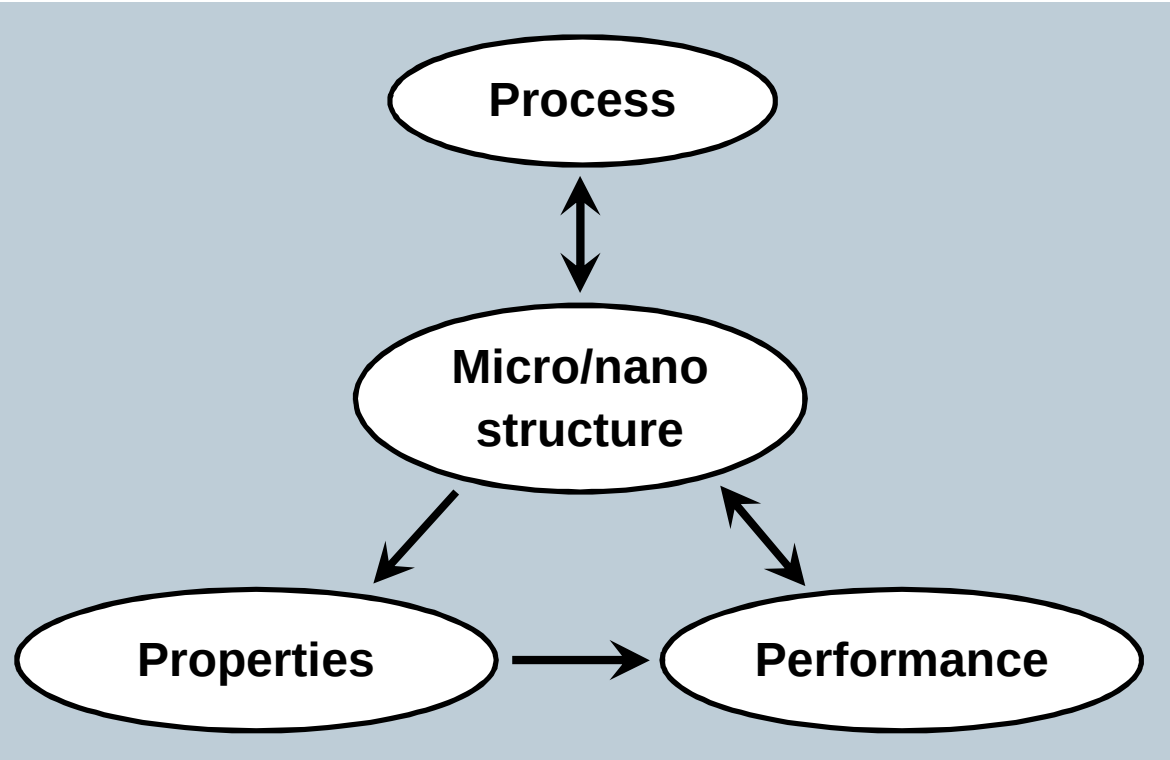
Metallurgiske undersøgelser af rulle-lejer

DMS Vintermøde, Viborg, Januar 2016

Introduktion

Figur fra materialelære på DTU:



Når noget kommer retur til metallurgisk undersøgelse, vigtigt med al information:

- Hvad er den født med?
- Anvendt hvordan?
- Udsat for hvad?
- Skader?
  - Primære skader?
  - Sekundære skader?

Eksempler på undersøgelser af skadede lejer

Til slut nogle metallurgiske udfordinger, som vindmølle industrien står overfor

Introduction – Load on bearing

Load on bearing is characterized by Hertzian pressure P_0

Cylindrical roller bearing

$$P_0 = \frac{2F}{\pi a L}$$

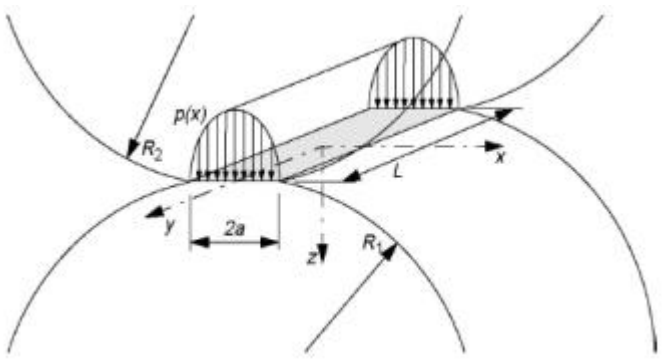
$$a = \sqrt{\frac{4FR'}{\pi L E'}}$$

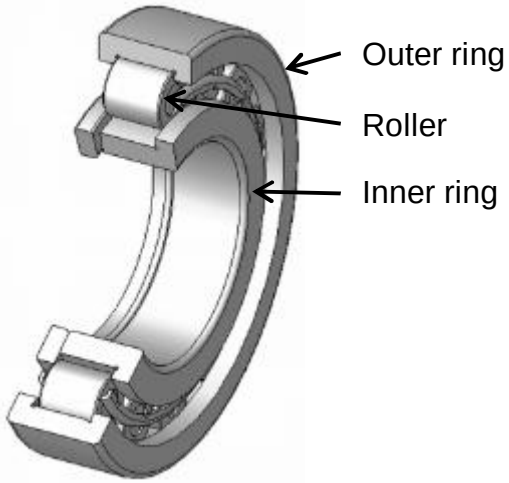
$$\frac{1}{R'} = \frac{1}{R_1} + \frac{1}{R_2}$$

$$\frac{1}{E'} = \frac{1-\nu_1^2}{E_1} + \frac{1-\nu_2^2}{E_2}$$

$$z_0 = 0{,}78a$$

Contact between roller and inner ring





Examples of numbers:

F = Force (75000 N)

P_0 = Max pressure (Inner: 1403MPa; Outer: 1145MPa)

L = Contact length (70 mm)

a = Contact width (Inner: 486µm; Outer: 596µm)

R = Radius (Roller: 25mm; Inner: 100mm; Outer: -150mm)

E = Young modulus (210 GPa)

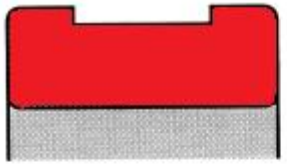
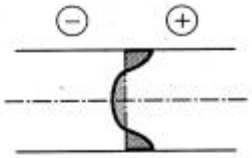
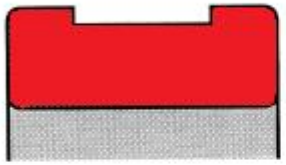
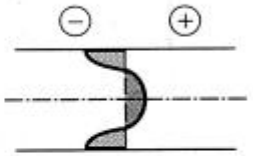
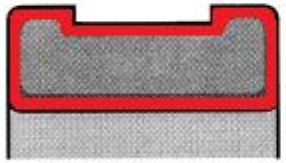
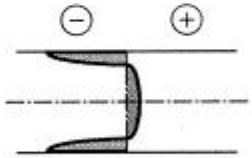
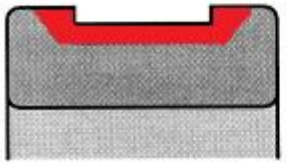
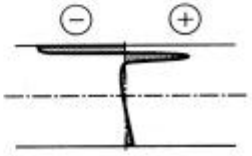
v = Poisson's ratio (0,3)

Z_0 = Depth with max Tresca stress (Inner: 379µm; Outer: 465µm)

Introduction – Bearing material and heat treatment

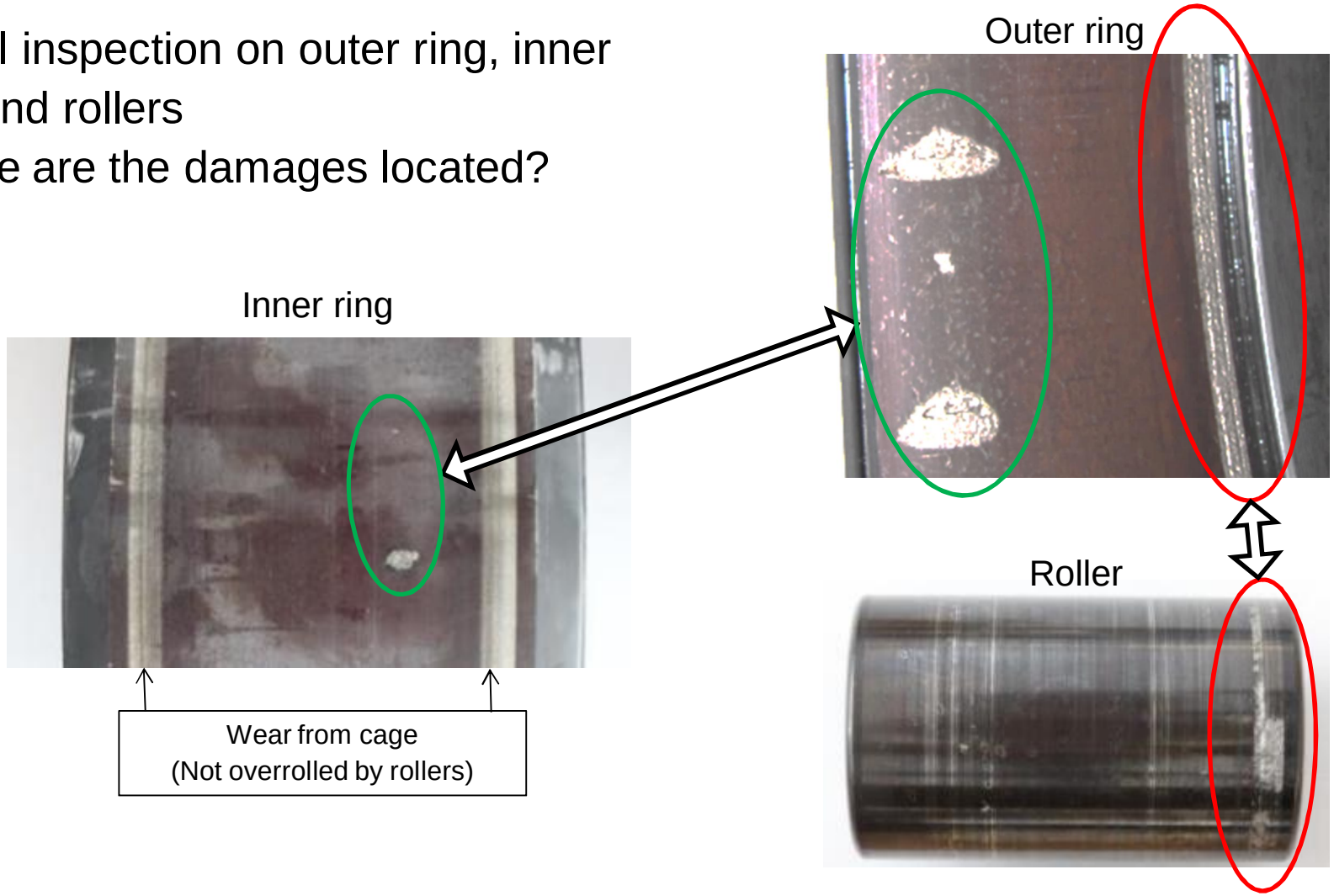
Typical alloying elements:
0,2-0,6% Si
0,3-1,0% Mn
1,0-1,7% Cr
0-0,3% Mo
(Ni)

Surface hardness:
Around 700 HV
(60 HRC)

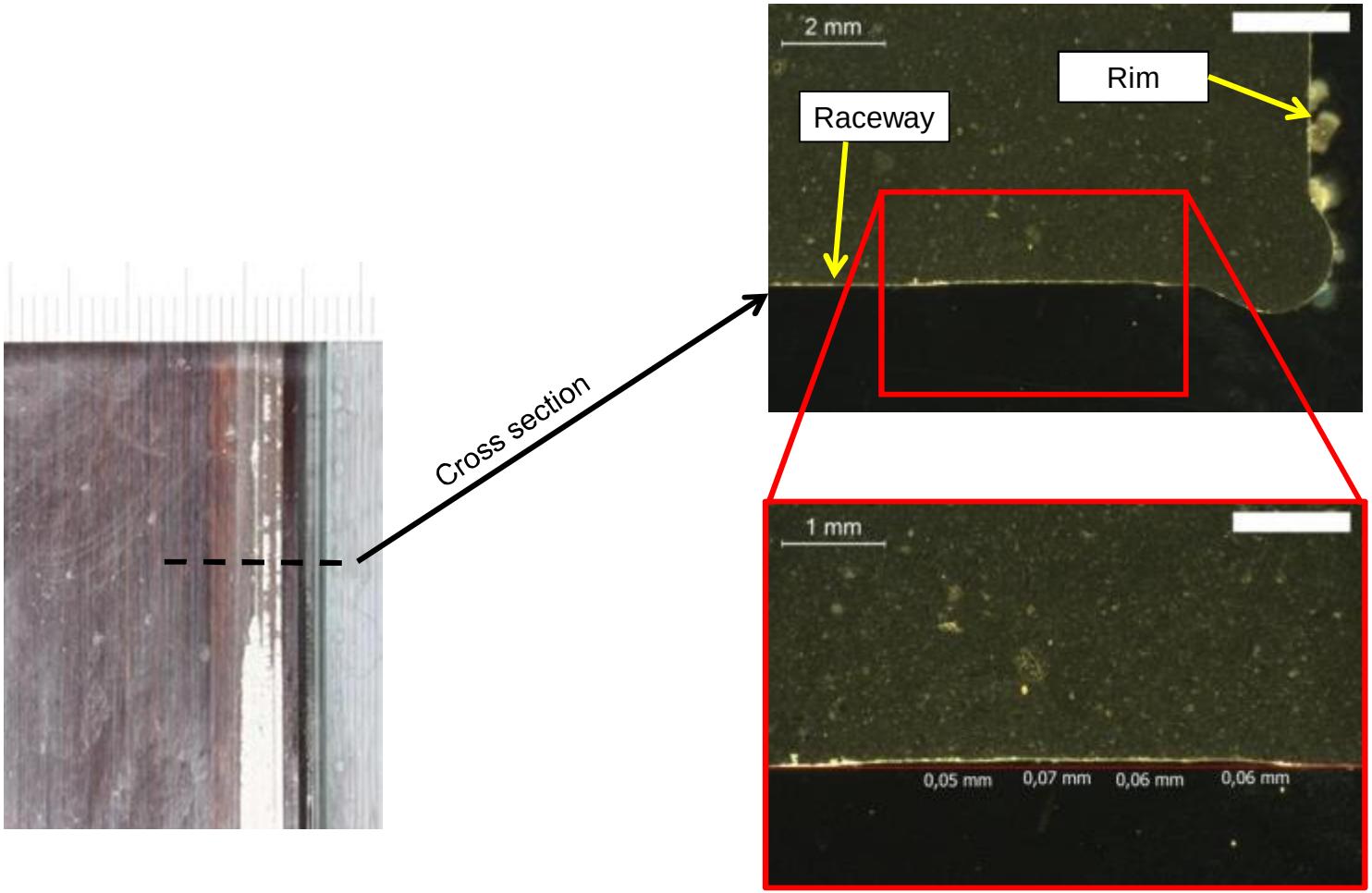
Heat treatment	Typical C-content (w%)	Cross section	Residual stress profile
Martensitic (M)	~1		
Bainitic (B)	~1		
Case carburized (CC)	Surface: ~0,7 Core: ~0,2		
Induction (I)	0,4-0,5		

Example 1 – Visual inspection

Visual inspection on outer ring, inner ring and rollers
Where are the damages located?

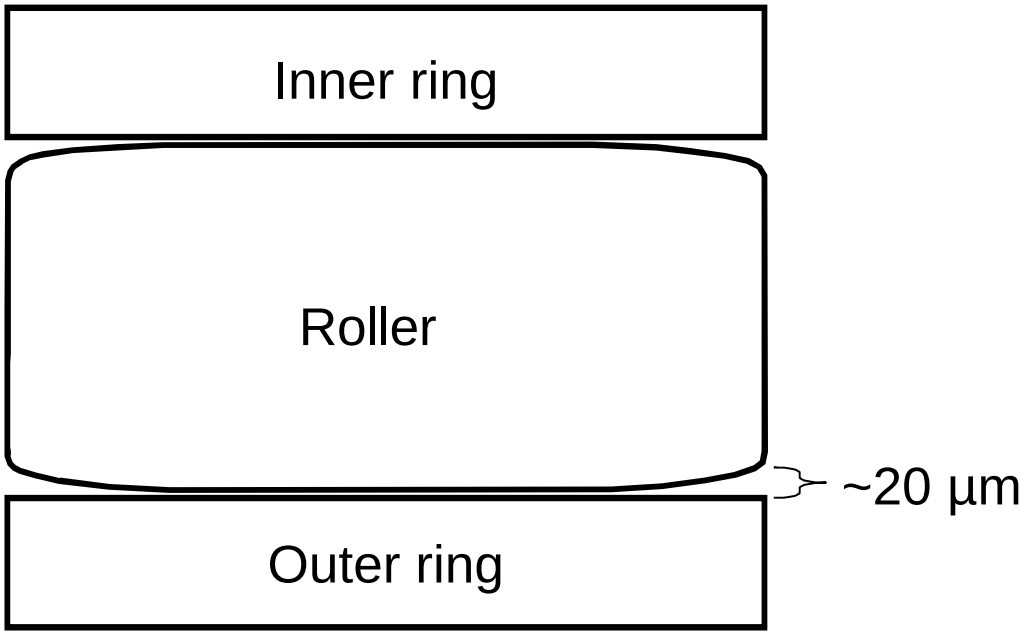


Example 1 – Outer ring

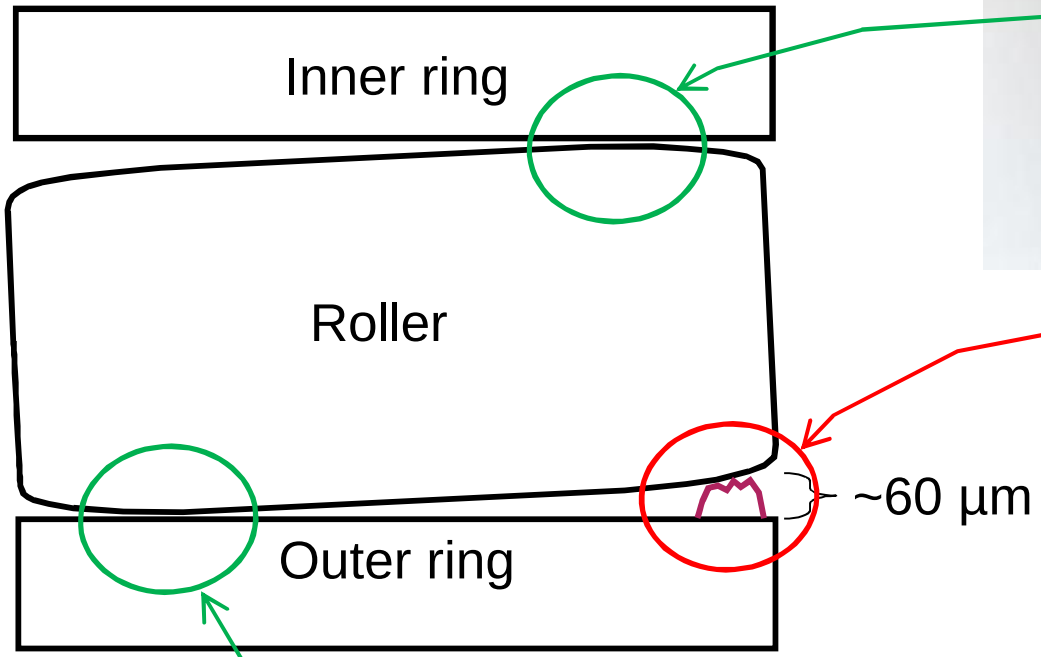


Example 1 – Influence of roller profile (crown rollers)

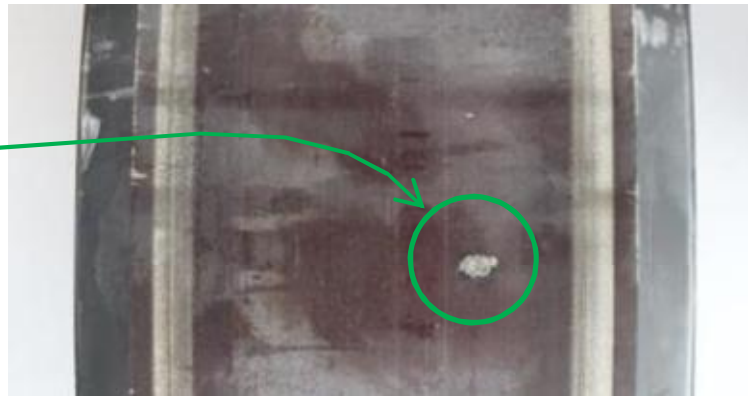
In order to avoid high stress peak at edge of rollers, profiling are used on rollers



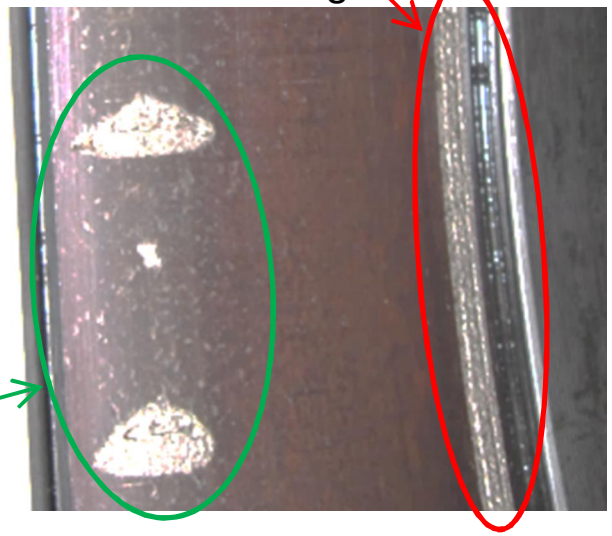
Example 1 – Influence of roller profile (crown rollers)



Inner ring



Outer ring



Example 2 – Visual inspection

For most cases:

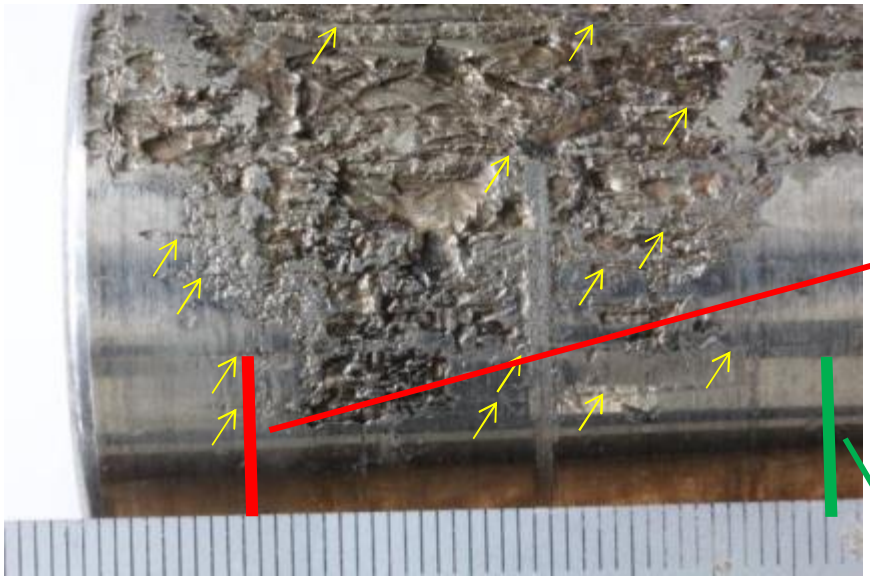
Bearing failure starts on inner ring

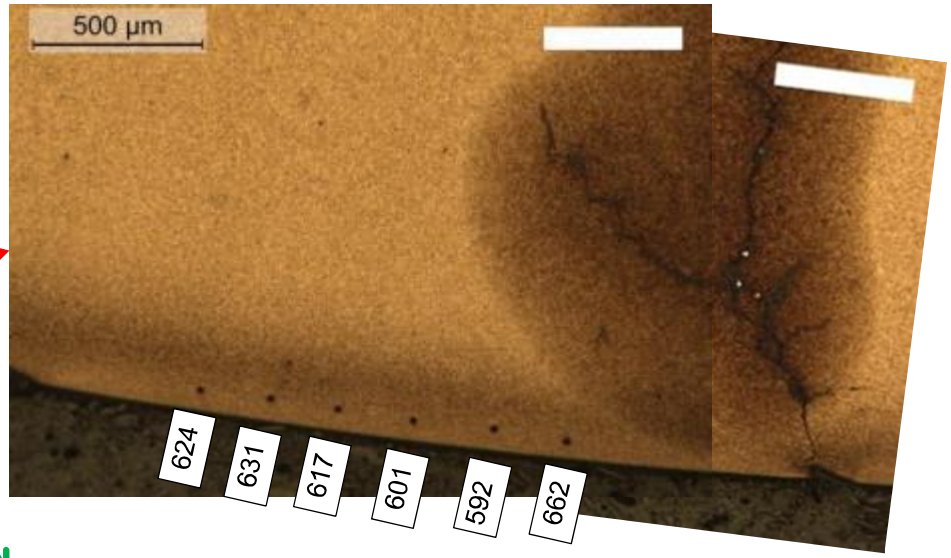
Rollers

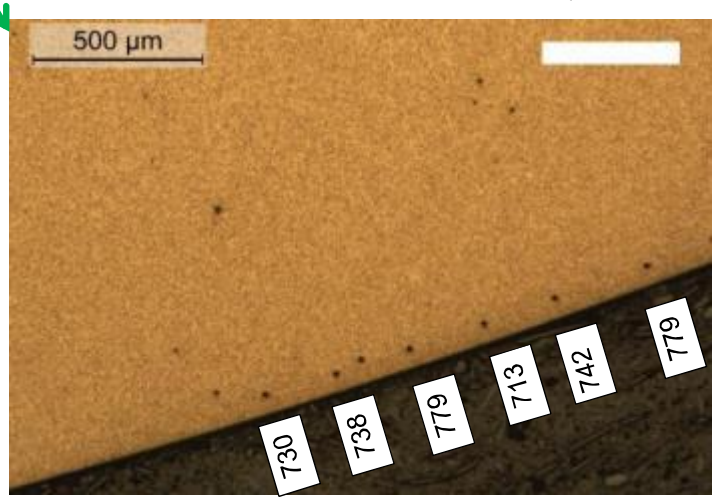
Inner ring

Outer ring

Example 2 – Cross section of roller







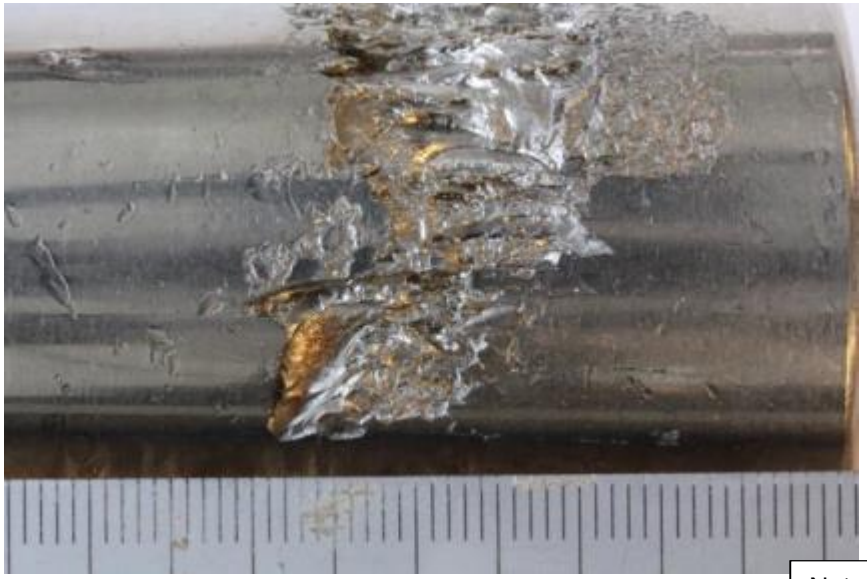
Axial cracks on roller

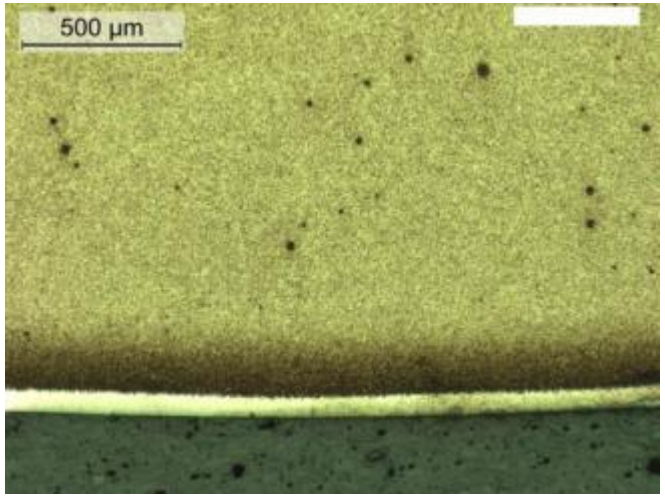
Cross section – Nital etched

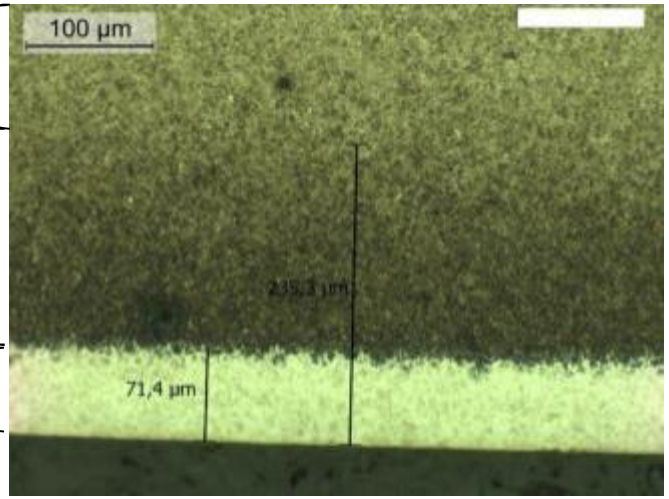
Hardness measurement

Grinding burns (grinding tempering)

Example 3 – More severe grinding burns







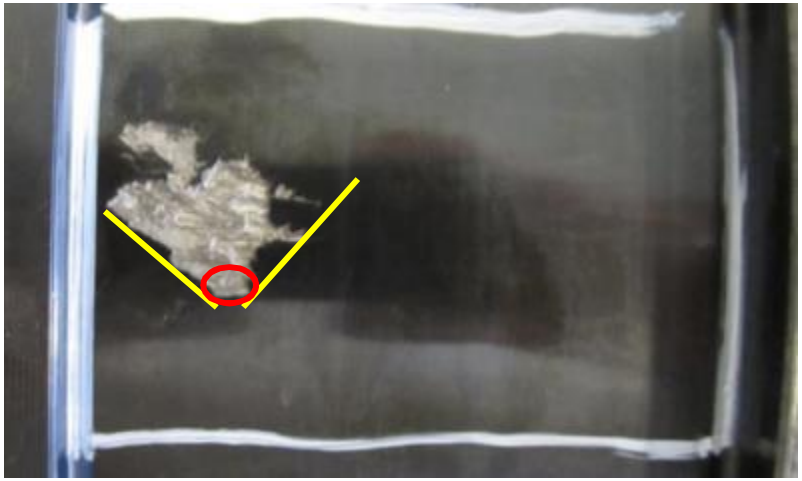
Not affected

Tempered at high temperature

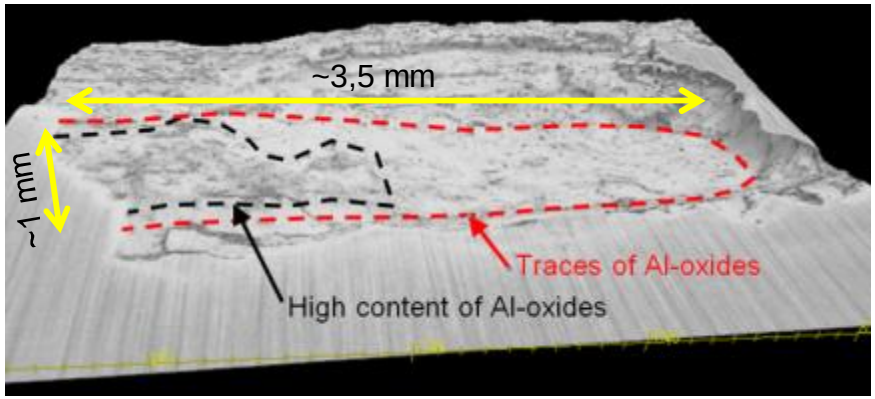
Untempered martensite

Axial cracks on roller
Cross section – Nital etched
Grinding burns (grinding tempering)

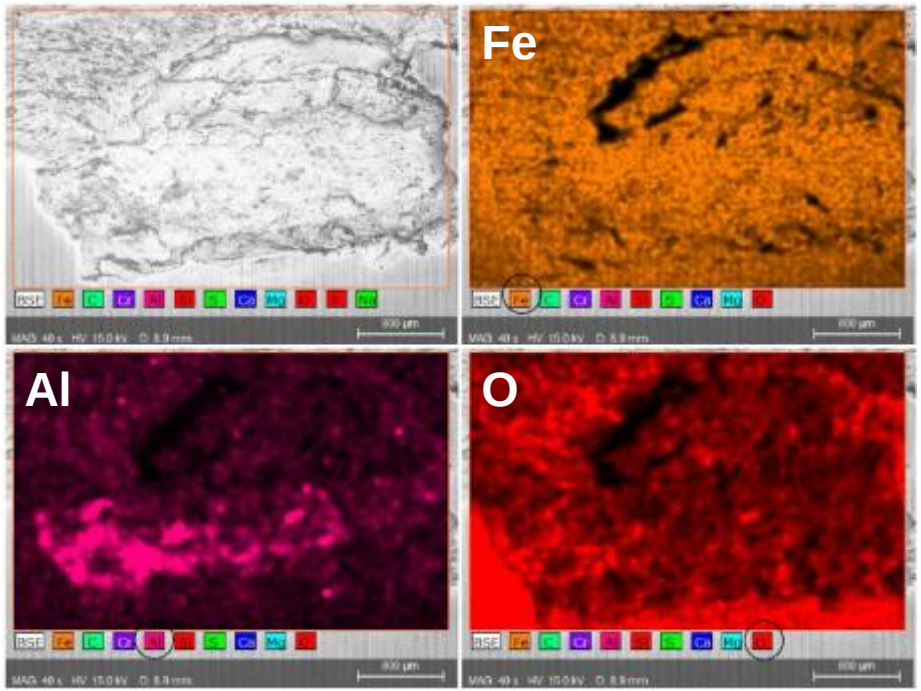
Example 4 – Macro inclusions



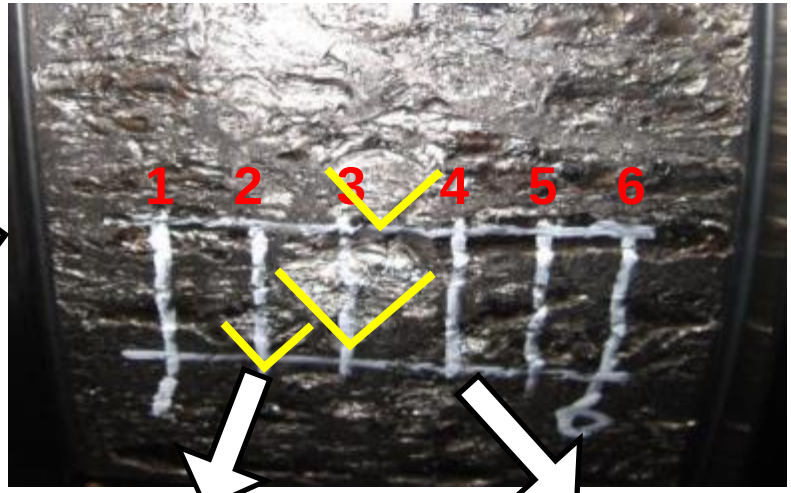
Spalling on bearing
V-shape indicates starting point
Al and O (Al-oxide) present at starting point

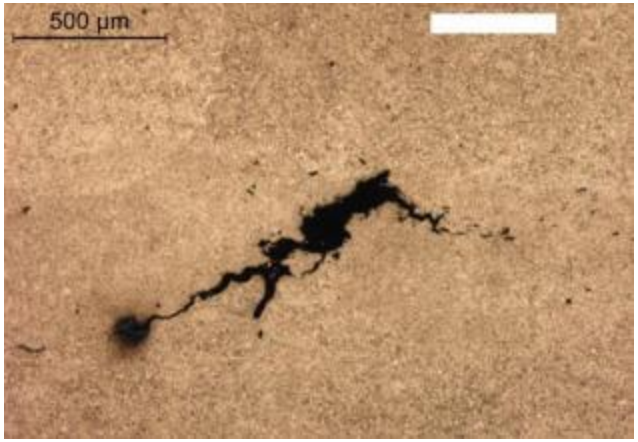


Element mapping by EDS



Example 5 – V-shape starters (and a bit of luck)

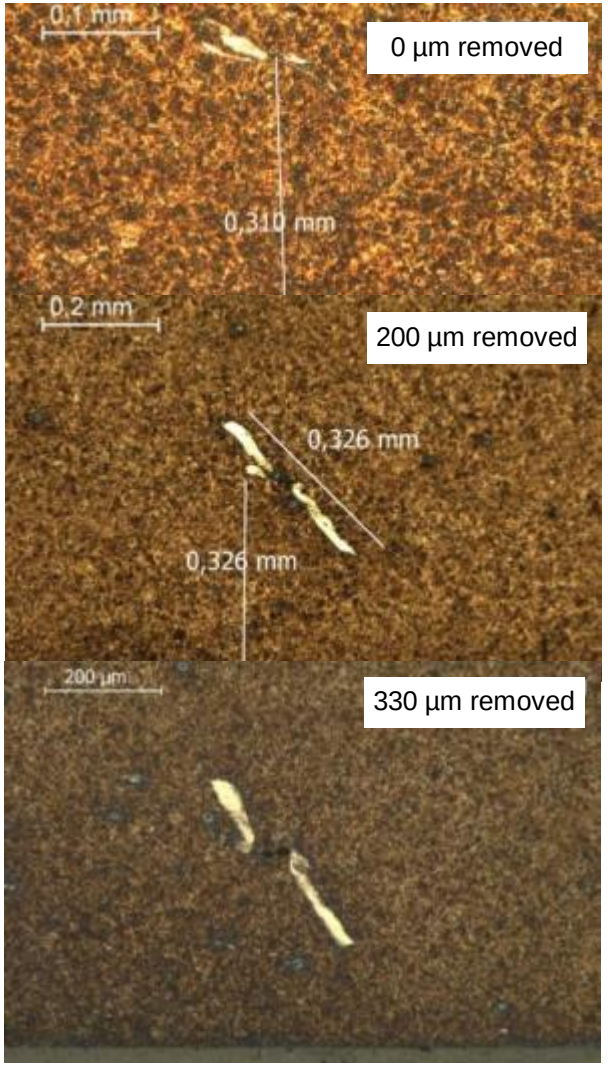


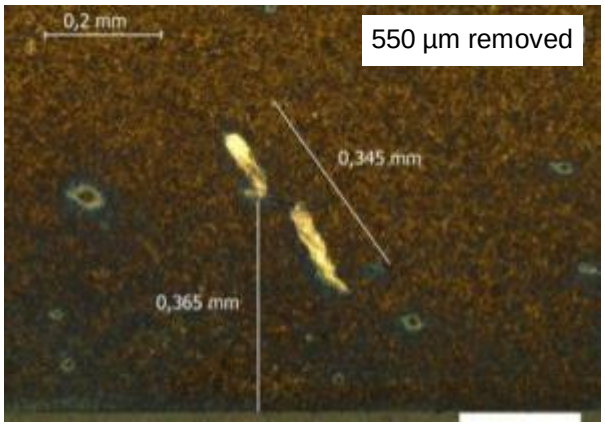


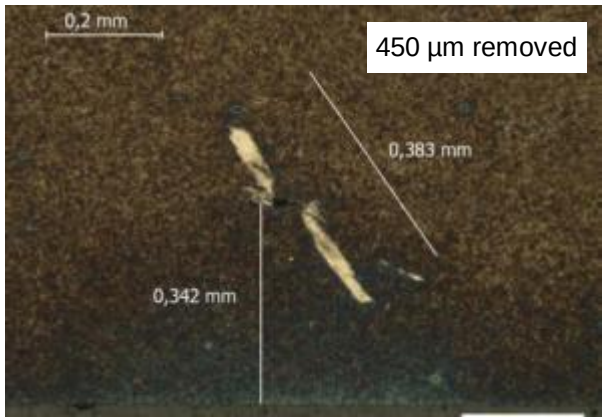
Example 6 – Butterflies at micro inclusions

- Circumferential cross section
- Raceway downwards
- Sample re-grinded several times
- Axial length of inclusion >550 µm

For long inclusions, butterflies can grow to a critical size

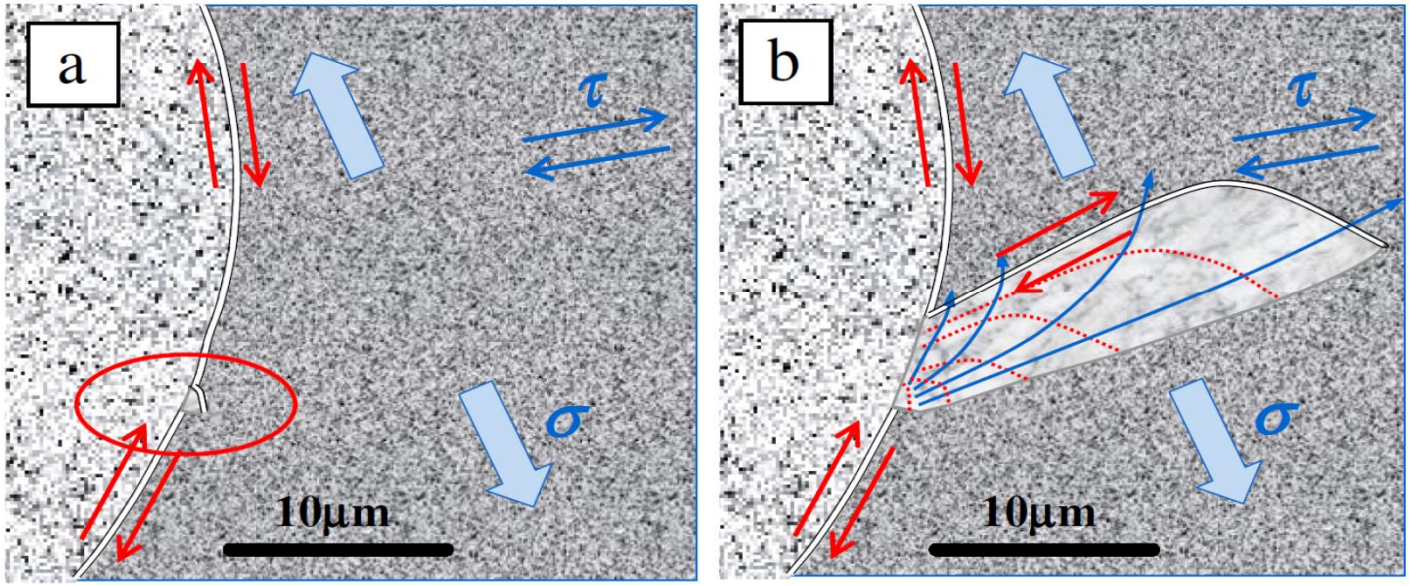






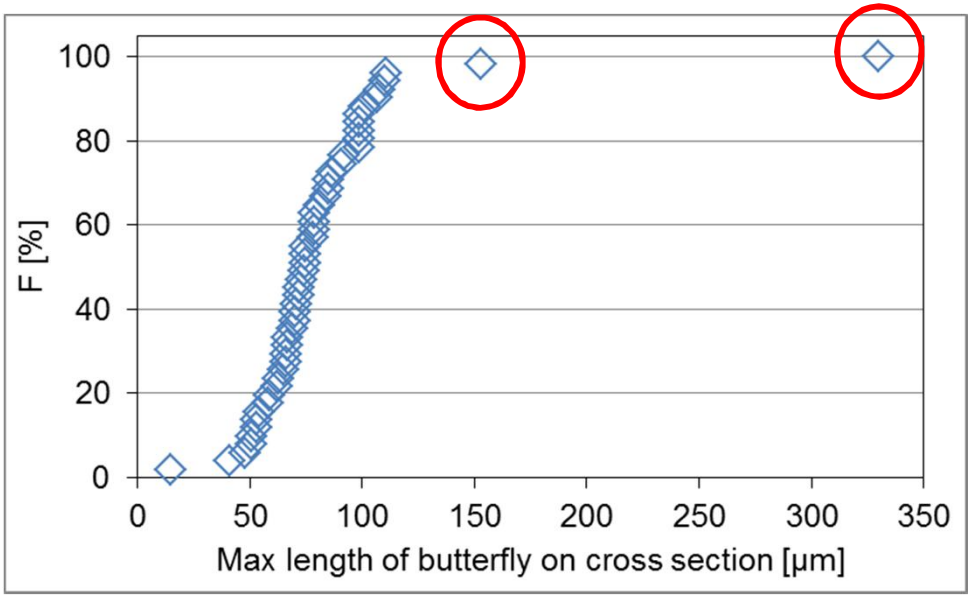
Example 6 – Growth of Butterflies

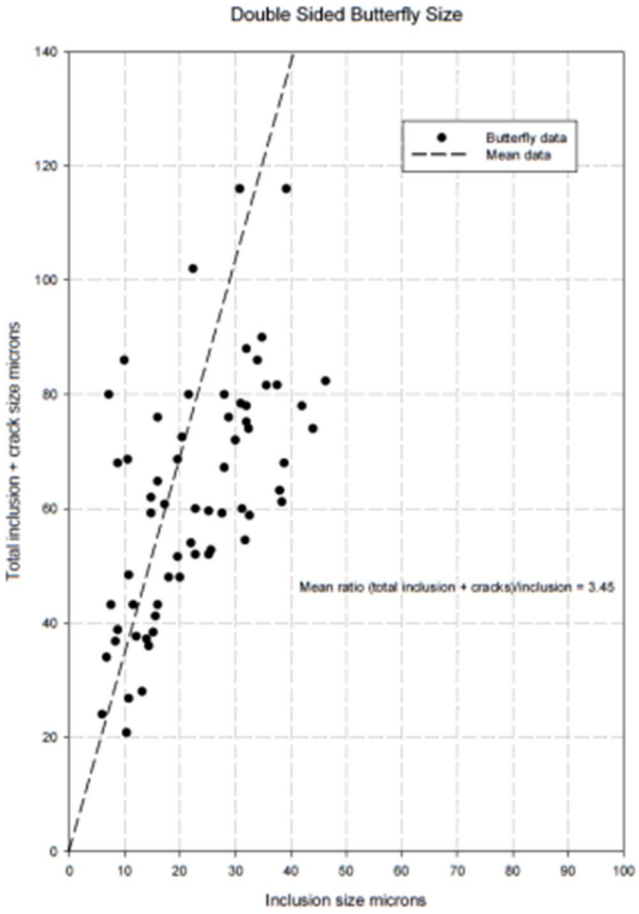
- Rubbing of interface between inclusion and steel matrix
- Transfer of material from steel matrix to surface of inclusion
- Recrystallization of deposited material into nanosized ferritic grains
- Crack growth by repeated depositing material across crack interface



Ref: Aleksandro Grabulov, Fundamentals of rolling contact fatigue, PhD Thesis, ISBN 978-90-77172-55-1 (2010)

Example 6 – Length of butterflies





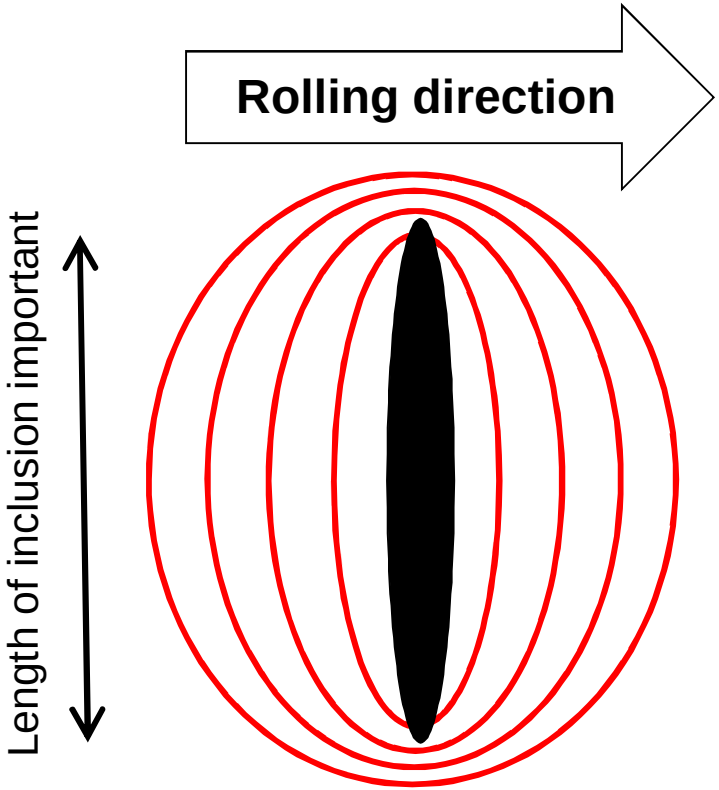
General observation on for butterflies:

- Present in most used bearings
- Total butterfly length typically <120 µm

Source: M W J Lewis and B Tomkins: A fracture mechanics interpretation of rolling bearing fatigue; J. Eng. Tribology Vol 226, No 5 p. 389-405; 2015

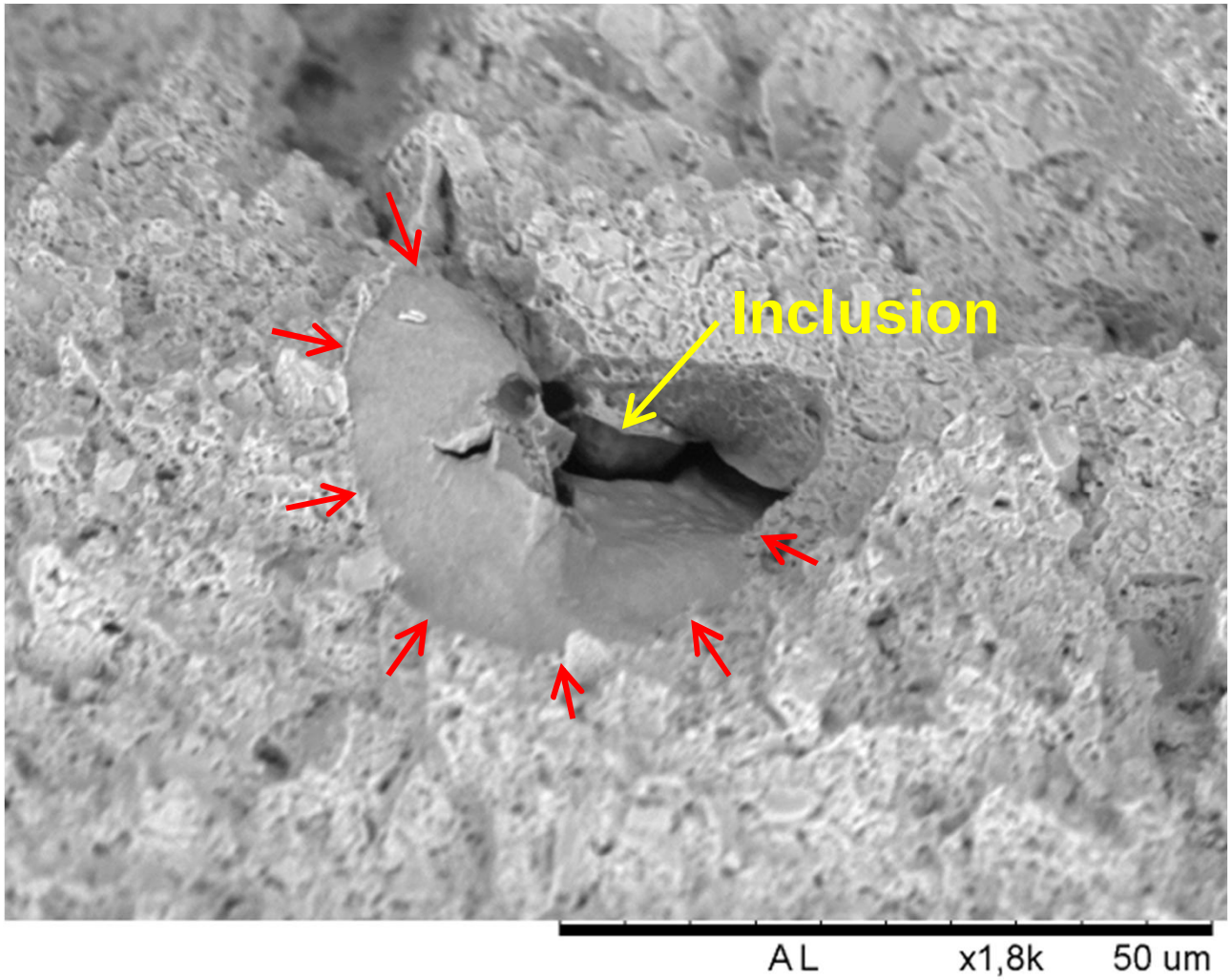
Example 6 – Growth of butterflies at inclusions

- Initiates on front and back side of inclusion in relation to rolling direction
- Mechanism probably differs from normal fatigue crack growth (inclusion too small to initiated growth of fatigue crack)
- Growth of butterflies appear to slow down or stop at certain distance from inclusion
- Unless inclusion is too large. Then it continues to grow……

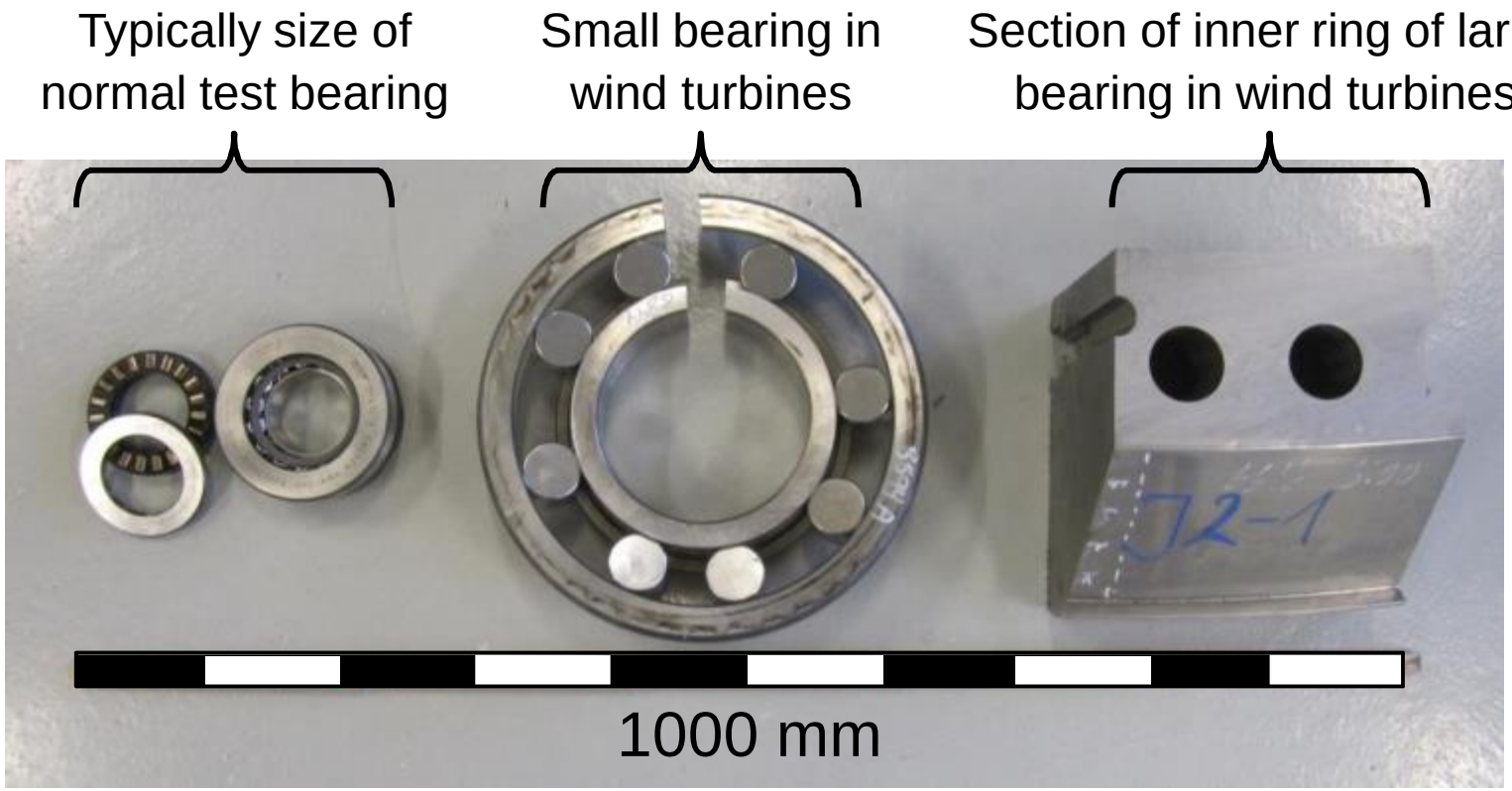


Example 6 – Growth of butterflies at inclusions

Self made fracture on bearing revealing part of butterfly at inclusion



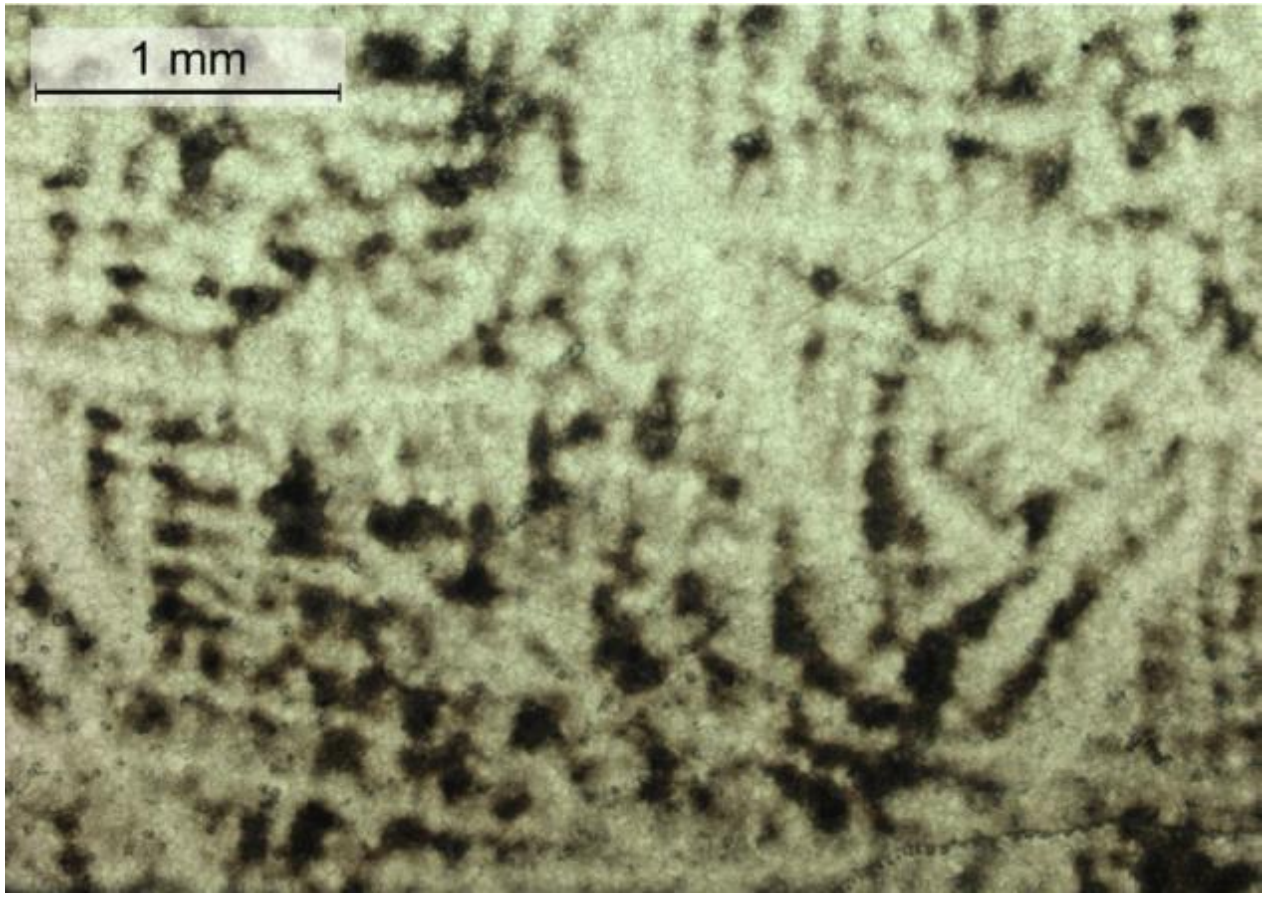
Challenges for industry: Scale of size



- Influence of casting of raw material (Solidification time -> segregation)
- Influence of forging ratio (homogeneity, grain size)

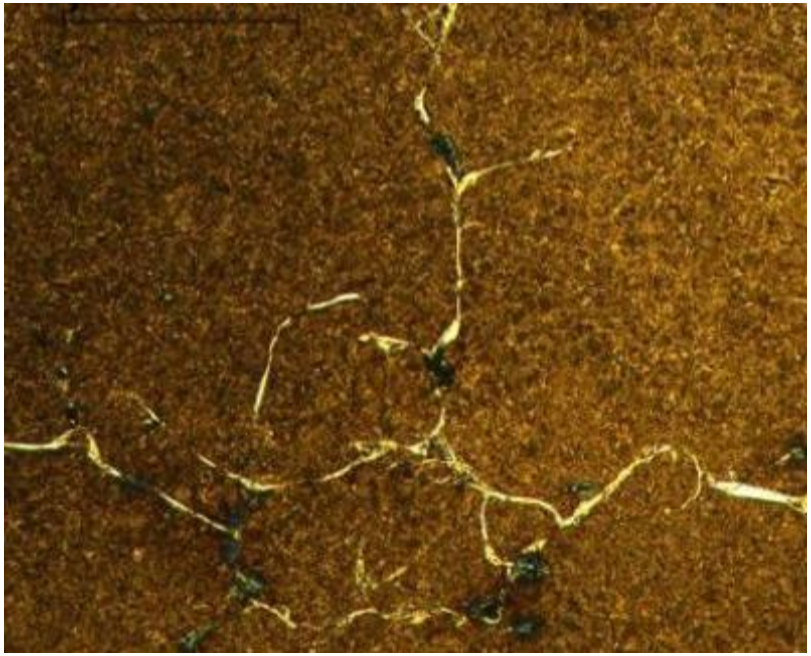
Challenges for industry: Scale of size

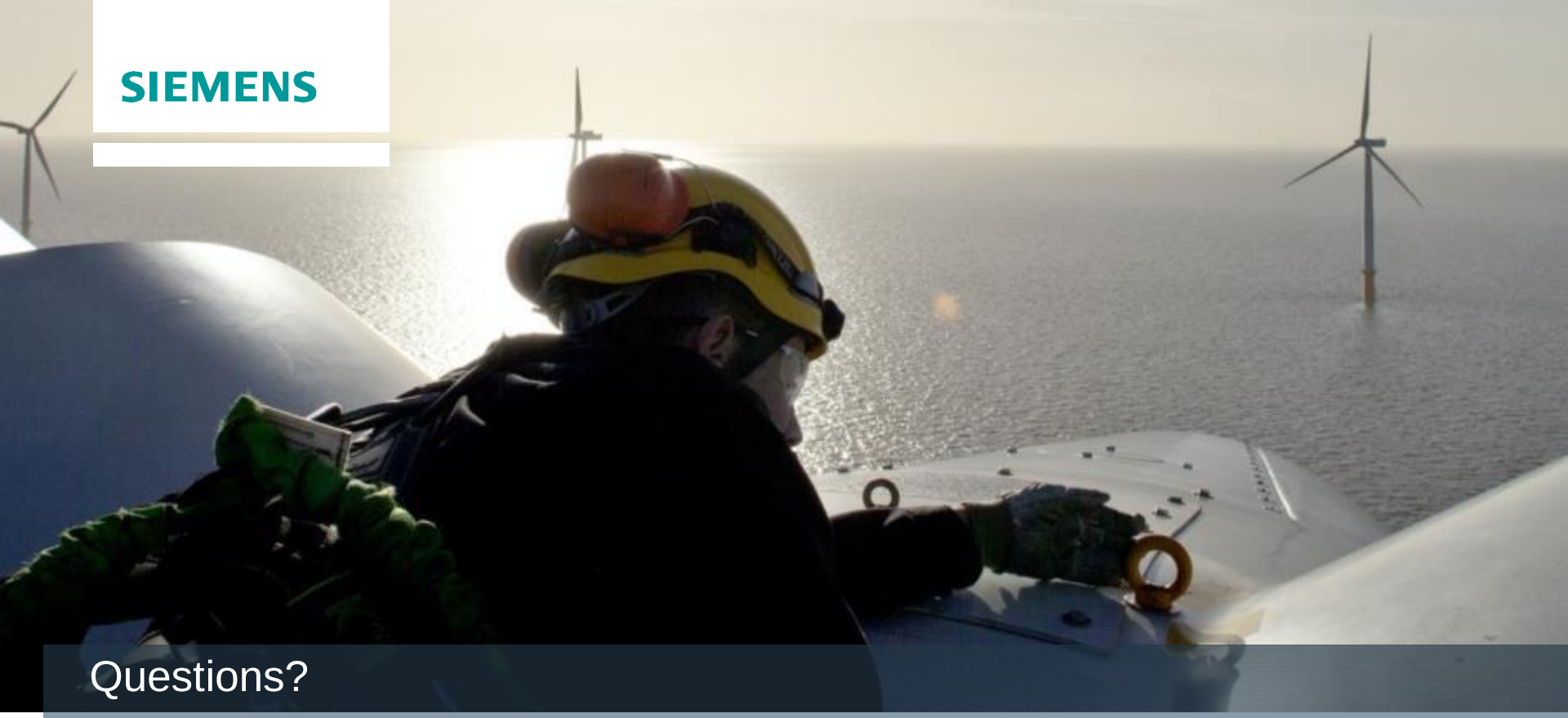
Dendritic structure visible in final part



Challenges for industry: IRWEC

- Irregular White Etching Cracks, also known as:
  - IRWEC, WEC, WEA, white flaking, axial cracks, white matters etc.
- Premature failure of bearing
  - 1 to 20% of calculated bearing life
- Associated with irregular subsurface cracks with “white etching area (WEA)”
- No common understanding of root cause
  - Many different root causes had been discussed and more will probably pop up
- No known calculation method present
- Know in many industries:
  - Wind turbine, automotive, washing machine, paper mills, coal pulverizer, crane lifting unit, etc.





Questions?

Thank you very much!

Contact page

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