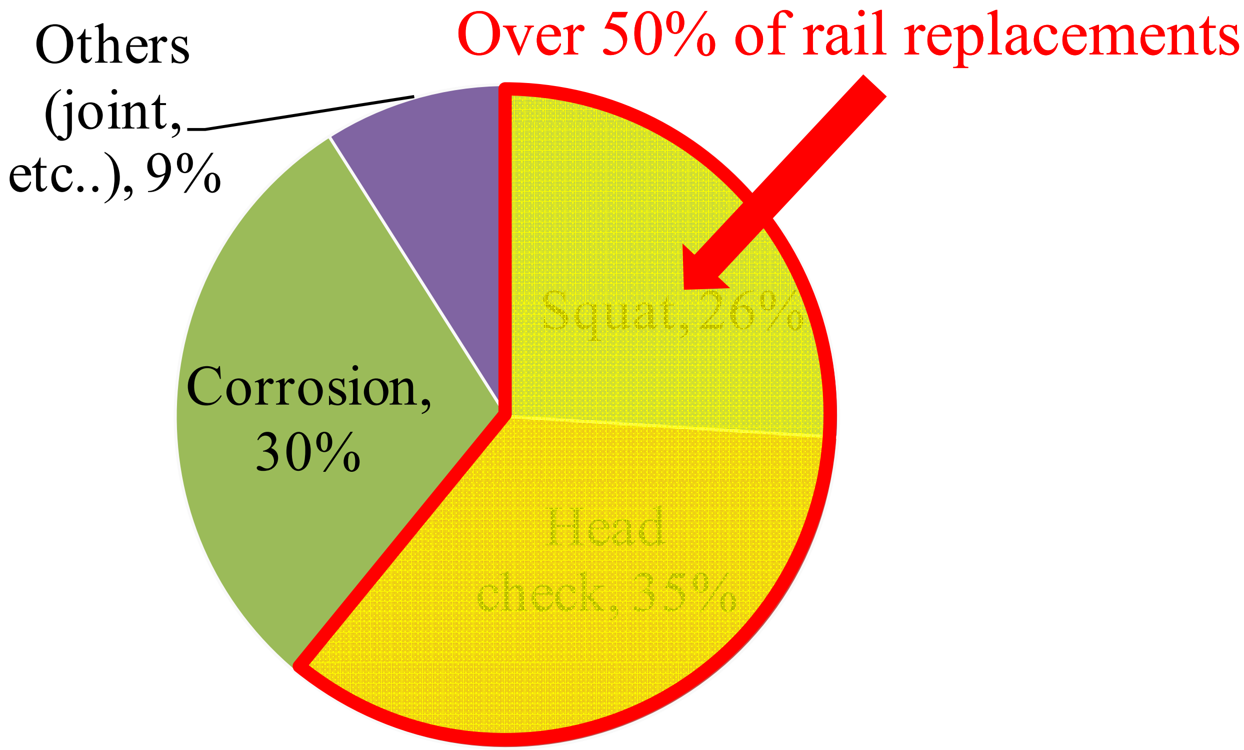
Head hardened : only curve rail (usually less than R800m)

Mechanical strength of rail in Japan

	Tensile strength (MPa)	Total elongation (%)
As-rolled	≧800	≧10
Head hardened (HH340)	≧1080	≧8

:JIS (Japanese Industrial Standard)

Portion of RCF damage for rail replacement



2008-2009 in Tokyo district

Reduction in reliability and operational life of rails

Mitigating action (Rail grinding by grinding stones)

Grinding operation

SPENO grinding car for Shinkansen line

Rail grinding operations are periodically performed to remove the RCF layers.

↓

Grinding depth and interval are almost empirically decided.

↓

Quantitative microstructural analyses on RCF layers

Purpose of this work

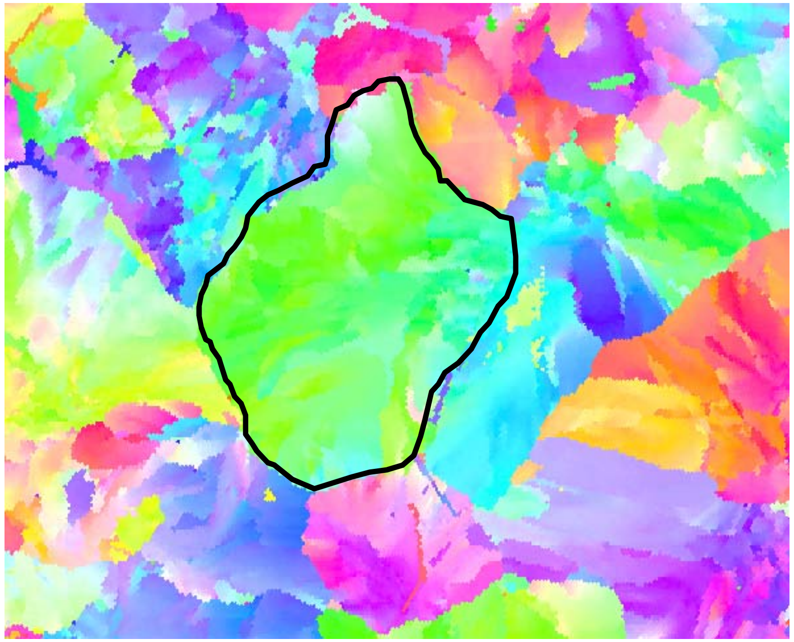
Clarify how the RCF layer forms from a material aspect, aiming at the effective mitigating actions for RCF damage

Estimate the crystallite size and dislocation density of RCF layer using x-ray diffraction

What is crystallite ?

Grain size from x-ray measurement

Crystal grain with nearly the same crystal orientation



What is dislocation ?

Irregularity of alignment of atoms

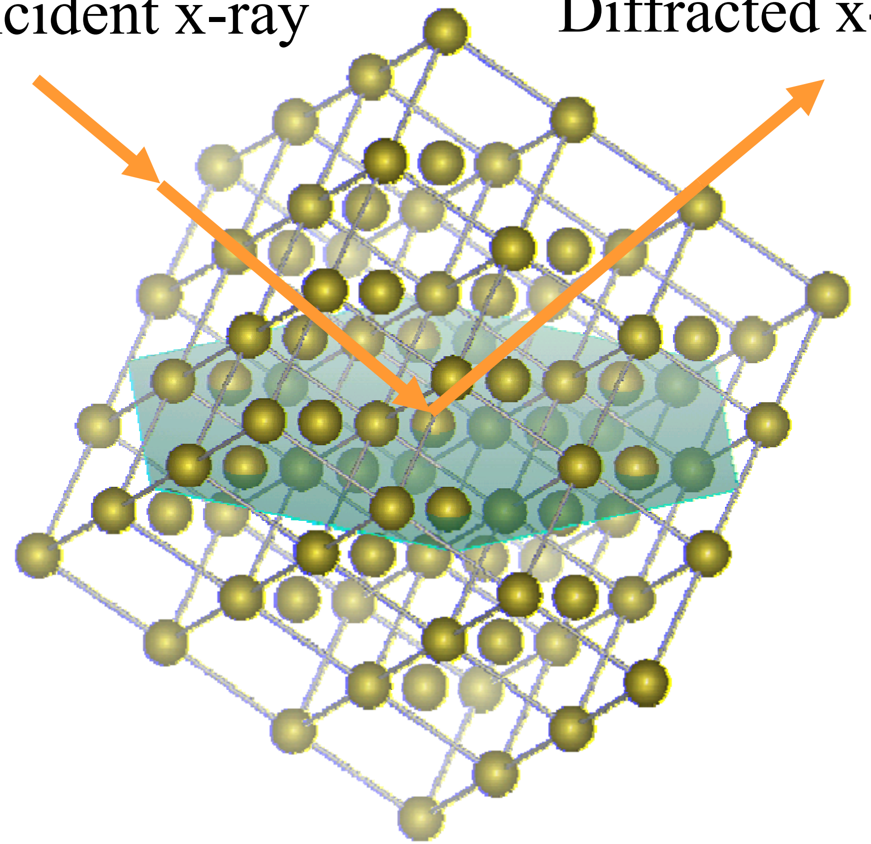
↓

When a material is plastically deformed, dislocations are induced and increase.

Principle of x-ray diffraction

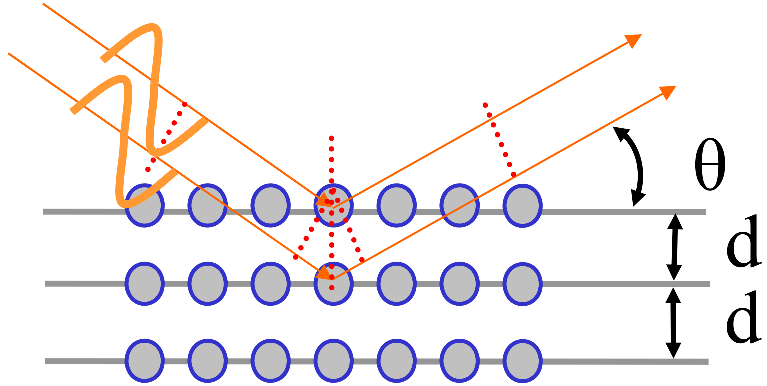
Incident x-ray

Diffracted x-ray



Bragg's law

$$n\lambda = 2d \cdot \sin\theta$$



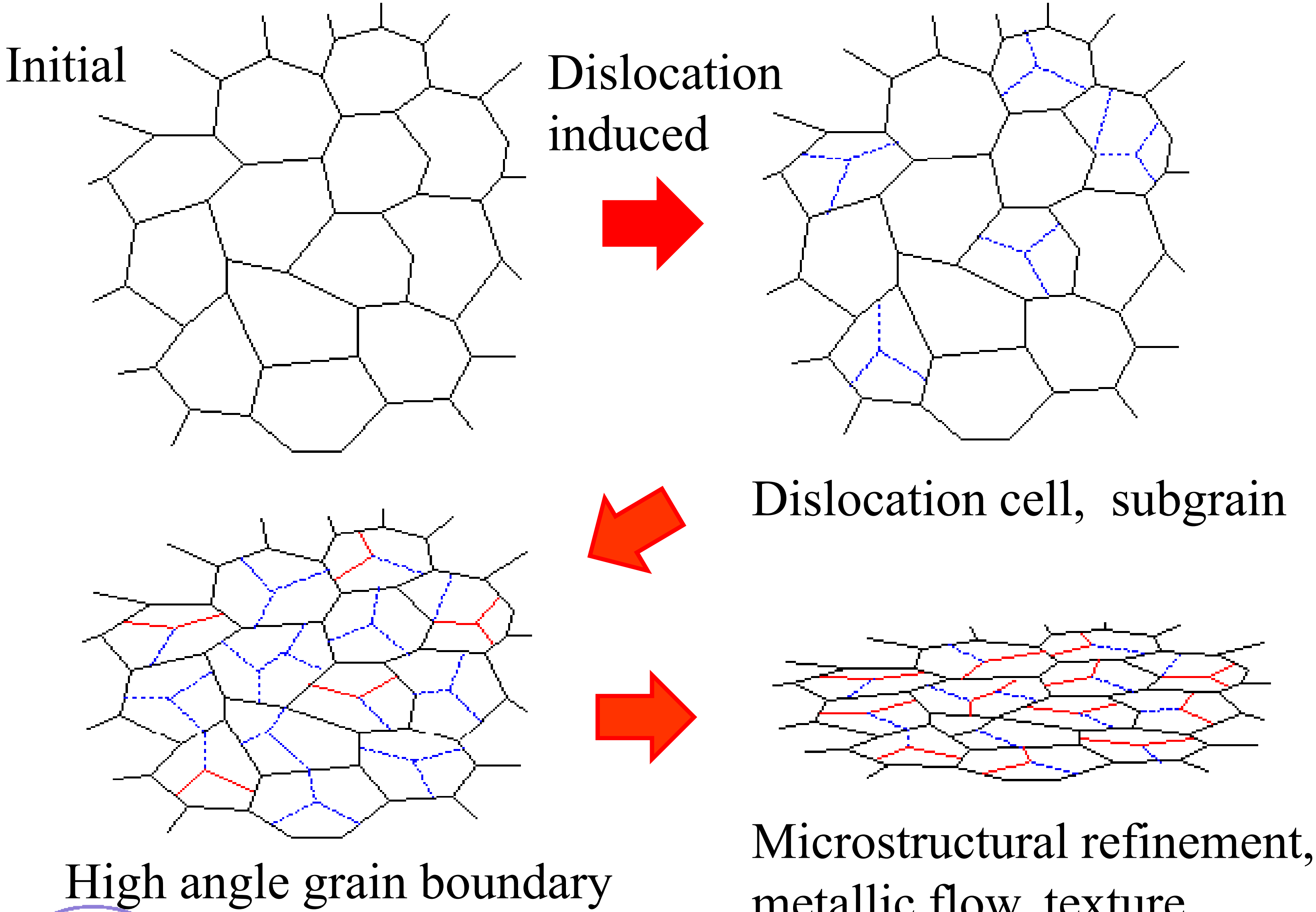
Wavelength : λ

Lattice spacing: d

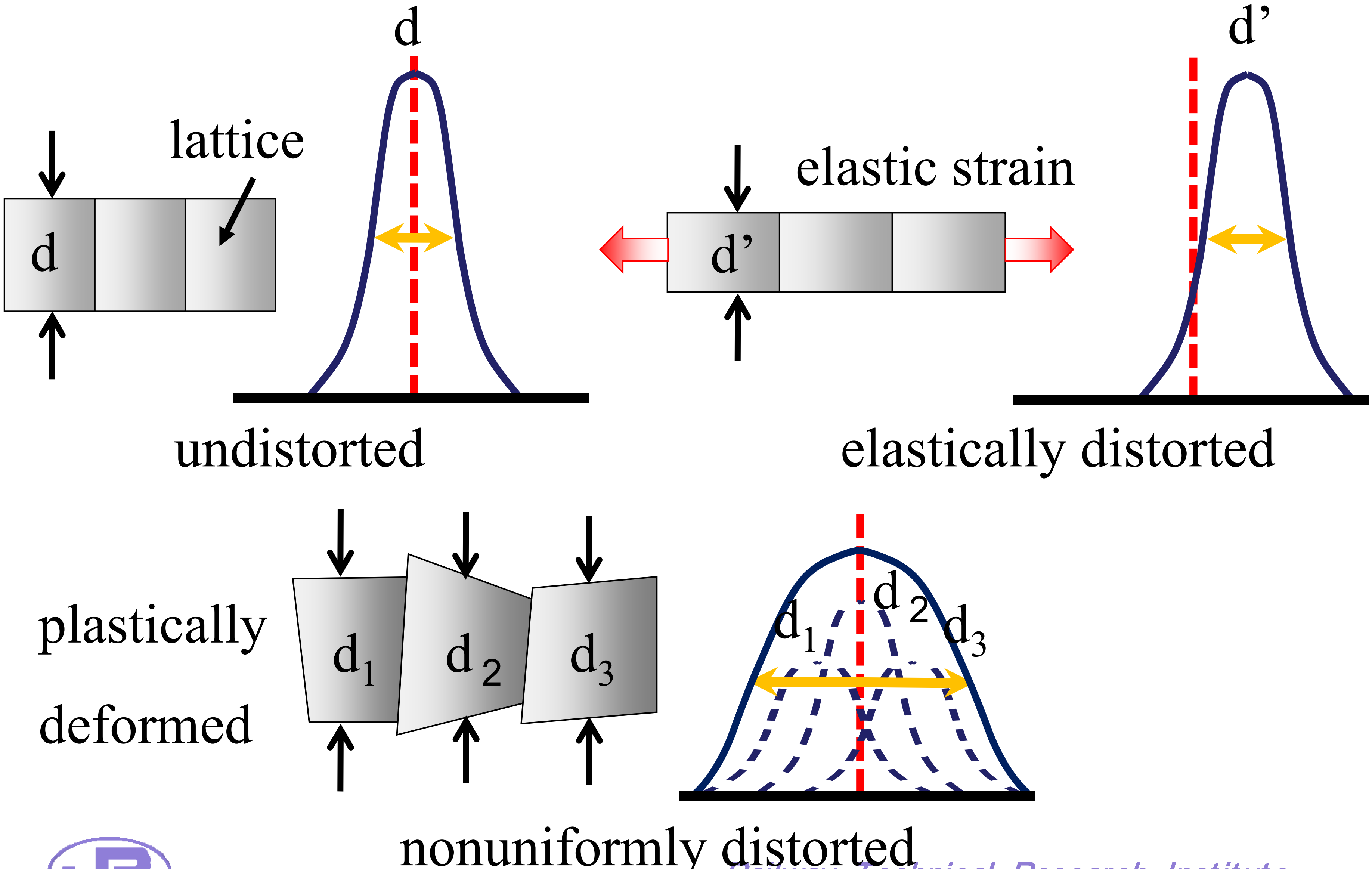
angle: θ

Texture formation, crystallite size, nonuniform distortion(lattice strain) and dislocation density etc..

Microstructural evolution due to RCF(grain subdivision)



Effect of strain on x-ray diffraction peak



How to estimate crystallite size and dislocation density

Williamson-Hall equation

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

β： integral peak width
θ: diffraction angle
η： nonuniform distortion
ε： crystallite size (nm)
λ： incident x-ray wave length

Modified Williamson-Hall equation

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

$$\alpha' = \frac{1}{\varepsilon'} \qquad K = \frac{2\sin\theta}{\lambda}$$

C: dislocation contrast factor defined by Warren

Modified Warrren-Averbach equation

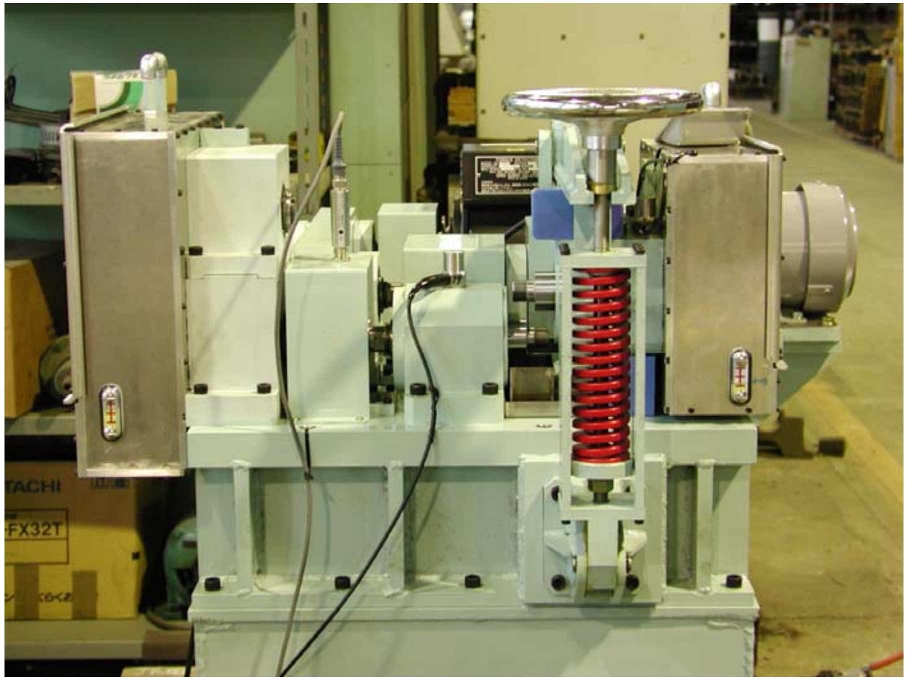
$$\ln A(L) = \gamma - X(L)(K^2C) + P(K^2C)^2$$

L: Fourier length
A(L): real part of Fourier coefficient of (hkl) diffraction

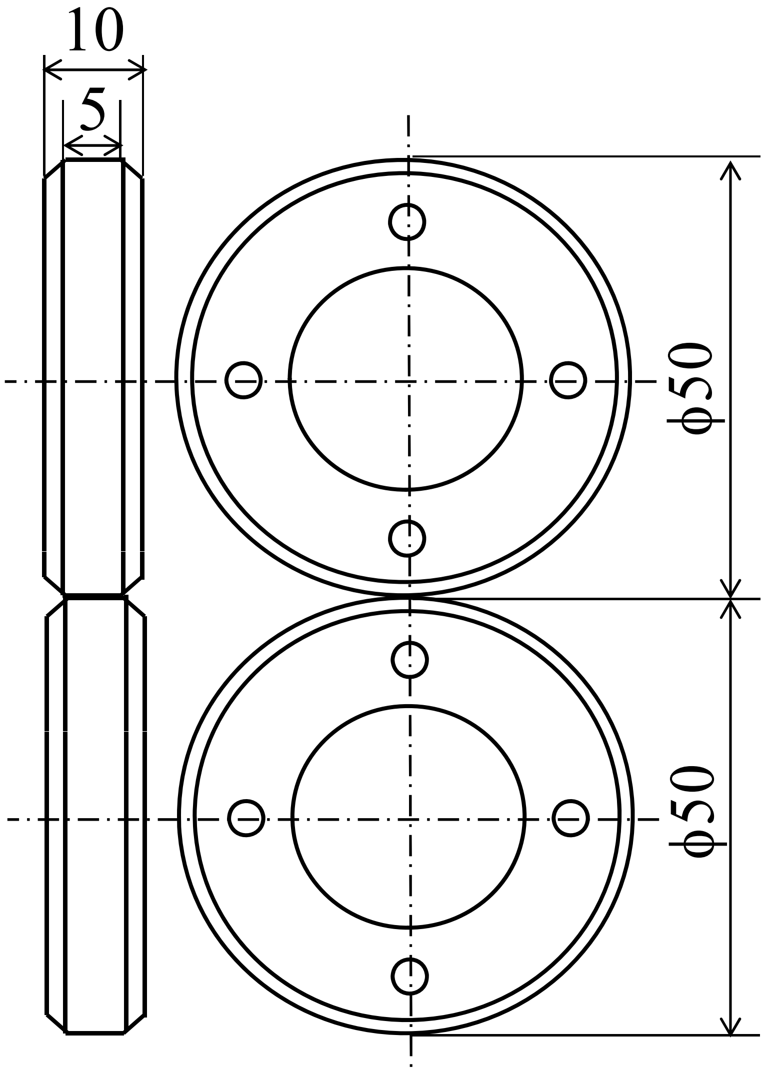
$$X(L) = \frac{\pi b^2 L^2}{2} \rho \ln\left(\frac{R_e}{L}\right)$$

ρ: dislocation density ($1/m^2$)

RCF test equipment



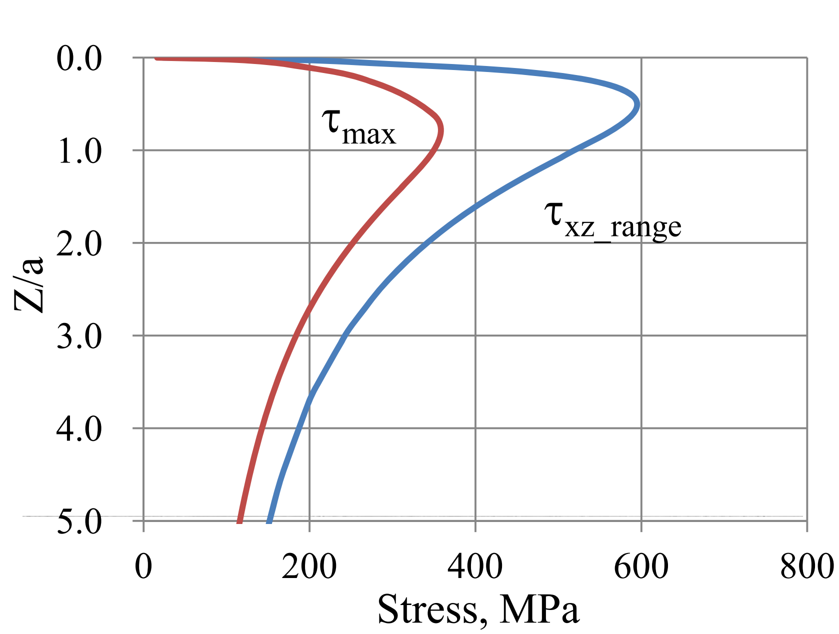
Overview

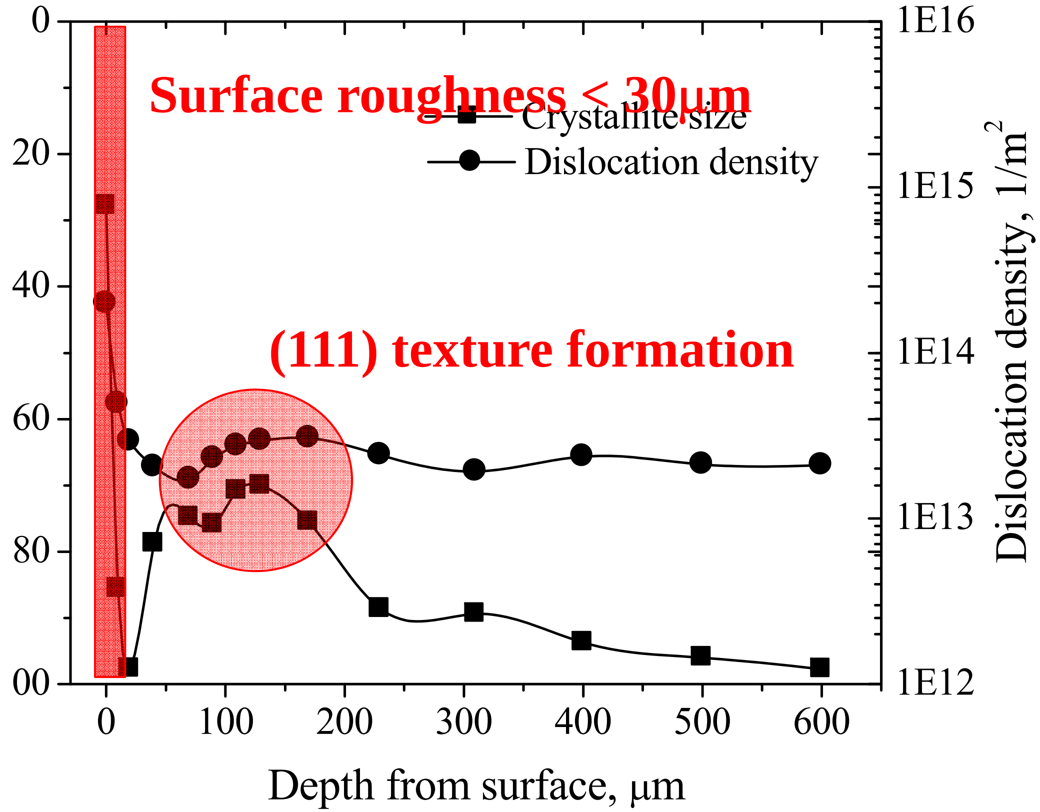


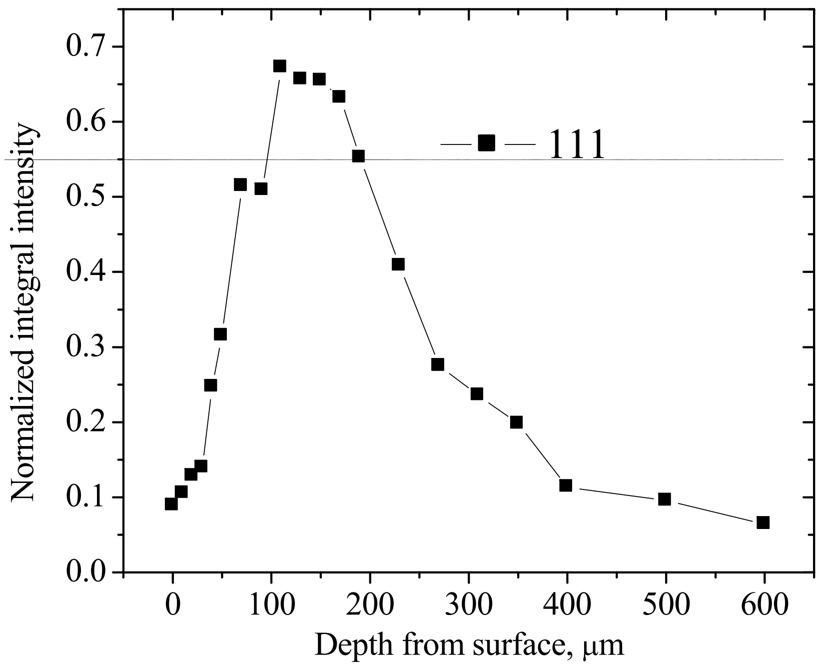
Test sample

CF test

Contact pressure : 1.2GPa
Slip ratio : 0%
100,000 cycles
Dry
Rarely worn after test

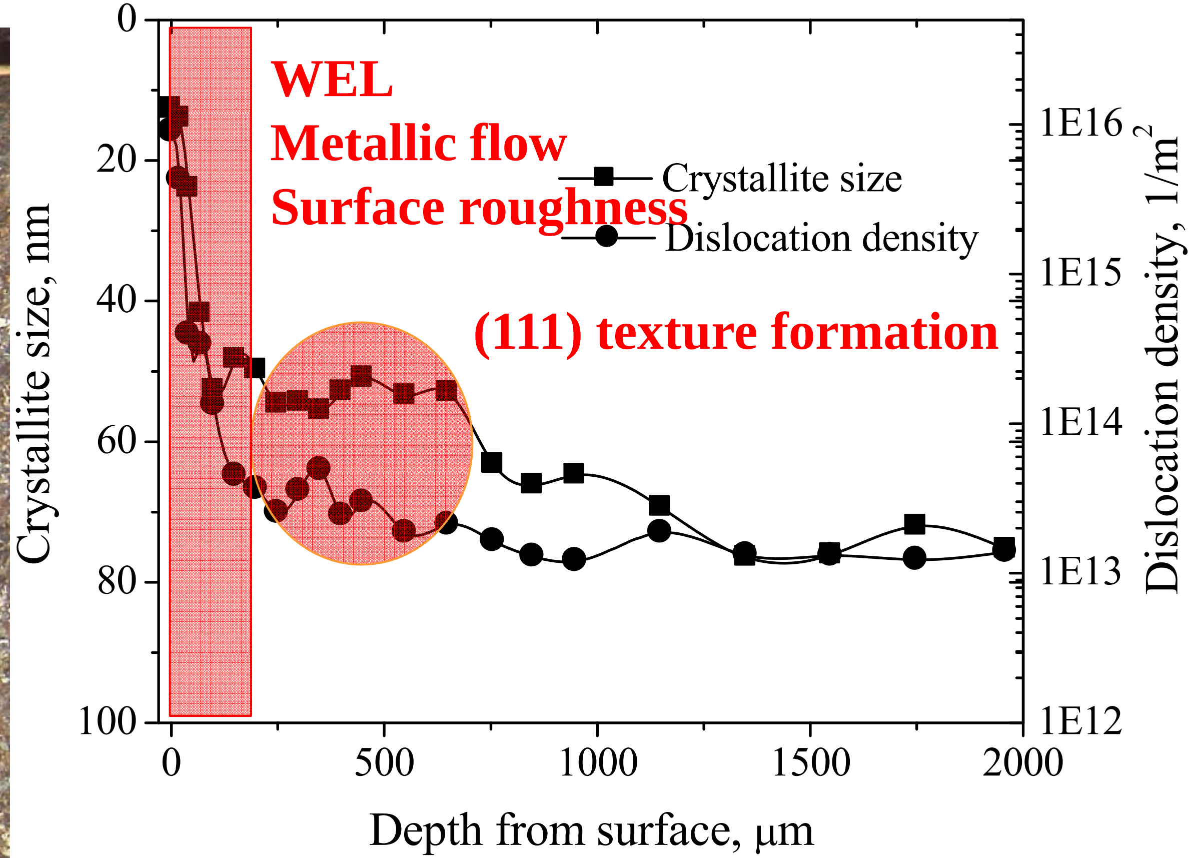






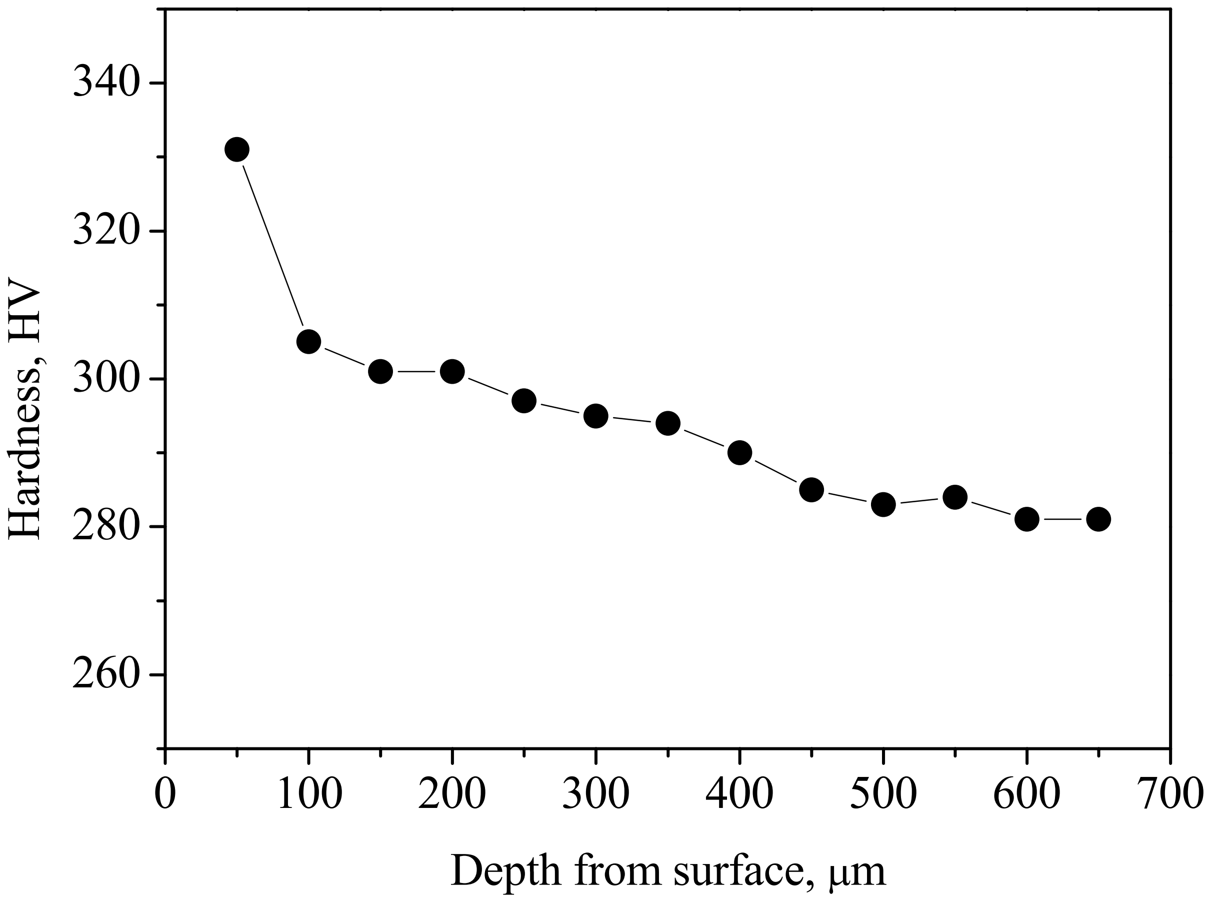
It is significant to consider the effect of surface roughness on the contact patch

Serviced tangent rail without rail grinding (500MGT, passenger & freight mixed)



- Similar tendency to the test sample.
- It is possible to investigate how the RCF evolves even in the case of serviced rail.

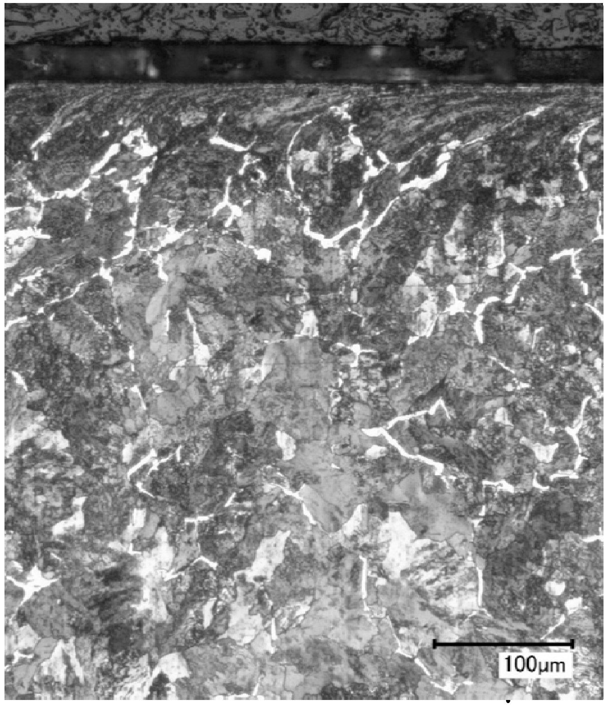
Hardness (500MGT)

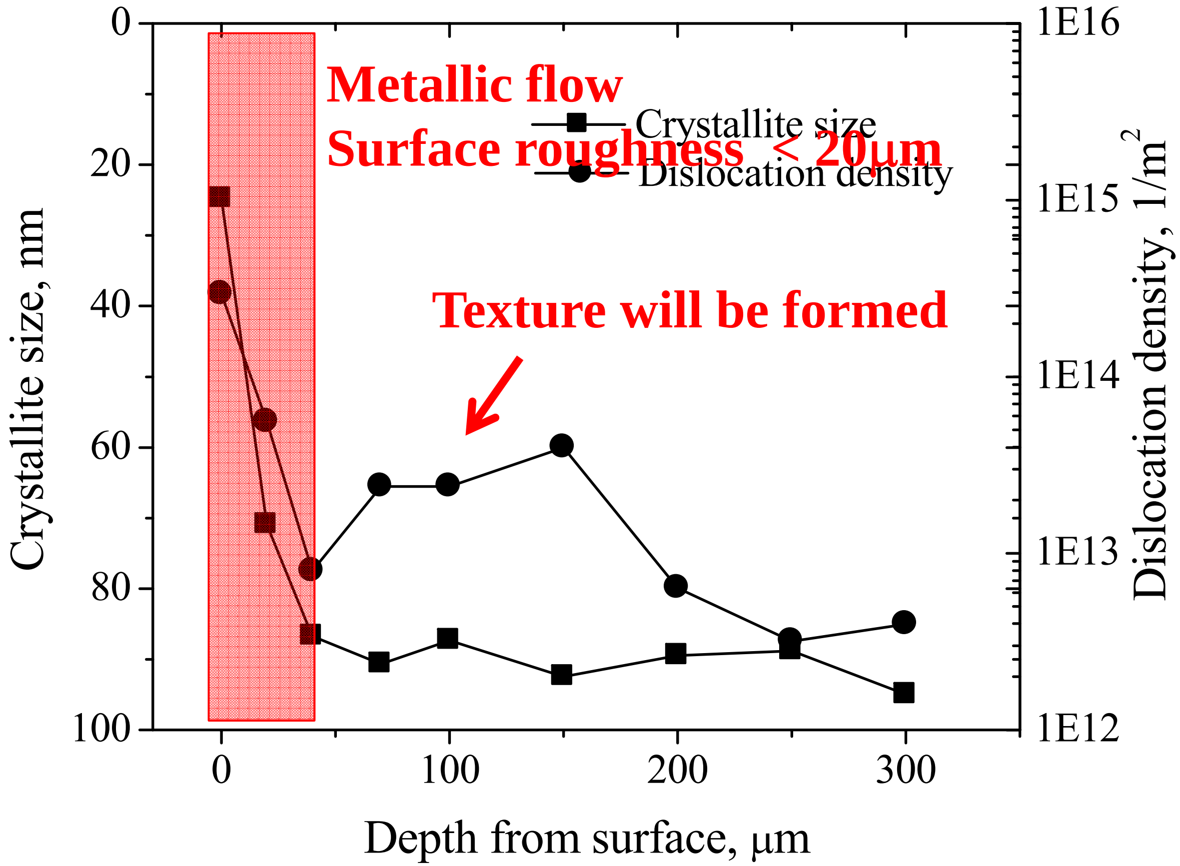


Vickers hardness distribution (0.3HV)

- Total RCF layer is not evaluable.
- Measurement beneath the surface is difficult.

Serviced tangent rail without rail grinding (50MGT, passenger & freight mixed)





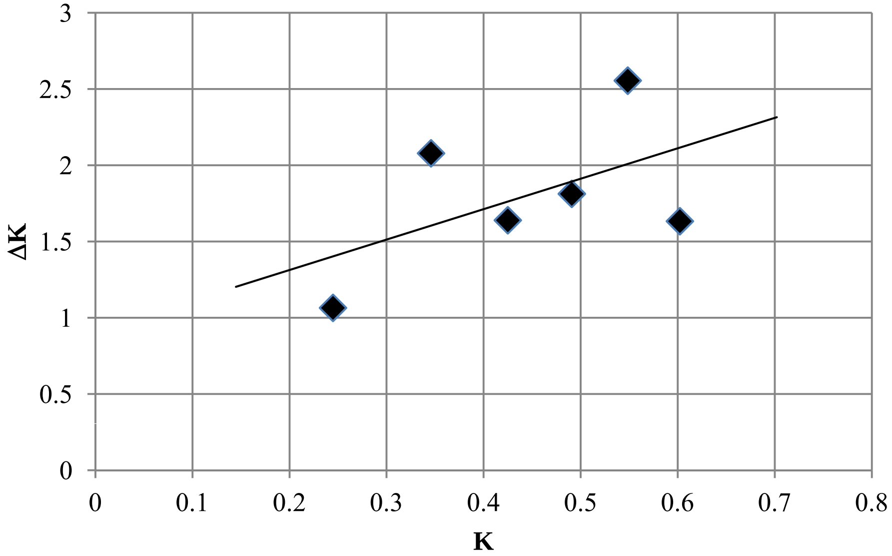
X-ray is feasible even for a thin RCF layer.
We can quantify the degree of RCF layer formation for each condition.

Conclusions

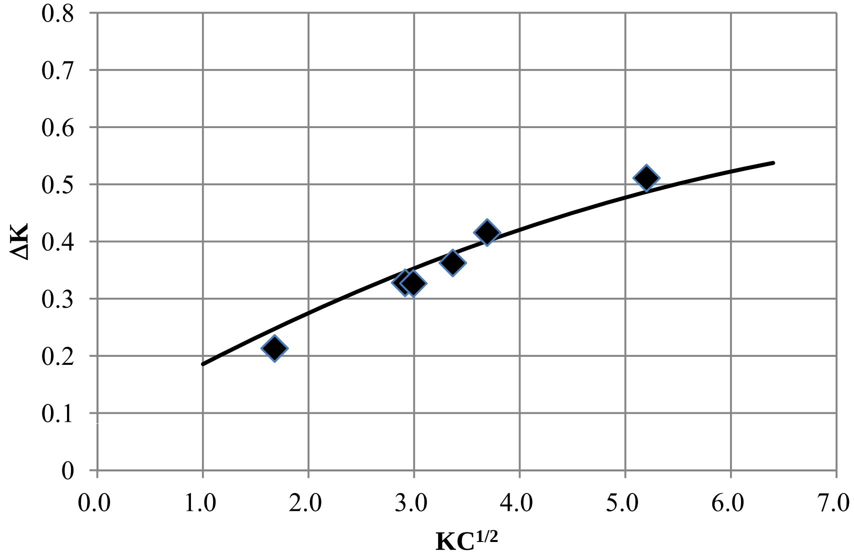
1. This x-ray measurement makes it possible to quantify the RCF layer from the surface and into the material in one method. Especially it is feasible even for a quite thin layer.
2. On the other hand, it is hard to carry out hardness measurement just on the surface. The hardness measurement could not cover the total RCF layer.
3. Both crystallite size and dislocation density largely change in RCF layers. The surface layer was in all cases more damaged by RCF than the subsurface layer. (111) texture is formed in some depths. (111) texture can be highly enhanced after a while serviced as a tangent rail.
4. It is significant to consider the surface roughness in the contact patch in the evaluation of RCF layer.

Thank you for your kind attention

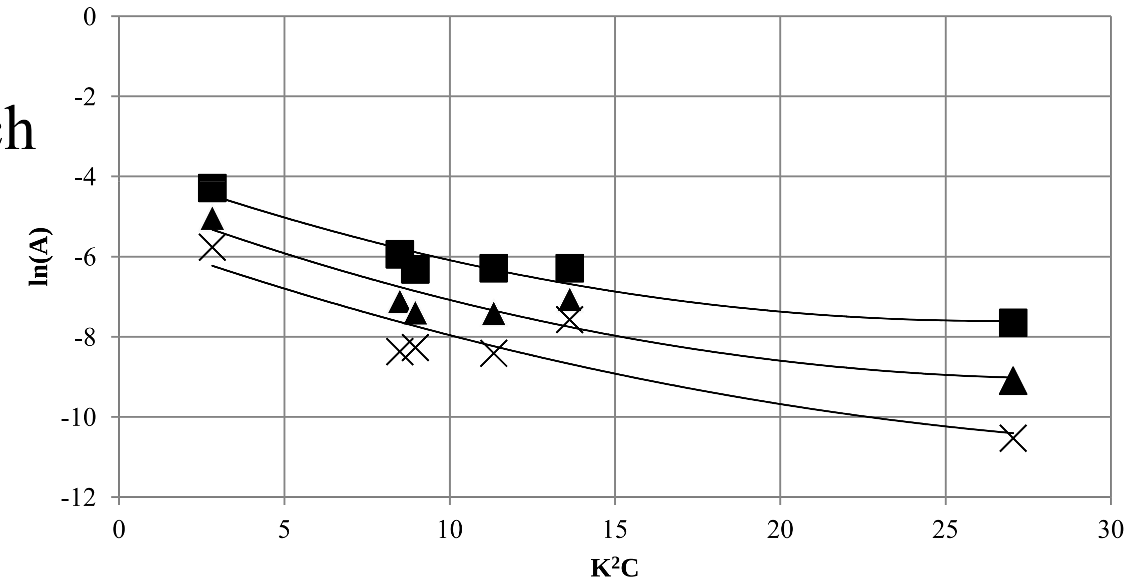
Williamson-Hall



Modified Williamson-Hall



Modified Warrren-Averbach



111 texture formation(500MGT, serviced tangent rail)