NSK Premium Technology For Wind

Contents

Think NSK.

- Bearing Failure in a Wind Turbine Gearbox
- White Structure
- NSK's Solutions
  - STF and AWS-TF material and TF heat treatment specification
- Comparison Chart
- Questions

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NSK Experience

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- NSK has been researching white structure failures in multiple applications for over two decades. NSK experience has led to solutions across the following industries:
  - Industrial Gearboxes
  - Automotive bearings
  - Machine Tools
  - Pumps
  - Wind Turbines
- NSK can consistently reproduce white structure spalling and cracking failures on test stands.

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Bearing Failure Appearance

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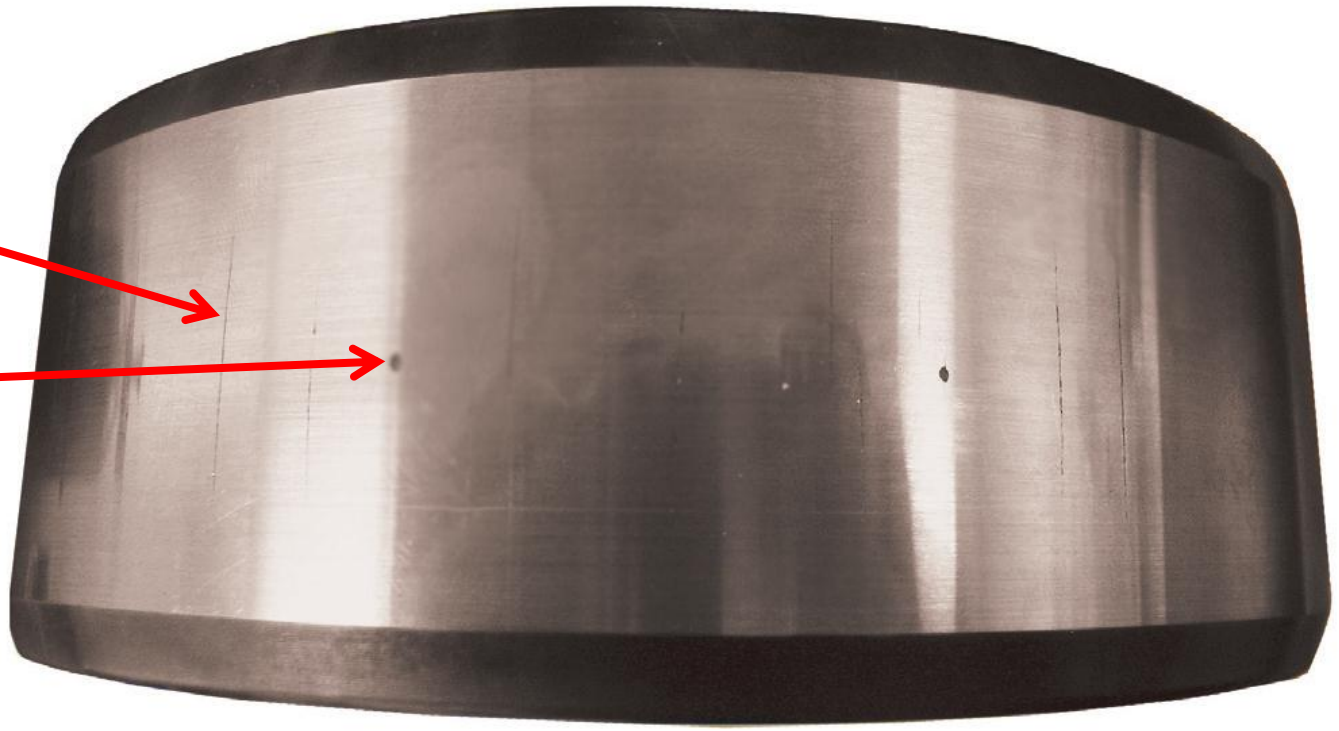
- Roller Bearings
  - Surface appearance is:
    - Multiple axial cracks with no matching frequency
    - Spalling or flaking
  - No apparent cause of cracking
    - No Dents
    - No Scratches



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Cylindrical Roller Bearing [Flaking]

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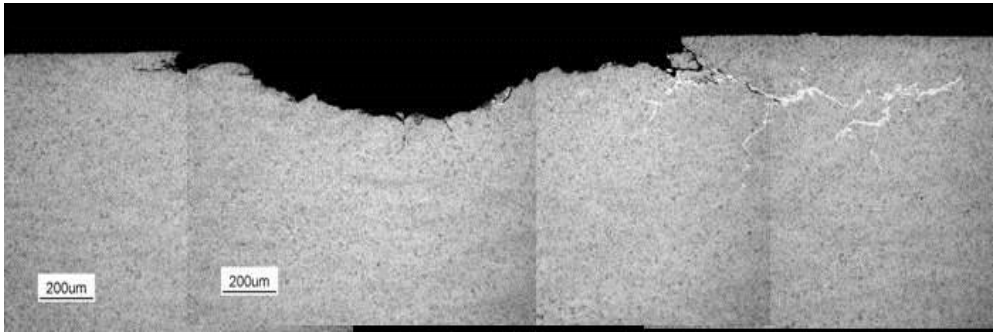
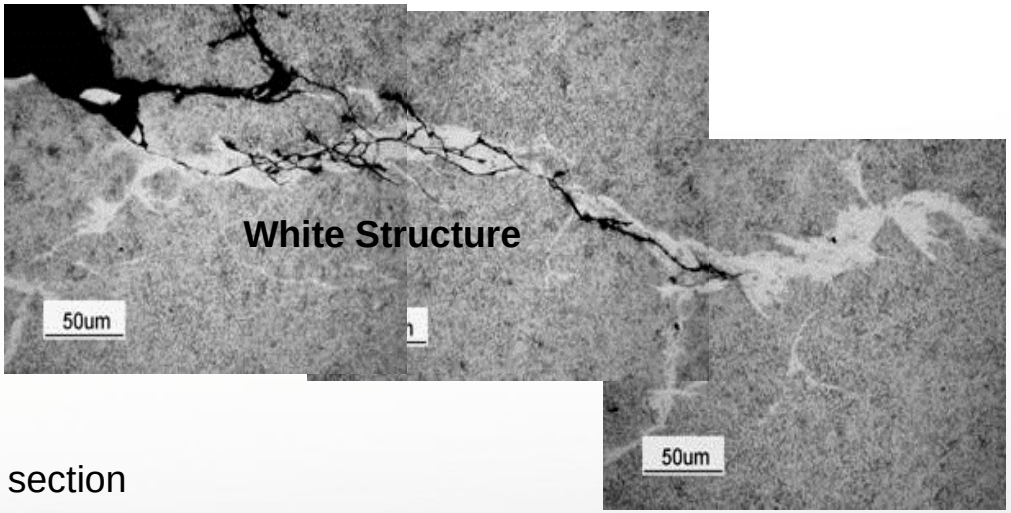
Inner ring raceway

Small-flaked regions

Cross section

Cross section of small flaking





Cylindrical Roller Bearing [Cracking]

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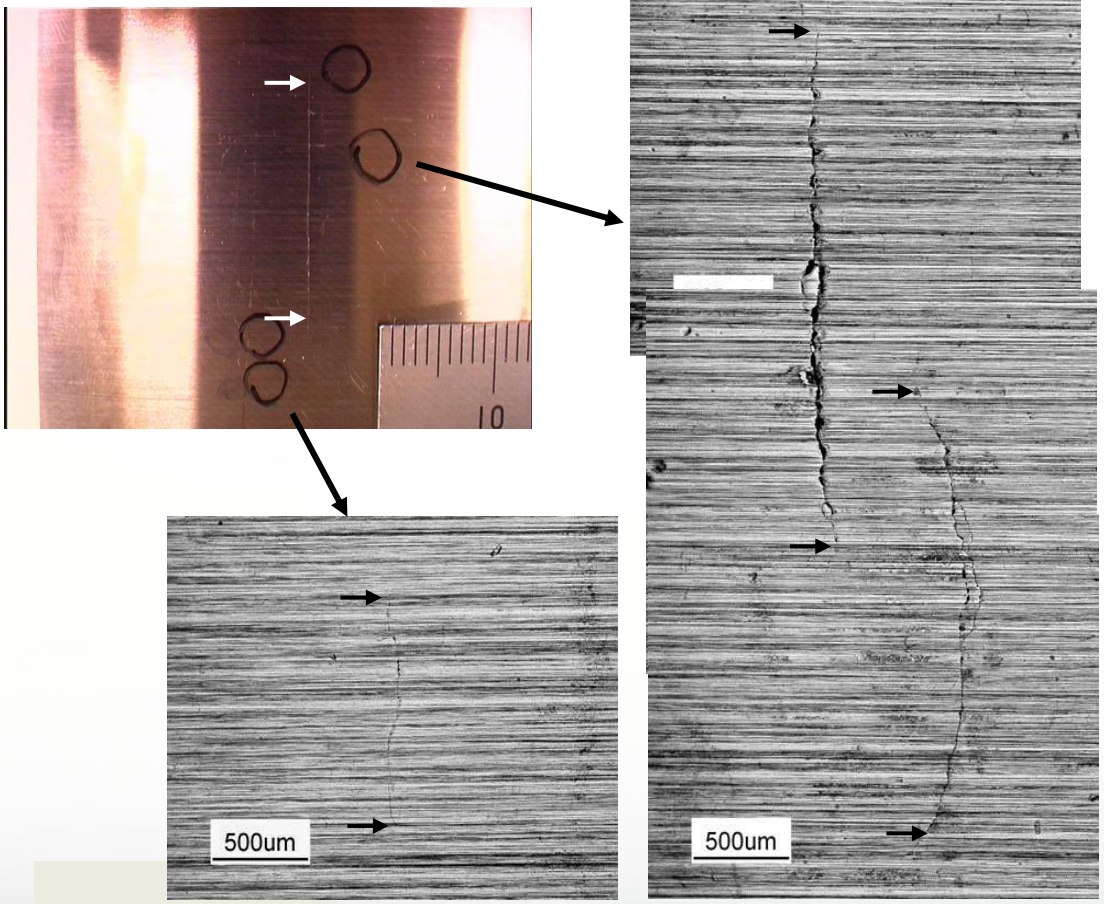
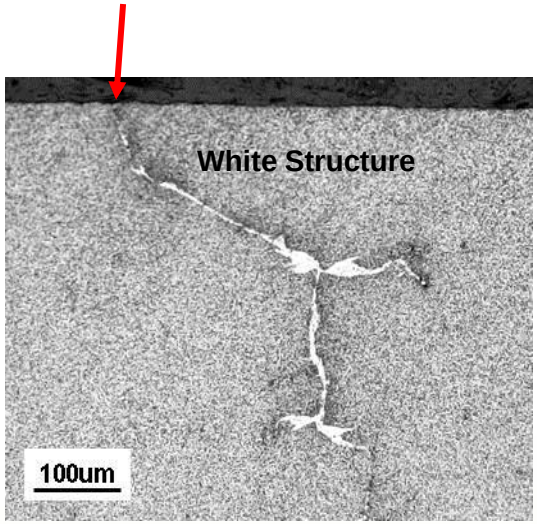
Long axial crack on raceway surface



Small cracks around a long axial crack

Crack reached the surface.



Cross section of a small crack

Types of White Etching Failures

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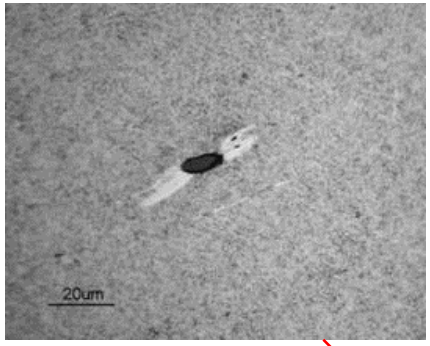
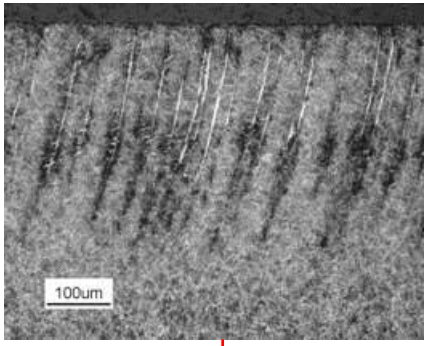
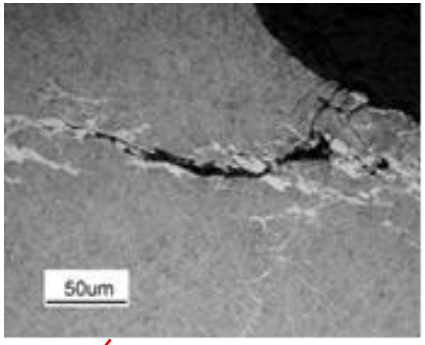
Nonmetallic Inclusion

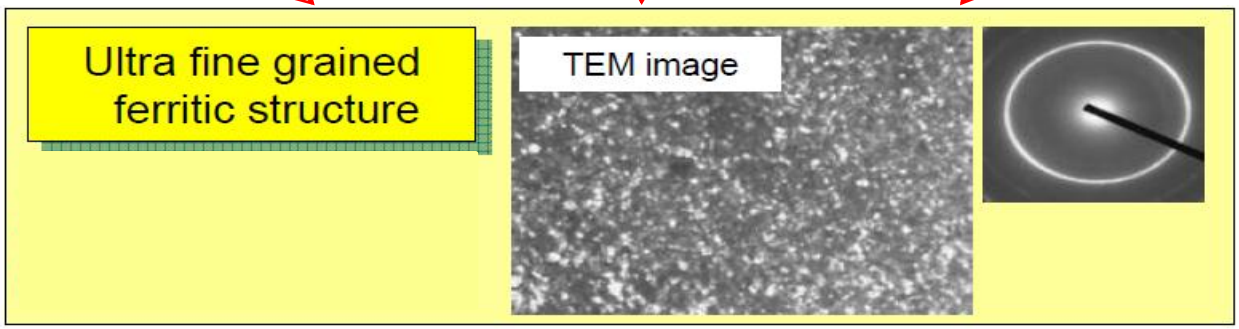


White Etch Constituent



White Structure





All three failure modes have the same microstructure with a different root cause.

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The Factors Influencing White Structure Formation

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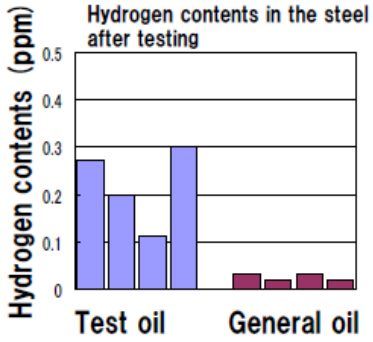
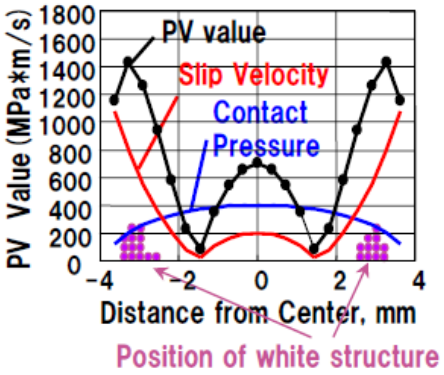
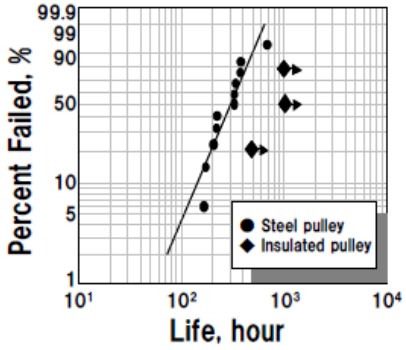
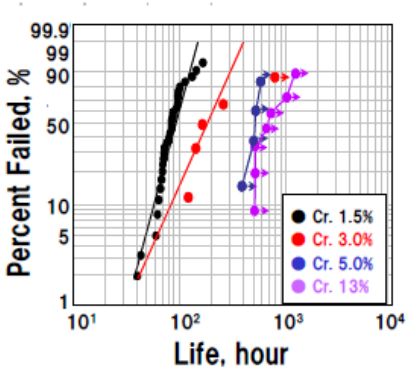
White Structure flaking

- **Hydrogen generation**
  - **Type of lubricant**
  - **Slip (Metal contact)**
  - **Electricity**
- **Resistance to hydrogen**
  - **Materials**









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Cause of Wind Turbine White Structure Failure

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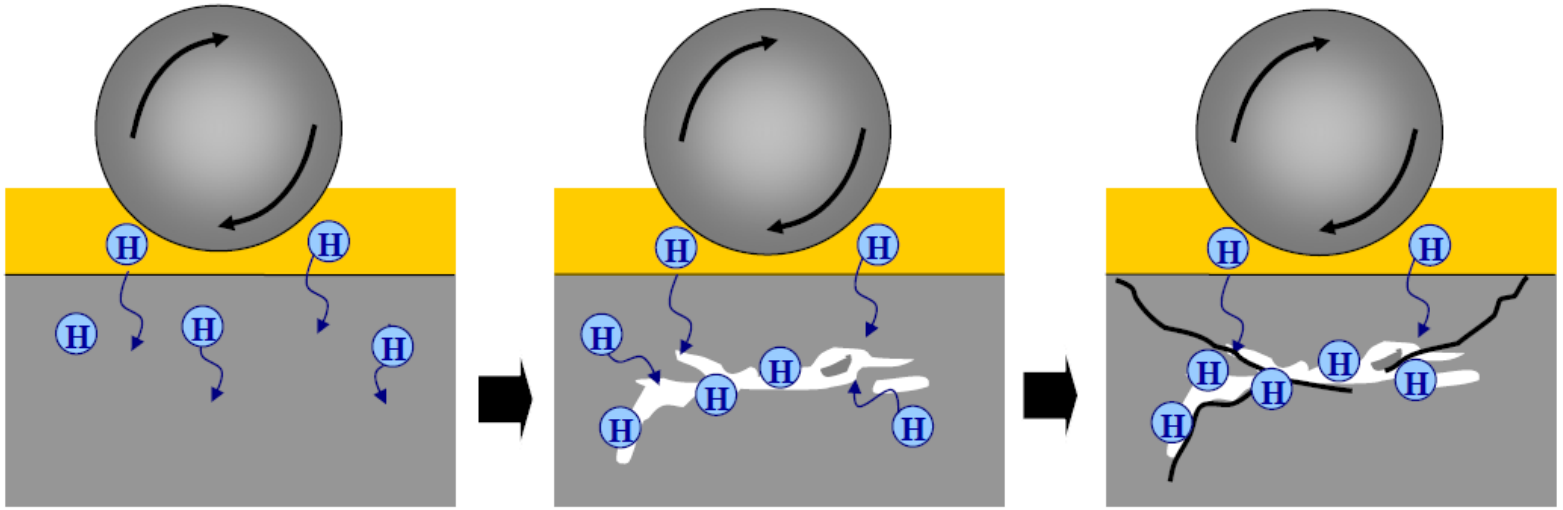
- **The abundance of hydrogen ions being generated in the gearbox.**
  - Generation of hydrogen ions from degradation of lubricant
    - Some lubricants release more hydrogen than others under heat and pressure.
    - Mechanism of smearing or sliding creating a strong negatively charged metal surface.
  - Hydrogen follows the old austenite grain boundaries and settles in the grain boundaries.
    - Hydrogen weakens the atomic bonds of the material by sharing electrons and accelerates degradation of the material under repeated cyclical stressing.



Mechanism of Failure

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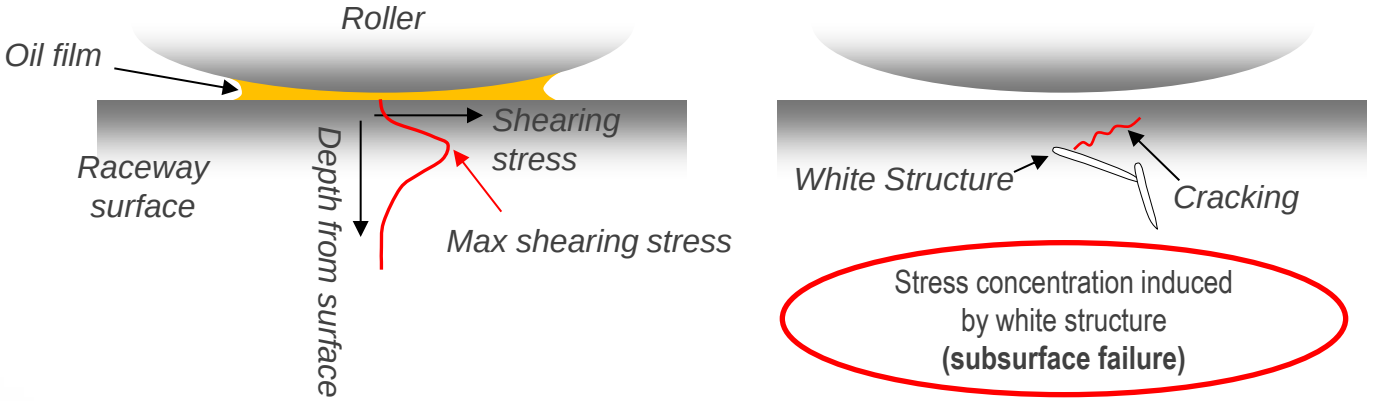
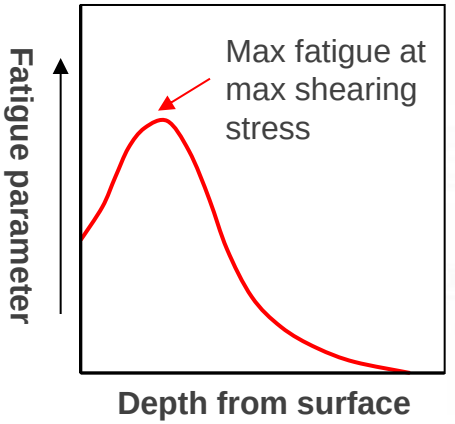
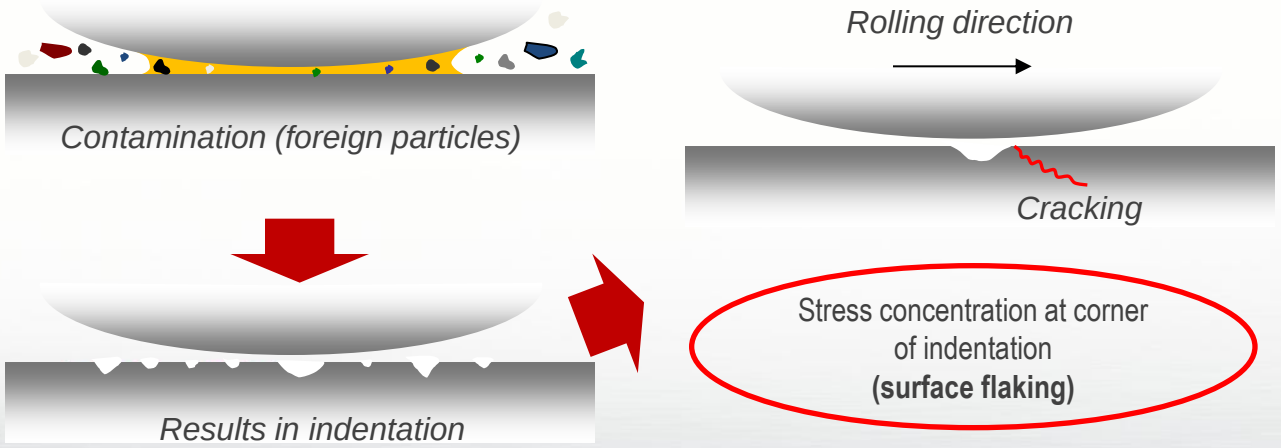
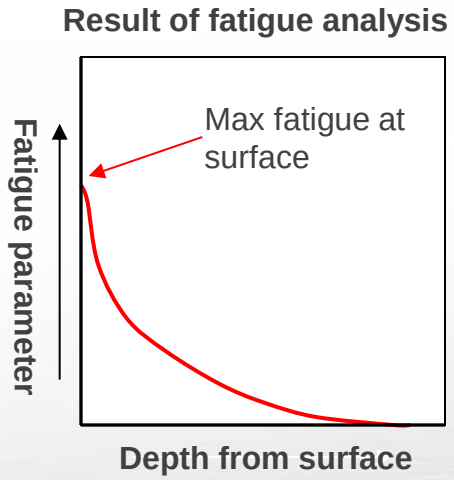
Mechanism of subsurface originated failure AWS-TF material designed to combat white structure





Mechanism of flaking due to indentation STF material designed originally for debris resistance





AWS-TF(Anti-White Structure Tough) Material

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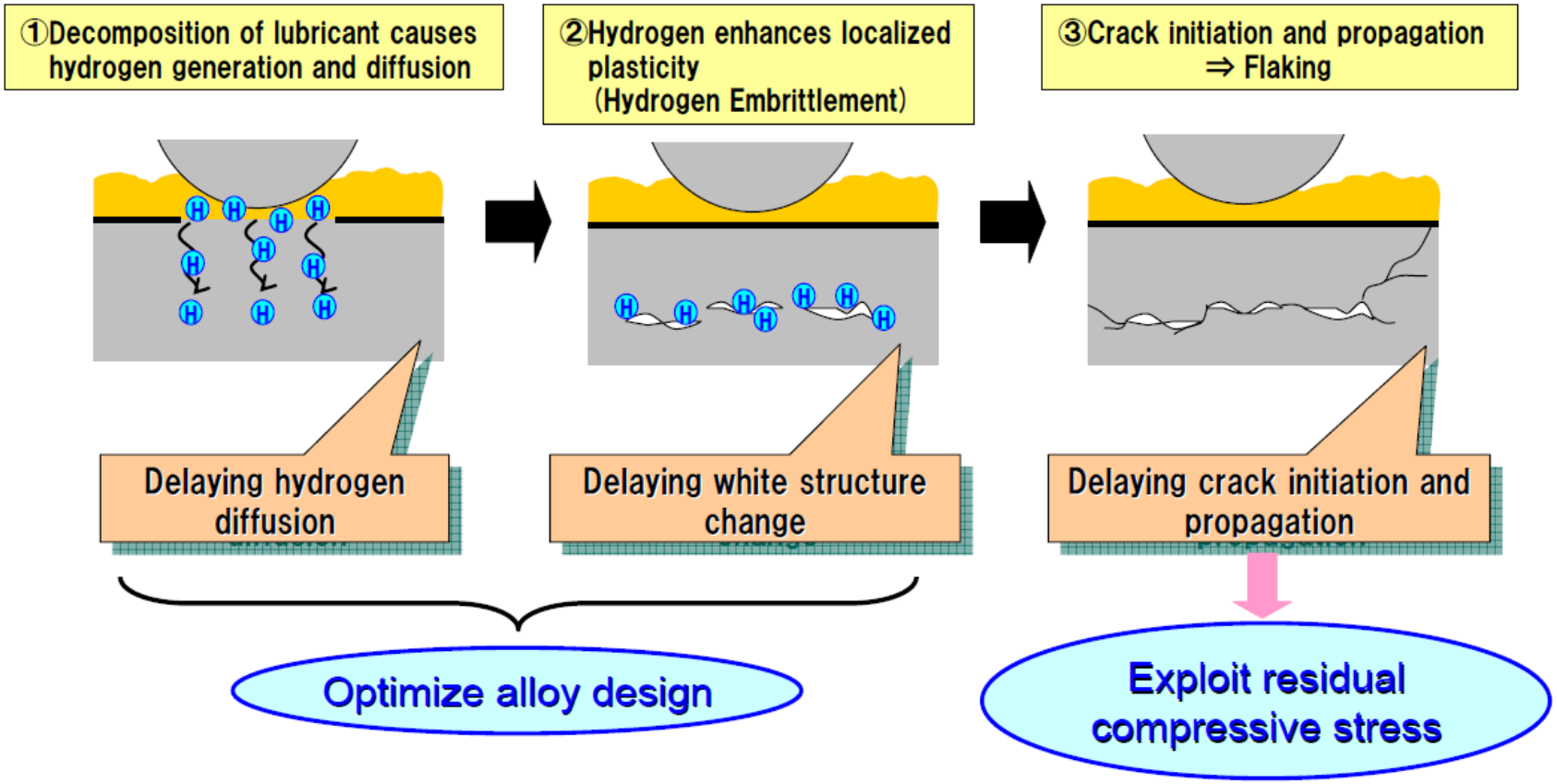

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Contamination Damage Reduction

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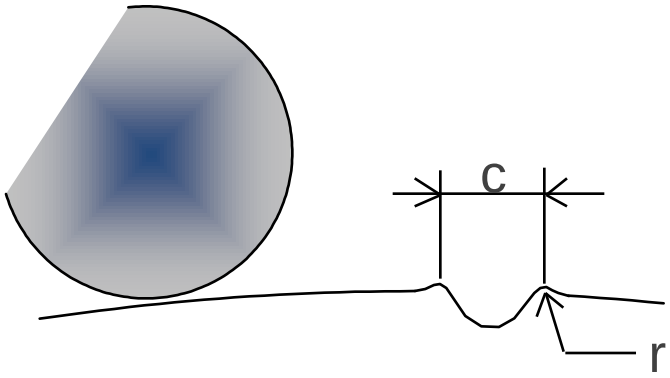
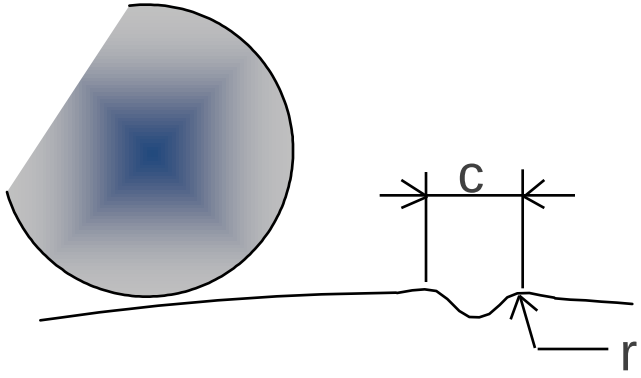
Standard Steel



Sharp edge corner

Tough Steel



Smooth edge corner

Large "c/r" Ratio

- Ridge is sharp ("r" is small) and tends to become sharper over time
- Stress level is extremely high
- Early failure

Small "c/r" Ratio

- Ridge is low and broad ("r" is large) and tends to broaden over time
- Stress level is greatly reduced
- Extended life

Tough Steel reduces effects of contamination damage

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Tough Steel ™ - How Does It Work?

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Fig. 1 *Tough Steel*

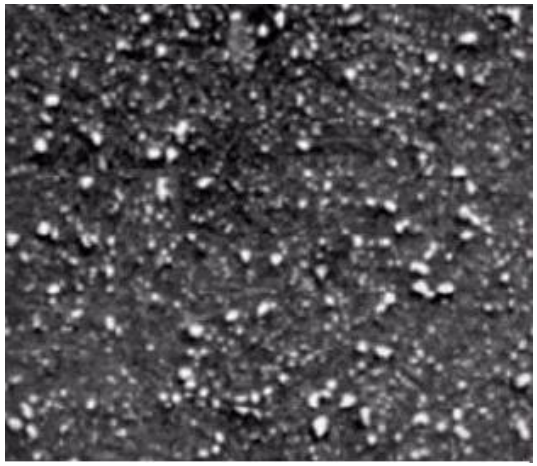
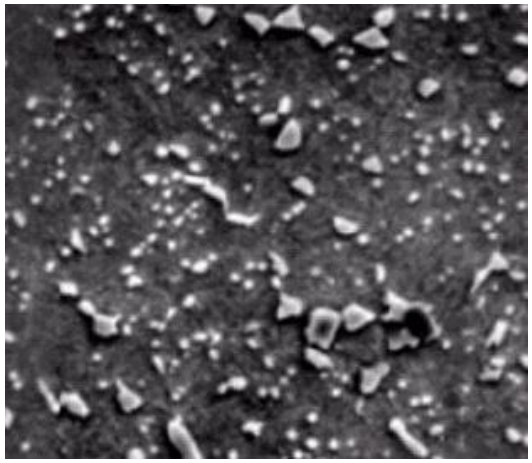


Fig. 2 *Carburized Steel*



- Figures 1 and 2 show the distribution of carbides and carbonitrides in *Tough Steel* versus typical carburized steel (x4000 magnification)
- Uniform distribution and reduced diameters of the particles in *Tough Steel* leads to improved fatigue life

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NSK's AWS-TF Material Solution

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- Benefits:
  - Base alloy and heat treatment engineered and designed to resist white structure formation.
    - Longer bearing life in hydrogen ion enriched environment
      - Resists hydrogen diffusion
      - Resists microstructural changes
  - Smear and wear resistance
  - Resistant to seizure
  - Longer bearing life in contaminated oil (debris in oil).
  - Regenerating passivation layer
  - Carbonitride heat treatment
    - Induces compressive residual stress near the material surface
    - >25% retained austenite in a thin band at the surface of the case.
    - <1/2 the total retained austenite of through hardened JIS SUJ material

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Competitor Comparison Chart

Think NSK.

	NSK		Competition
	AWS-TF	STF	
Material	"SHX3 (NSK Specific Alloy for White Structure Resistance)"	"SAC2 (NSK Specific Alloy for Debris Resistance)"	AISI 3310
Heat Treatment	Carbonitride	Carbonitride	Carburize
Compressive Residual Stress	Yes	Yes	Yes
Retained Austenite	>25%	>25%	>15%
Coating	BOC Available	BOC Available	DLC
Life Improvement over AISI 52100 for White Structure	+7x	4x	2x
Life Improvement over AISI 3310 for Low Lamda (smearing resistance)	3.5x	5.5x	3.5x
Life Improvement over AISI 3310 for Debris Conditions	6x	10x	2x

+ Denotes test stopped with no white structure failure.

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- Questions?